



Overview

Australia  2021
State of the Environment

Dhawurayina, ngurayina, gawarwarri ngaladji.

‘Our Country, our Homeland, is always in our hearts’.

**Ngurawari, gawar dhawurangu wanggiralidjiny,
winanganguru nimidjanguru.**

‘In our Homeland our hearts heed the Country,
with strength and with health’.

Ngunnawal Nation



Overview

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Contents

2021 letter to the minister	8
Key findings	10
Outlook and impacts	13
Outlook	13
Our future depends on connecting to Country	13
Connection to Country	13
Our current outlook	14
Impacts	17
Impacts on the environment	18
Impacts on human health and wellbeing	19
The pathway forward	20
Environment	22
Climate	22
Landscapes and seascapes	26
Land	30
Inland water	30
Coasts	34
Marine	36
Air	37
Urban	40
Antarctica	41
Ecosystems	44
Terrestrial ecosystems and native vegetation	46
Freshwater ecosystems	47
Marine and coastal ecosystems	50
Biodiversity	54
Species decline	56
Threatened species	58
Threatened ecological communities	59
Fauna	59
Plants	63
Fungi and microorganisms	65
Migratory species	65

Human society and wellbeing	67
Food, water and air quality	70
Impacts of changing climate and extreme events	71
Livability	72
Indigenous wellbeing	74
Indigenous, historic, natural and geoheritage	77
Pressures	82
Climate change and extreme events	82
Greenhouse gas emissions	85
Climate shifts	86
Other climate-related changes	87
Extreme events	88
People	94
Urbanisation	94
Land clearing	96
Pollution	97
Recreation and tourism	100
Industry	101
Transportation	102
Resource extraction	103
Industrial pollution	107
Energy production	109
Invasive species and range shifts	112
Biosecurity and sources of invasive species	114
Impacts of invasive species	114
Range shifts and extensions	119
Indigenous governance, rights and access	120
Access and rights to Indigenous estate	122
Indigenous access and rights to natural resources	122
Indigenous cultural and intellectual property	123
Cumulative pressures	124
Management	128
Environment management framework	128
Legislation, policy and international obligations	128
International obligations and treaties	130
National, state and territory legislation and policy	133
<i>Environment Protection and Biodiversity Conservation Act 1999</i>	134



Management approaches	136
Integrated management	137
Indigenous management	140
Stewardship	145
Natural capital accounting and environmental–economic accounting	148
Management of specific sectors and resources	149
Protected areas	150
Biodiversity and natural resources	153
Water resources	161
Coastal and marine	163
Heritage	164
Urban	165
Antarctica	166
Management of pressures	166
Environmental impacts	167
Climate change mitigation and adaptation	168
Extreme events management	170
Invasive species management	172
Pollution management	176
Air pollution	177
Cumulative impact management	179
Resources	181
Funding	182
Data	191
Human resources	197
New research technologies	201
Authors and acknowledgements	202
Approach	214
Acronyms and abbreviations	218
References	219
Index	253

2021 letter to the minister

Dear Minister

On behalf of the independent state of the environment 2021 authors, we are pleased to present the 6th national state of the environment report for tabling in Parliament, as required under the *Environment Protection and Biodiversity Conservation Act 1999*.

Australia state of the environment 2021 (SoE 2021) is written by a panel of independent authors, using the best available evidence, assured through consultation, peer-review and fact-checking processes, and building on 25 years of experience in national environmental reporting. This is the first time the report has included Indigenous voices, highlighting the importance of cultural knowledge that has sustained Australia for tens of thousands of years.

The framework adopted for SoE 2021 adapts that used in 2011 (SoE 2011) and 2016 (SoE 2016). Although SoE 2021 provides updates to the information in SoE 2011 and SoE 2016, its focus is to bring together the extensive information that has emerged over the past 5 years, and to report on the main emerging issues facing Australia. We have included 2 new themes: 'Indigenous' provides a long overdue voice for Indigenous Australians on the health of their Country and connections, and 'Extreme events' reflects the major focus that has emerged in this area in the past 5 years.

This overview provides a synthesis and overall outlook for the Australian environment, summarising more detailed content and assessments found in 12 thematic chapters on air quality, Antarctica, biodiversity, climate, coasts, extreme events, heritage, Indigenous, inland water, land, marine and urban. Each

of these web-based chapters contains detailed discussions of the condition of the Australian environment, taking into account the pressures on it and the effectiveness of management. These are brought together to present the overall outlook for the Australian environment and the potential impacts on our wellbeing.

Indigenous authors have written in almost every part of this report. A report of this nature, which discusses different categories of the environment and heritage in isolation from one another, runs counter to the Indigenous holistic world view where all aspects of the environment and culture are linked. This report emphasises the interconnectedness of environment and culture.

We have sought to improve the usefulness of the SoE report for input into evidence-based policy and management. The 2021 report has refocused its purpose to enable users in government, industry, natural resource management, Indigenous land and sea management, nongovernment organisations and the finance investment sector to explore and discover information of interest to them. We have improved the user experience through a revised digital delivery of SoE, providing easy access to the extensive research that sits behind our analysis.

Many of the pressures facing Australia's environment and heritage today are the same pressures described in previous reports – climate change, land-use change, habitat degradation and invasive species. However, the impacts of these are becoming more intense, and we find stronger evidence that the interactions between pressures are resulting in cumulative impacts, amplifying the

threats faced by the Australian environment. Improvements in the management of our natural capital is required to support Australia's economy and wellbeing in the longer term.

All Australians can be part of the solution, and we encourage the Australian Government to take a strong leadership role in addressing the key challenges facing Australia's environment and heritage.

We trust that this report will build greater community awareness and understanding of Australia's environmental issues, and assist all decision-makers across the country to make prompt and sound policy and management choices that improve Australia's environmental and heritage outcomes.

We commend the report to you and, through you, to the people of Australia.



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Key findings

In a rapidly changing climate, with unsustainable development and use of resources, the general outlook for our environment is deteriorating

Overall, the state and trend of the environment of Australia are poor and deteriorating as a result of increasing pressures from climate change, habitat loss, invasive species, pollution and resource extraction. Changing environmental conditions mean that many species and ecosystems are increasingly threatened. Multiple pressures create cumulative impacts that amplify threats to our environment, and abrupt changes in ecological systems have been recorded in the past 5 years.

The Australian Government's 2015 *Threatened Species Strategy 5-year action plan* achieved partial success by improving the trajectories of 21 priority species by 2020, but many did not show improvements and, overall, the number of listed species has grown by 8% since 2016. The number of listed entities will increase substantially in coming years as a result of the 2019–20 bushfires.

Our inability to adequately manage pressures will continue to result in species extinctions and deteriorating ecosystem condition, which are reducing the environmental capital on which current and future economies depend. Social, environmental and economic impacts are already apparent.

Immediate action with innovative management and collaboration can turn things around

Adequately resourced, innovative, responsive and collaborative management measures will foster investment and renewed action to turn things around. Australia currently lacks a framework that delivers holistic environmental management to integrate our disconnected legislative and institutional national, state and territory systems, and break down existing barriers to stimulate new models and partnerships for innovative environmental management and financing.

Climate change is continuing and is increasing the impacts of other pressures on our environment. Immediate global action to reduce carbon emissions would result in reduced pressures and improved trajectories for most aspects of our environment.

Australian individuals, communities, nongovernment organisations and businesses are engaging with nature and supporting biodiversity and heritage. Successful on-ground actions include the work of Indigenous rangers, citizen science, and restoration actions at many scales, providing opportunities that deliver benefits for people and Country. Urban planners and governments are recognising the need for change and a more collaborative, whole-of-system approach, with place-based outcomes that can build greater resilience and regenerate our urban areas.

Substantial data about the environment are becoming more available. Over the past 6 years, the National Environmental Science Program and the National Collaborative Research Infrastructure Strategy have become important sources of information for state of the environment reporting, and have provided critical funding for research informing policy and on-ground management of the environment. Better coordination of data and the introduction of national environmental standards will provide a direct mechanism for agreement between all jurisdictions, leading to improved environmental reporting at all levels.

There is also a clear need to empower Indigenous communities to manage the culturally appropriate collection and integration of data.

Indigenous knowledge and connections to Country are vital for sustainability and healing Australia

Indigenous people have cared for Country across generations for tens of thousands of years. With decreasing health of Country, Indigenous people continue to seek a larger role in managing its recovery back to health. Indigenous people seek greater participation in Australia's environmental management system. Respectful use of Indigenous knowledge, recognition of Indigenous knowledge rights, and Indigenous and non-Indigenous knowledge systems working together will lead to positive change.

A renewed emphasis on engagement across all sectors of society is required to reverse environmental decline and to achieve ecologically sustainable development that underpins future prosperity and the wellbeing of future generations. Renewed focus on restoration of the landscape, and greater recognition and empowerment of Indigenous land management practices, where possible, across large parts of Australia can help us to heal Country and find new ways to gain a broad range of benefits.

Environmental decline affects the wellbeing of Australians

Our health, living standards, cultural and spiritual fulfilment, and connection to Country are all interconnected and are negatively impacted by our deteriorating environment.



Outlook and impacts

Outlook

Our environment holds the key to our survival and wellbeing. The natural world is not separate from the human world – it is the source of our food, water, air and raw materials. Our culture and wellbeing are interwoven with the places where we live and walk. Ongoing environmental decline also has negative economic impacts on industries, businesses, regions and individuals. In a rapidly changing climate, with declining biodiversity, the general outlook for our environment is deteriorating. The impacts of this will affect us all.

It is in our own interest to understand, protect and restore the health of our environment.

It is also our responsibility. Our environment has intrinsic value beyond direct human use. Humans have a profound influence on the environment, and we must embrace our role as custodians of the lands and seas.

Our future depends on connecting to Country

The health and wellbeing of Country and people are fundamentally connected. The oldest continuing cultures in the world – Australian Aboriginal and Torres Strait Islander cultures – have held this truth at the core of their knowledge systems, their stories and their management practices for tens of thousands of years. In this report, Indigenous and non-Indigenous people have worked side by side, combining knowledge to create the first holistic assessment of the current state of Australia's environment.

This report explores the state of our environment (see 'Environment'), the pressures it is under (see 'Pressures') and how we are managing it (see 'Management'). We have assessed the health of every aspect of our environment – from our rivers, oceans, air and ice, to our land and urban areas – as well as how our environment is affecting the health and wellbeing of the Australian community and economy (see 'Impacts'). We have identified the areas of greatest need for action in our environment.

To improve the outlook for our environment, communities and economy, we will need to strengthen and build connections: connecting people with Country; connecting economics with the environment; and connecting biodiversity, lands, rivers, seas, skies and soils.

We need to learn from both western scientific and Indigenous knowledge systems, and to connect with each other. Individual, community, industry and government action are all needed, and this report points to ways in which we can improve our shared outlook. Working together, we can deepen our connections and build resilient Country and people.

Connection to Country

Indigenous knowledge and connections to Country are vital for sustainability and healing Australia. Indigenous people have cared for Country across generations, yet Indigenous knowledge and world view are rarely incorporated, valued or accessed by non-Indigenous environmental management.

Indigenous knowledge can provide a broader vision of sustainability for all Australia:

We're born from this land. We belong to the land. And we take care of the land. We respect this land. And we should only ever take from the land what we can give back to the land.

Wurundjeri knowledge holder and Elder Aunty Joy Murphy Wandin (Porter et al. 2020)

Indigenous people have a deep connection with the environment – Indigenous people have lived on the land and near waters of Australia for tens of thousands of years and have a cultural responsibility to care for Country.

For Indigenous people, the term 'environment' is integrated with the term 'Country'. Country is more than the physical land, waterways and seas; it includes all living things on the land and in the seas, and it also includes the connected language, knowledge, cultural practice and responsibilities. The concept of Country encompasses all aspects of the environment, including urban areas. Country is living, holistic, and constantly changing and evolving.

Indigenous people's connection to their Country is a deep cultural and spiritual bond. Country for Indigenous people is the source of life, identity and culture, and the health of Country and people are inextricably linked. Spiritual connection to Country manifests in many forms under law, through stories, songs and knowledge. It links back to the time of the ancestors, when ancestral beings made the landforms, the seascapes, the animals and people. Indigenous people continue to revitalise, practise, teach and pass on knowledge. Caring for Country is a cultural obligation. The capacity for Indigenous people to care for Country means that Indigenous knowledge systems can continuously evolve, develop and be passed through the next generations.

Our current outlook

All aspects of the Australian environment are under pressure, and many are declining. Although there have been numerous environmental initiatives at both national and state and territory levels, there is insufficient overall investment and lack of coordination to be able to adequately address the growing impacts from climate change, land clearing, invasive species, pollution and urban expansion. Innovations in conservation practice and technologies provide new hope, and increased Indigenous leadership and involvement of business and communities are helping to deliver on-ground change.

Australia's strategies and investment in biodiversity conservation do not match the scale of the challenge, and the state and trend of Australia's ecosystems and species continue to decline. Australia has lost more mammal species than any other continent and continues to have one of the highest rates of species decline among countries in the Organisation for Economic Co-operation and Development. The true number of extinctions is likely to be significantly higher because many species are poorly surveyed or poorly described, or both. Increasingly, we are resorting to the costliest conservation mechanisms of restoration, rehabilitation, ex situ conservation, translocations, and the creation of safe havens on islands and in fenced areas.

Intense competition for land and water resources in Australia has resulted in continued declines in the amount and condition of our land- and water-based natural capital – native vegetation, soil, wetlands, rivers and biodiversity – that together deliver ecosystem services. Reversing this trend requires collaboration and cooperation between governments, businesses and communities to build resilient

Indigenous knowledge and connection to Country

Embracing Indigenous knowledge and connection to Country is a vital step to restoring the health of our environment.

Indigenous people and their knowledge of our environment has continued for tens of thousands of years. Our environment – Country – holds this knowledge and connection in the plants, animals, land, sea and sky.

Everything is connected

We are all part of our environment.

Knowledge is connected to people and living culture

We need to empower Indigenous people and embrace traditional knowledge to heal Country.

Listening to and involving Indigenous people is key

Embracing Indigenous values helps us protect our environment and ensure a sustainable future for all Australians.



landscapes, to achieve balanced and equitable environmental, economic, social and cultural benefits.

The total area of land and sea that is under some form of conservation protection is increasing, but the overall level of protection is declining. If we improve our capacity to manage and monitor the state and trends of our protected areas, we will better understand the protection levels necessary to ensure ecosystem integrity. Continuing to expand the role of Indigenous land and sea management – including Indigenous Protected Areas (IPAs) within the National Reserve System – will be fundamental to improvements in the state of the environment. Greater recognition of the important role of Indigenous rangers in conserving both cultural heritage and natural values is required, as well as the connection between Indigenous rangers and the wellbeing gains from being on and caring for Country. The current funding arrangements for Indigenous land and sea management and IPAs are inadequate to meet the demands and require greater certainty into the future.

Our oceanic marine areas remain in generally good condition, but nearshore reefs are in poor condition. In addition, many coastal habitats and communities are highly impacted in locations where multiple pressures combine to overwhelm ecosystem health and function. Climate change continues to warm and acidify the ocean, and we have experienced several major marine heatwaves during the past 5 years, resulting in an overall deteriorating trend.

For all aspects of our environment, the outlook is affected by the increasing pressure of climate change. Increasing temperatures on land and sea, changing fire and rainfall regimes, and rising sea levels and ocean acidification are having profound effects that will continue into the future. Some of the largest climate change effects are being seen

in Antarctica. Changes in sea ice extent, and land and sea temperatures will drive profound changes in Antarctic species and ecosystems. Changes in the Southern Ocean and Antarctic environments as a result of climate change will in turn have substantial and ongoing impacts on Australia's climate and sea levels.

The growing understanding of the impacts of climate change has resulted in a substantial increase in resilience planning activities from all 3 levels of government, enormous community mobilisation and engagement, and innovative approaches from commerce and industry, but the need remains to coordinate and look for synergies between approaches.

The intensity and frequency of extreme weather events are also changing. Climate science predicts that there will be increasing impact from many extreme events, including a potential expansion in their distribution, changes in their duration, and increasing complexity of linked impacts. Increasing frequency and severity of extreme events are also having direct effects on human wellbeing. Tropical cyclones, hailstorms, flooding rains, storm tides, heatwaves, bushfires, blizzards and other natural phenomena can change natural and urban landscapes, and sometimes have irreversible impacts on ecosystems and human society. Changes to our landscapes through habitat fragmentation, agricultural management practices, expansion of invasive species and other pressures are exacerbating the impacts of extreme events and inhibiting post-event recovery.

Our inland water systems, both surface water and groundwater, are coming under increasing pressure as temperatures increase and rainfall patterns are affected by climate change. Although desalination plants and water recycling are being increasingly used to reduce this pressure, the challenge remains to balance the needs of people and industry with environmental and cultural water needs.

Our urban populations are growing, placing the environment and resources of our cities and towns under greater pressure, and there is increasing interest in circular economy approaches. With the digital revolution and working from home due to the COVID-19 pandemic, more people are considering a lifestyle change to move to regional areas or more suburban locations. As a consequence, land prices in some regions have increased faster than in cities, intensifying conflict with agricultural industries. The potential for increased impacts on the land environment (e.g. through clearing of bush remnants and loss of agricultural land) will need to be managed. Rebuilding major urban areas to be more environmentally sensitive and nature focused is also increasing in popularity.

Increased appreciation for Indigenous values in major cities and larger regional centres is reflected in recent planning legislation and policy development, as well as academic institutions that include Indigenous content in environment and planning curriculums. Managing green links and corridors within urban areas can support habitats and urban biodiversity, and help to limit the impacts of a warming climate on our cities. Managing ecological systems through empowering Indigenous communities and enabling Indigenous knowledge systems can improve environmental and social outcomes.

Our air quality is likely to remain good on most days of the year. However, changes in the climate are likely to cause more summertime smogs in urban areas, and the increasing intensity of storms in some regions may increase the potential for serious thunderstorm asthma events, which will affect health, especially for vulnerable individuals and populations. The predicted increase in the number of extreme heatwave events will also lead to increased summer bushfire activity,

leading to poor air quality as a possible recurring feature of future Australian summers.

Although Australia has various heritage protections in place, lack of resourcing and inadequate governance are affecting all types of heritage, and are likely to lead to further degradation of heritage. The outlook for heritage overall is poor, given the many pressures and management issues. For Indigenous heritage, additional issues include the continued trauma and mistrust within the Indigenous community due to ongoing lack of recognition, protection and a rights-based approach, and difficulties in accessing Country. Self-determination and access to Country, along with major changes to Indigenous heritage legislation and significant governance changes regarding free, prior and informed consent, are needed.

Climate change is continuing the incremental destruction of Indigenous places and cultural values. Many cultural sites and values are unidentified or undocumented because of population displacement, lack of access to Country, and impacts on traditional knowledge and cultural practice. Environmental changes wrought by temperature change and extreme events are also affecting the abundance and distribution of native plants and animals of cultural significance, further threatening the intergenerational transfer, persistence and application of cultural knowledge and people's cultural connections to Country.

Impacts

The current impacts on our environment, and how well we deal with existing and emerging pressures, will affect both the future of our natural resources, and human health and wellbeing.

Impacts on the environment

The top 5 global risks in terms of likelihood to cause significant negative impacts within the next 10 years are extreme weather, climate action failure, human environmental damage, biodiversity loss and infectious diseases (World Economic Forum 2020). Environmental degradation is now considered a threat to humanity, which could bring about societal collapses with long-lasting and severe consequences. The World Economic Forum described the global risk of biodiversity loss and ecosystem collapse as having ‘irreversible consequences for the environment, humankind, and economic activity and a permanent destruction of natural capital, as a result of species extinction and/or reduction’.

Multiple pressures create cumulative impacts that amplify threats. Abrupt changes in ecological systems are occurring in Australia, such as the transition of Tasmania’s giant *Macrocystis* kelp forests to beds of the shorter common kelp (*Ecklonia radiata*).

Climate change is putting pressure on all parts of the environment. The 2017–19 drought exceeded the previously worst-ever drought, the federation drought from 1895 to 1903. Extensive, catastrophic bushfires were followed by months of heavy and continuous rain. The combined effect of increasing temperatures, changing rainfall patterns and extreme weather events are affecting our soils, water and vegetation, and all the species that rely on them. Climate change and associated extreme events, compounded by other pressures, have had a major impact on biodiversity over the past 5 years, and further consequences are likely to be magnified in the future.

Many of Australia’s most valued and iconic ecosystems are at risk from climate change and environmental extremes. For example, the Great Barrier Reef is adversely impacted

by unprecedented marine heatwaves that cause bleaching events and threats to coral recruitment. Bushfires have ravaged much of Australia in the past few years, including burning in ecosystems that are normally resistant to fire.

Invasive species continue to impact the environment, the economy, human health and our way of life. Australia is burdened by thousands of non-native species introduced deliberately or by accident over the past 200 years. There are now more foreign terrestrial plant species in Australia than natives. Many are likely to become even more problematic with climate change. Established invasive species require ongoing management and enhanced surveillance to prevent new incursions. The total annual cost of weeds (revenue loss plus expenditure) to Australian grain growers has been estimated at \$3.3 billion (Llewellyn et al. 2016), and across all grain, beef and wool industries is nearly \$5 billion (McLeod 2018).

Agriculture also faces significant effects from climate change, including damage to tree crops caused by more severe storms and cyclones, the effects of heat stress on domestic animals, and more insidious impacts that disrupt the lifecycles of pollinators and beneficial predatory insects.

The continuing legacy of colonial law and policies disempowers Indigenous environmental management practices. Clearing of land, climate change and expansion of mining are among many environmental changes damaging Country and Indigenous Australians’ heritage, cultural connections and obligations to Country. Many environmental programs pay insufficient attention to Indigenous cultural obligations. Key customary activities, cultural responsibilities and access to Country are often impeded.

Other countries increasingly will not accept our waste. Landfill and waste strategies have unacceptable impacts on our land through soil and water pollution, and illegally dumped waste also has a significant impact on the land through its direct effect on soils, waters, biota and habitats. There are estimated to be 600 registered landfill sites and potentially as many as 2,000 unregulated facilities (Infrastructure Australia 2019). Litter and illegally dumped waste have a significant impact on our land, waterways and seas through their direct effect on plants and animals, and their habitats, as well as through the spread of diseases and pest species.

Impacts on human health and wellbeing

The environment and human health are strongly linked, and environmental degradation affects our communities, economy and way of life. The current negative trends in biodiversity and ecosystems will undermine progress towards most of the targets of the United Nations Sustainable Development Goals related to poverty, hunger, health, water, cities, climate, oceans and land.

Our environment sustains all life, and the link between the environment and human wellbeing is well understood. Nature provides the essential services for our food, water and clean air; the basis for many human livelihoods; cultural and spiritual connection; and physical health. Along with benefits for the environment offered by biodiversity, contact with nature is associated with positive mental health benefits, and can promote physical activity and contribute to overall wellbeing. Biodiversity and green and blue spaces in urban settings are linked to stress reduction and mood improvement (Cox et al. 2017, Schebella et al. 2019), increased respiratory health (Liddicoat et al. 2018), lower rates of

depression and high blood pressure (Shanahan et al. 2016), and overall improvements in human wellbeing (Taylor et al. 2018b). There is strong evidence that participation in caring for Country activities by Indigenous people in Australia is associated with improved health and wellbeing outcomes, as well as greater participation in cultural activities and knowledge of language. Regenerative land management and Landcare volunteering have also been shown to have health and wellbeing benefits for non-Indigenous people.

The Closing the Gap initiative includes measurement of Indigenous wellbeing. In 2020, the new National Agreement on Closing the Gap acknowledged the need to accelerate progress focused on the fundamental underpinnings of community, and connections with kin and Country. Outcome 15 deals with caring for Country, and the need for Indigenous people to maintain a distinctive cultural, spiritual, physical and economic relationship with their land and waters. Indicators include the number of Indigenous Land Use Agreements, income of registered native title bodies corporate, the number of Indigenous people employed in water and land management, and Australia's conservation estate that is managed by Indigenous people. This framework will provide critical measurements of Indigenous wellbeing for future state of the environment reports.

Our changing climate has a significant impact on the durability of our built infrastructure and the resilience of urban ecosystems. Pressures on the urban environment are expected to increase with climate change, including a rise in urban temperatures, raised sea levels and urban flooding, as well as loss of biodiversity (see also 'Livability'). Extreme events also affect the built environment. The increased frequency and intensity of extreme events occurring with climate change will exacerbate impacts on buildings

and infrastructure, and the effectiveness of current engineering solutions to these events. Changes in the distribution of events means that existing policies and regulations that are regionally based may need to be revised to ensure that codes used during construction will encompass events likely to occur in the lifetime of structures, and that such codes are also applied to maintenance and upgrade activities.

All aspects of the environment require careful planning and management, based on reliable data, to ensure that our environment continues to support human health and wellbeing, and to minimise the impacts of change on our communities in the future.

The pathway forward

Greater national leadership will help foster coordinated action and encourage investment to address our mounting environmental and heritage issues. To enable Australia to measure progress and undertake effective adaptive actions, significant new effort is required to consistently manage environmental and heritage matters. This includes monitoring and reporting across all states and territories on the state and trend of our natural and cultural assets, and to significantly extend our current efforts in data collection, curation and analysis to provide an open and accessible framework for adaptive and integrated management.

Although this overview reports on significant and ongoing declines in the environment, it also highlights where current investments and the hard work of many Australians have made a difference. By building on these achievements, we can encourage new partnerships and innovations based on what has worked and amplify them across Australia. To achieve this efficiently, new sources of innovative financing and commitment from government and industry are required to fund

the level of change needed. Crucially, we must expand collaboration across governments and nongovernment sectors, including through listening and co-developing solutions with Indigenous and local communities, building on and learning from Indigenous and western scientific knowledge.

To do all of this will take courage and leadership, but it is critical if we are to reverse the declines and forge a stronger, more resilient country to face the challenges in front of us.

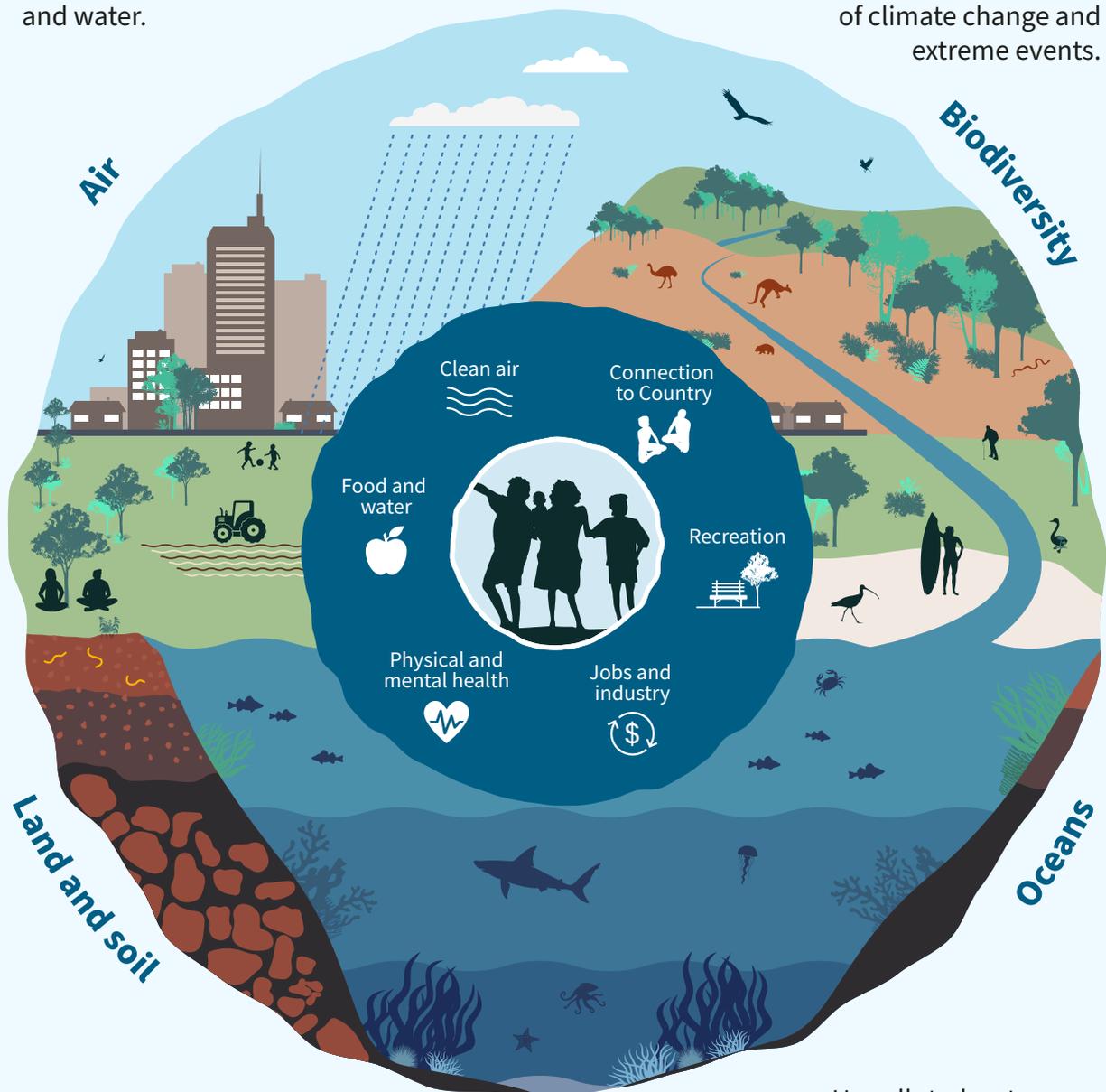
Wellbeing

A healthy environment provides us with the things we need to survive and thrive.

But the health of our environment is declining, threatening our health, living standards and cultural and spiritual fulfilment.

Functioning ecosystems improve the quality of our air, soils and water.

Healthy environments are more resilient and can better recover from the impacts of climate change and extreme events.



Soils and land provide us with food and water, and support native vegetation.

Unpolluted waterways and marine environments support food production, jobs, recreation and industries.



Environment

Climate

Australia's climate is the backdrop against which our landscapes and seascapes, our ecosystems and biodiversity, and our society and economy have all developed. The nature of our soils, vegetation, species, ecosystems, air and urban environments all depend on the Australian climate. Australia's climate is naturally variable across seasons, years and decades. Much of this variability is driven by broader influences in the global climate system driven by ocean and atmospheric changes and cycles, such as the El Niño–Southern Oscillation, and associated El Niño and La Niña events.

Australia's climate, along with the global climate, is changing as a result of human-induced climate change (see 'Climate change and extreme events'). Climate change is also having a high impact on the variability of our climate. We are already experiencing increased temperatures, changed rainfall patterns, increased extreme bushfire weather, and changed frequency and severity of extreme events such as heatwaves. These changes are having a profound effect on all aspects of our environment (see 'Landscapes and seascapes', 'Ecosystems', 'Biodiversity', and 'Human society and wellbeing').

The Australian climate has warmed by a mean of 1.4 °C on land and 1.1 °C in the oceans since consistent national records began (see 'Climate shifts'). Some parts of Australia are warming faster than others, but almost all areas are warming in all seasons. Our warmest year on record was 2019, with temperatures 1.5 °C above the average for the standard

1961–90 reference period. The decade from 2011 to 2020 was Australia's warmest on record, and every individual year from 2013 to 2020 ranks in the top 10 warmest on record nationally.

Temperature is a fundamental driver of all biological processes, and rapid changes in temperature (as observed across Australia) present a stress to most ecosystems. They may result in changes to species' ranges (both expansions and contractions), changes to growth and reproduction rates, or mass mortality events. For example, across the Great Barrier Reef, the first-ever consecutive years of mass coral bleaching, in 2016 and 2017, were followed by an additional bleaching event in 2020, all of which occurred during periods of abnormally high sea surface temperatures.

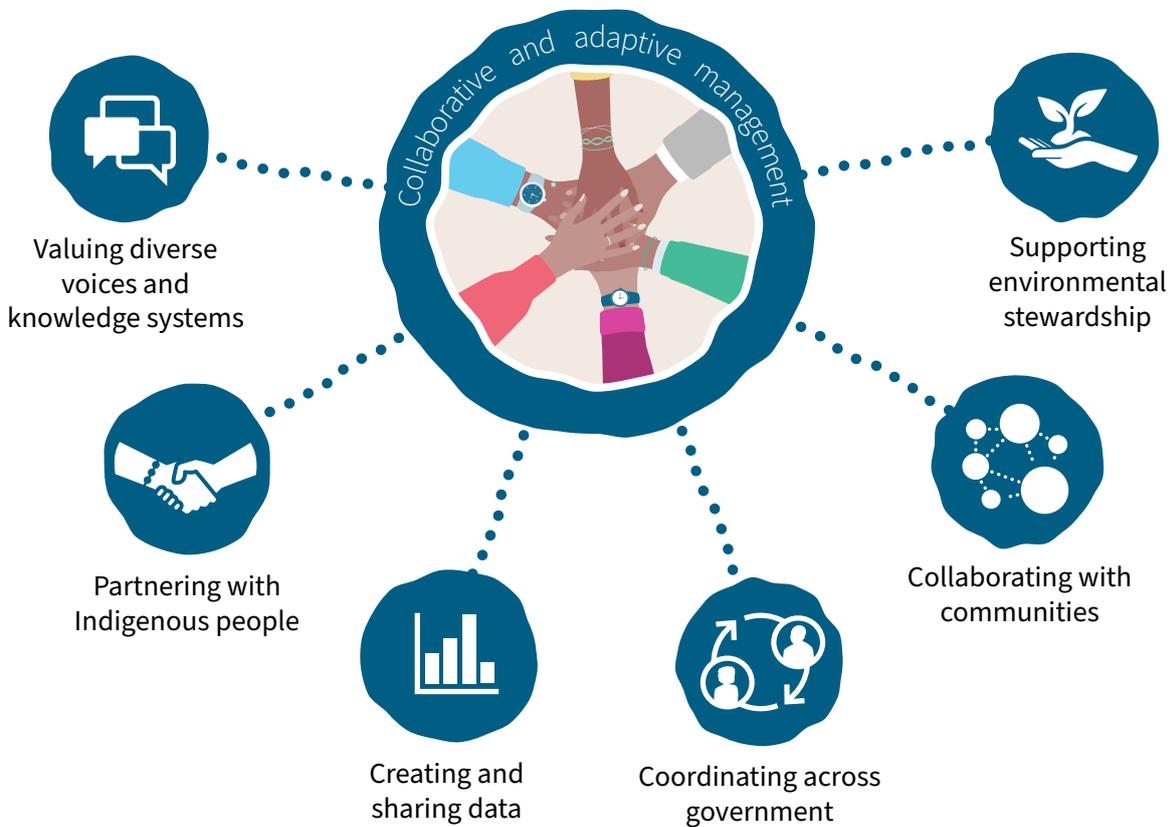
There have also been substantial changes in many other parts of the climate system, including rainfall. Rainfall has decreased in south-eastern and south-western Australia since 1970, and increased in north-western Australia, with indications of shorter but more intense rainfall events (BOM 2021b). Declines in water availability strongly influence the distribution of plants and animals, and the health of terrestrial and aquatic ecosystems.

Low rainfall and high evaporation rates are having a profound effect on river systems. Since 2016, many water storages have fallen below 10%, with acute impacts in the Murray–Darling Basin (BOM 2021b), including large-scale fish deaths in 2019. Sea level rises along much of Australia's coastline continued to be above the global average of 3–3.5 millimetres per year, and the low-lying

Taking action now will help protect our future

Human pressures are combining to threaten our environment.

Innovative management and collaboration among all Australians can turn things around.



Taking action now can restore our environment and ensure a sustainable future and the wellbeing of all Australians.



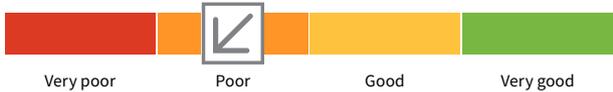
Torres Strait islands are highly vulnerable (see 'Other climate-related changes') (Green et al. 2010, Suppiah et al. 2011, TSRA 2014, Rainbird 2016).

Although Australia is no stranger to extreme events such as tropical cyclones, hailstorms, blizzards, flooding rains, storm surges, heatwaves and bushfires, climate change

is affecting the frequency, intensity and distribution of these events, and even creating new forms of environmental impact – for example, fires that increase lightning strikes from the firestorms they create, and smoke-induced oceanic phytoplankton blooms (see 'Extreme events').



Assessment Climate and extreme events



Overall grade: **Poor**
Overall trend: **Deteriorating**

Assessments of state are poor
Assessments of trend are deteriorating



Assessment Climate



Overall grade: **Poor**
Overall trend: **Deteriorating**

Australia's lands and seas are warming, and much of the south has experienced reduced winter rainfall and severe drought in recent years. Rainfall is increasing in the north-west. Sea levels continue to rise faster than the global average and threaten coastal communities.

Assessments of state are poor
Assessments of trend are deteriorating
Related to United Nations Sustainable Development Goal targets 11.5, 13.2, 15.3

✓ **Assessment** Extreme events



The impacts of climate-related extreme events on the Australian environment are mixed, with heatwaves having a negative impact on land and in the oceans, but floods and bushfires having a mixture of negative and positive impacts depending on location and context. The combined impacts of all extreme events are increasing as they change in frequency, intensity, duration and distribution.

Assessments of state range from poor to good
Assessments of trend range from deteriorating to stable
Related to United Nations Sustainable Development Goal target 15.3

Assessment ratings

For assessments in the ‘Environment’ section

- **Very good:** The environment is in very good condition, resulting in enhanced environmental values.
- **Good:** The environment is in good condition, resulting in stable environmental values.
- **Poor:** The environment is in poor condition, and environmental values are somewhat or slowly declining.
- **Very poor:** The environment is in very poor condition, and environmental values are substantially and/or rapidly declining.

Trend

- Improving:** The situation has improved since the previous assessment (2016 state of the environment report).
- Stable:** The situation has been stable since the previous assessment.
- Deteriorating:** The situation has deteriorated since the previous assessment.
- Unclear:** It is unclear how the situation has changed since the previous assessment.

Landscapes and seascapes

Australia has diverse landscapes and seascapes, from our desert interior to our farming lands, beaches, coral and temperate

reefs, open oceans, wetlands and rainforests. This state of the environment report assesses these various aspects of our environment, along with the ecosystems and biodiversity they support.



Assessment Landscapes and seascapes



Overall grade: **Good**
Overall trend: **Deteriorating**

Assessments of state range from very poor to very good
Assessments of trend range from deteriorating to stable



Assessment Land and soil



Overall grade: **Poor**
Overall trend: **Deteriorating**

Soil and land condition is generally poor as a result of high overall loss of soil organic carbon. The trend in condition is deteriorating as a result of land clearing, unsustainable agricultural practices and erosion, and climate change, although there are some recent improvements in soil under forests.

Assessments of state range from poor to good
Assessments of trend are deteriorating
Related to United Nations Sustainable Development Goal targets 2.4, 12.4, 13.2, 15.3

✓ **Assessment** Inland water



Low levels of rainfall in southern Australia, combined with demand for town water and irrigation, have reduced both groundwater and surface water levels, particularly in the south-east. Similarly, in northern Australia, water resources were reduced by the late onset of the monsoon seasons in 2017–19, with associated poor rainfall during the wet season over consecutive years.

Assessments of state are poor
Assessments of trend are deteriorating
Related to United Nations Sustainable Development Goal targets 6.1, 6.5, 6.6

✓ **Assessment** Coasts



Waterways, beaches and shorelines are generally in poor condition in areas near urban centres, due to coastal development and climate change, but in good condition in more remote areas. Rocky shorelines, mudflats and sandbars are vulnerable to ongoing pressures.

Assessments of state range from poor to good
Assessments of trend range from deteriorating to stable
Related to United Nations Sustainable Development Goal target 14.2

✓ **Assessment** Marine



The marine environment is predominantly in good condition overall, but nearshore reefs are in poor condition and deteriorating as a result of the effects of climate change and cumulative pressures. Also, many habitats and communities that are in good condition overall are highly impacted in some locations. Climate change continues to warm and acidify the ocean, and we have experienced several major marine heatwaves over the past 5 years, resulting in an overall deteriorating trend.

Assessments of state range from very poor to good
Assessments of trend range from deteriorating to improving
Related to United Nations Sustainable Development Goal targets 14.1, 14.2, 14.4, 14.5

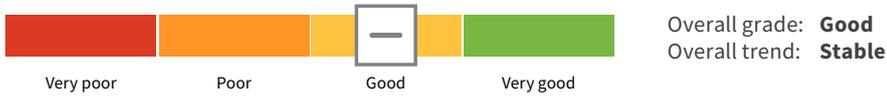
✓ **Assessment** Air



Air quality in Australian cities is generally within national standards, although particulate matter and ozone are increasing in several capital cities. Measurements are taken only at a limited number of places. There were substantial impacts from bushfires in 2019–20.

Assessments of state range from good to very good
Assessments of trend range from deteriorating to stable
Related to United Nations Sustainable Development Goal targets 3.9, 11.6, 12.4

✔ **Assessment** Urban



Australia’s urban environments are in good, livable condition; however, housing affordability and accessibility of services are an issue in some areas. Livability is lower in smaller urban communities than in larger cities. Continuing urban growth, climate change and waste processing are ongoing challenges.

Assessments of state are good
 Assessments of trend are stable
 Related to United Nations Sustainable Development Goal targets 9.4, 11.1, 11.2, 11.3

✔ **Assessment** Antarctica



Although the state of Antarctica is generally good, signals of change and variability are continuing to emerge. Most significantly, the ice sheet is providing an increasing contribution to global sea level rise; sea ice is showing large regional variability; and changes are occurring in the acidity, salinity and temperature of the Southern Ocean.

Assessments of state range from poor to good
 Assessments of trend range from deteriorating to unclear
 Related to United Nations Sustainable Development Goal targets 11.4, 12.4, 12.5, 13.2, 14.2, 14.a, 14.c

Land

Australia's land cover is constantly changing in response to both natural processes and human activities. Land use in Australia continues to intensify. Almost half of Australia is used for grazing. The land areas committed to forestry, irrigated cropping and dryland cropping have increased.

Many parts of Australia are becoming highly degraded, and all remaining native vegetation has been modified to some extent. For example, in 2013, averaged across New South Wales the capacity for habitat to support native species and ecosystem was only 33% of the original capacity. In 2018, the New South Wales Government reported that only 15% of remnant native vegetation was in near-natural condition. Following the millennium drought (2000–10), periods of drought in the past 5 years have further degraded the condition of the land, particularly in the Murray–Darling Basin (see 'Terrestrial ecosystems and native vegetation'). In addition, in the summer of 2019–20, bushfires burned more than 8 million hectares of native vegetation across 11 terrestrial bioregions, and 17 major vegetation types were severely burned. In an analysis of the current state and recent trajectories of 19 ecosystems, spanning Australia's lands, seas and terrestrial Antarctica territory, 10 of the 18 ecosystems at risk of collapse are terrestrial (Bergstrom et al. 2021).

Soils underpin the productivity of the land. They were formed over very long time periods from the weathering of rocks, transport of sediments and interactions with living organisms. A decline in the amount and health of soil directly affects its ability to provide important ecosystem services that support our natural environment and agricultural industries. The ecosystem services that soils deliver are valued at an estimated \$930 billion

per year, making soils Australia's most valuable natural asset (Soil Science Australia 2019).

Soil stores 3 times more carbon than either the atmosphere or terrestrial vegetation, and depleted soils can potentially contribute to reductions in atmospheric carbon (see 'Greenhouse gas emissions'). Higher levels of organic carbon in soil increase land productivity through enhanced fertility and water-holding capacity. As a result of changed land use over the past 2 centuries, Australia has the third highest amount of soil organic carbon loss in the world, behind China and the United States (Sanderman et al. 2017). Ongoing clearing and unsustainable agricultural practices continue to impact the health of soils in Australia; however, in recent years, slight increases in below-ground carbon stocks have been detected where land use is stable under forests (DISER 2021b).

Between 2010 and 2019, the net carbon budget associated with land-use change in Australia reversed so that land-use change became a 'sink', with 15 million tonnes of carbon dioxide (CO₂) sequestered per year on average (Canadell 2021). Overall, net ecosystem productivity (above and below ground) sequestered 746 million tonnes of CO₂ per year over the same period. However, the extensive 2019–20 bushfires across eastern Australia caused major losses, releasing 670–830 million tonnes of CO₂ to the atmosphere. Moreover, the sinks from the land sector are still not enough to balance Australia's carbon budget with industry sources, resulting in a net release of 23 million tonnes of CO₂ to the atmosphere on average each year over that decade (Canadell 2021).

Inland water

Water availability and quality are vital to the wellbeing of Australia's people, ecosystems and economy. Our freshwater resources

and river flows are driven by highly variable rainfall and climate. Since 2016, Australia has experienced both years of higher-than-average rainfall and the driest 24-month period on record. The state and trends of surface waters, groundwater, water quality, ecological processes and species populations deteriorated across many parts of the country, largely due to the extreme climatic conditions and ongoing pressures from water resource development, land use, salinity, bushfire and introduced pests. Northern freshwater systems have generally been subject to fewer pressures and are in a much better state than those in the south.

Rainfall and streamflow

In many parts of Australia, our highly variable rainfall has a significant impact on the availability of water resources (Gill 2011). Australia's streamflow is the third most variable in the world, and its variability is double that of most other countries. Australia has a mean annual rainfall of 457 millimetres (1900–2020). The mean rainfall for 2016–17 was 580 millimetres; this was the tenth wettest year on record measured across the whole of Australia, although the east coast and much of the south-west were drier (BOM 2018). The calendar year 2019 was Australia's driest on record, with 276 millimetres of rainfall, and the 24 months from July 2018 to June 2020 were also the driest on record (BOM 2020a). Drought conditions across south-eastern Australia intensified in 2018–19, particularly in the northern parts of the Murray–Darling Basin. North-western Australia was also dry, with a delayed monsoon onset contributing to a below-average wet season (BOM 2020b).

Northern Queensland was an exception in 2018–19, with higher-than-average flows and annual streamflows in several rivers the highest on record. Heavy rainfall in early 2019 produced extensive flooding in Townsville,

major flooding in the Burdekin River and high flows into Kati Thanda–Lake Eyre, which resulted in an explosion of biodiversity, including a significant increase in waterbird abundance in the Lake Eyre Basin (BOM 2019).

Dry conditions during the latter half of 2019 contributed to generally below-average streamflow across the whole country. Low rainfall, streamflows and storage levels resulted in pressure on water-dependent ecosystems (see 'Freshwater ecosystems') and industries, with low allocations to water licence holders. Recovery commenced in 2020, with flows occurring in all the major rivers within the Murray–Darling Basin. Flow in the lower Darling River reconnected with the Murray River in mid-April 2020 for the first time since January 2018. In February 2020, the first major flows in 8 years occurred from the lower Balonne River into the Ramsar-listed Narran Lakes wetland system (see 'Wetlands') (BOM 2021b).

Water storage and use

In Australia, only 9% of rainfall becomes run-off, on average, and approximately 2% percolates through the soil to recharge groundwater. The rest evaporates back into the atmosphere, mainly through vegetation (Davis 2007). The level of run-off produced by rainfall depends not only on rainfall levels, but also on temperature and catchment condition. Run-off levels may take a considerable time to recover after drought conditions improve.

Australia's high variation in rainfall and streamflow, and high temperatures, have meant that large reservoirs have been built to ensure reliable supply (McMahon et al. 2007a,b,c). Australia has more than 500 major surface-water storages, several thousand small storages and more than 2 million farm dams.

After reaching full capacity in April 2011 following the end of the millennium drought, the accessible storage volume of water across Australia has varied but has generally been well below full capacity due to lower-than-average rainfall across much of the country (see Figure 1).

Groundwater

Groundwater supports a range of different ecosystems, including wetlands and rivers (see ‘Wetlands’), terrestrial ecosystems relying on subsurface groundwater (see ‘Terrestrial ecosystems and native vegetation’), and cave and aquifer ecosystems (see ‘Groundwater species’).

Groundwater also supplies a significant amount of water for human use, although less than surface water. In many regions, groundwater is the only reliable water source for agriculture, mining and urban use. Groundwater for urban water supply is particularly important for Western Australia, where the Gnamptara groundwater system

is Perth’s lowest-cost and largest source of good-quality water (DWER 2021).

Drought conditions and the resulting decrease in surface water availability increased dependency on groundwater across much of the country over the past 5 years; on average, groundwater comprised 20% of water supply in 2019–20 compared with 14% in 2016–17. Groundwater responds more slowly to climatic conditions, and many aquifers have not yet returned to pre-millennium drought levels. The lower-than-average groundwater levels experienced in 2018–19 in many parts of Australia persisted in 2019–20 for all aquifer groups. The majority of bores in the middle and lower aquifers, where most extraction occurs, had below-average groundwater levels (56% and 54%, respectively), with generally stable or declining 5-yearly trends (BOM 2021b).

The Murray–Darling Basin and south-eastern Queensland have low groundwater levels because there has been limited aquifer recharge due to the low rainfall experienced across the region over the previous 3 years, coupled with an increase in the volume of

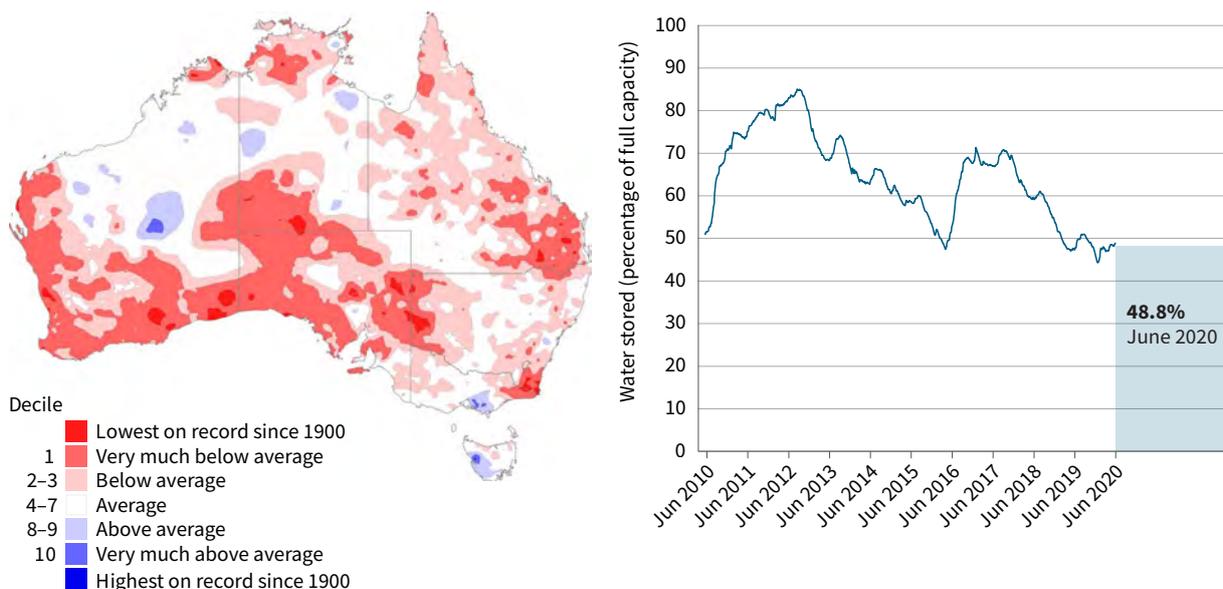


Figure 1 Australia’s rainfall anomaly in 2019–20 and the trend in the national level of water storage since 2010

allocated groundwater taken. When rainfall conditions and surface water availability started to improve in early 2020, groundwater extraction decreased. But despite the rainfall and reduced extraction, groundwater levels did not recover completely.

Similarly, bores in the Darwin and Daly–Roper water control districts in the Northern Territory had declining trends across 2015–20 because the normal increase in groundwater levels during the wet season did not occur as a result of 2 poor wet-season rainfalls (BOM 2021b). Aquifer discharge into parts of the Daly River system provides dry-season flow, which makes it one of the few perennial river systems in northern Australia with consequently high cultural and environmental values (BOM 2021a).

In south-west Western Australia, groundwater levels have generally been declining for the past 40 years as a result of decreasing rainfall (BOM 2018) coupled with increasing groundwater demand. Measures to reduce and redistribute groundwater extraction have been undertaken to slow the rate of decline in groundwater levels, and groundwater trends in the previous 5 years have been mostly stable.

Salinity

In many parts of Australia, soils, surface water and groundwater have a high salt content due to the dry climate and highly weathered landscape. Many Western Australian streams are naturally more saline than streams in northern Australia and along the eastern divide, where greater rainfall dilutes salt concentrations (BOM 2021b). Clearing of deep-rooted native vegetation for irrigated or dryland crops and pastures has changed water balances in many catchments, mobilising highly soluble salts that rise to the surface and eventually discharge into waterways. In 2019–20, 61% of Australia’s river and stream sites were on average fresh and suitable

for drinking, 13% were marginal, and the remaining 26% were brackish or saline. For the previous year, 73% sites were fresh, 9% were marginal, and the remaining 18% were brackish or saline (BOM 2021b).

Dryland salinity adversely impacts agriculture and available water resources, as well as biodiversity, particularly in wetland areas in many parts of southern Australia. South-western Australia is particularly affected. A review found that government agencies have focused on protecting individual, high-value assets, and have not met wider legislated responsibilities to prevent and mitigate land degradation, and protect water resources and biodiversity throughout the south-west (OAGWA 2018).

Environmental water

In all states and territories, areas of intensive water use are subject to water planning processes to manage levels of extraction and to safeguard water to sustain the environment. Water for the environment is provided through rules-based ‘planned’ water (allocation limits and access rules) or, much less commonly, ‘held’ environmental water entitlements.

Overallocation of water resources and environmental degradation have been particularly pronounced in the Murray–Darling Basin, driving the 2012 Basin Plan initiative to rebalance environmental and consumptive use, and recover water for the environment (see ‘Murray–Darling Basin’). The allocation of water to all entitlement holders in the Murray–Darling Basin was low in 2018–19 and 2019–20, and this included allocations to held environmental water entitlements. A review of 3 major fish deaths in the lower Darling River in 2018–19, by the Australian Academy of Science (AAS 2019), found that ‘the root cause of the fish kills is that there is not enough water in the Darling system to avoid catastrophic decline of condition through dry periods’ (AAS 2019).

Nonetheless, assessments have found that environmental watering has started to achieve local benefits. Without it, ecosystem decline over the recent drought period would have been even more severe (Productivity Commission 2021b).

Environmental water also provides other cultural, social and economic benefits. In particular, the delivery of watering events is increasingly integrating Indigenous knowledge to improve environmental outcomes, and achieve distinct cultural and spiritual outcomes. However, existing laws for water management are inadequate to achieve these outcomes. Indigenous people call for greater recognition of Indigenous water rights, and to enable Traditional Owners to give effect to their laws and customs for management of water on Country. This includes increasing use of existing water rights (O'Donnell et al. 2021). The National Cultural Flows Research Project identified 3 levels of Traditional Owner participation needed for cultural water: water rights, more influence in water landscapes, and transforming foundations (see 'Indigenous management').

Coasts

The productive shallow waters and fertile soils of Australia's much-loved 33,000 kilometres of coastline give rise to a huge number of species and a proliferation of life. However, with some 87% of Australians living within 50 kilometres of the shoreline, the diverse pressures on coastal environments are intense. As the pressures of climate change have accelerated over the past 5 years, human populations have simultaneously increased, and industry and urbanisation have expanded into new areas, leading to reductions in available natural habitat, and degradation of some ecosystems.

Overall, Australia's coastal land and waters are in poor condition. Of 19 major stressors on our

coasts assessed in this report, only 2 (nutrient pollution and aquatic invasive species) have improved since 2016; 10 have deteriorated, and 7 are stable. This highlights the inadequacy of conservation and restoration efforts over the period. At the same time, the balance of climate versus population and industry-driven pressures has shifted. Extreme climatic events, including heatwaves, droughts, bushfires and floods, have become the increasingly dominant pressure, dwarfing some of the population-driven impacts, and making coastal protection and restoration more complex and challenging.

Recent bushfires caused staggering losses to coastal biodiversity and the ecosystem services on which human wellbeing depends (see 'Bushfires'). The high loads of sediment and ash that flowed into waterways when above-average rains followed the 2019–20 bushfires exacerbated the impacts on burnt catchments. Substantial deaths were recorded for 11 species that live only in coastal estuaries; this is the first global record of bushfire impacts on water quality extending into estuaries (Silva et al. 2020). Bushfire run-off into estuaries and bays is likely to have also led to reduced oxygen levels and algal blooms, affecting the diverse, abundant invertebrates that play a critical role in local ecosystems (Joehnk et al. 2020) (see 'Marine and coastal ecosystems').

Overall, water quality in coastal regions is good, but conditions are variable, and multiple pressures persist. Although improved land management practices have somewhat reduced the levels of pollutants in the waters of the Great Barrier Reef, the overall estuarine condition remained poor in the 2019 Reef report card (DES 2021). Harmful algal blooms generally have a low impact across Australia; however, in southern Australia, river flows have declined significantly in the past 15 years following extended drought, so water quality

has declined in the riverine portions of estuaries, causing periodic algal blooms and occasional fish deaths. By contrast, New South Wales statewide monitoring found that 75% of estuaries had low algal abundance between 2017 and 2019, up from 57%, indicating potential improvement. But the monitoring also found that the temperature and acidity of estuaries were increasing in response to climate change at a much faster rate than ocean modelling predicts (Scanes et al. 2020).

Coastal areas

Australia's thousands of ocean beaches, loved for their exceptional aesthetic value and opportunities for recreation, are generally in good condition. Dune vegetation, however, has continued to decline nationwide, and beaches in coastal estuaries and bays, also valuable natural assets for recreation, are in poor condition and deteriorating.

The rocky shorelines that provide habitat for a highly diverse mix of species adapted to harsh conditions often support assemblages (collections of species) found only in the local region. Climate change-driven increases in air and sea temperatures stress many species such as rock oysters, and heatwaves can lead to large numbers of deaths, even in remote, pristine locations (Starko et al. 2019). As climate change pressures coincide with reduced water quality and continued urbanisation, rocky shorelines have deteriorated since 2016 and are in a poor state. Intertidal mudflats and sandbars support diverse communities of invertebrates, an important prey resource for fish and large, mobile invertebrates at high tide, and shorebirds at low tide. These habitats are currently in good condition but are also deteriorating.

Australia's coastal waterways are the arteries of coasts, transporting food, nutrients and waste, and providing key habitat for aquatic species.

These highly valued, productive and relatively sheltered places include a diverse range of wave- and tide-dominated estuaries, wetlands, bays, coastal lakes and lagoons, tidal creeks, deltas and stranded plains (Heap et al. 2001), all with unique traits. Their values also mean that they are exposed to numerous human pressures, including urbanisation, recreation, industry and trade (Hallett et al. 2016).

The environments of estuaries, and their wetlands and coastal bays include seagrasses, mangroves, shellfish reefs and rocky reefs, and a variety of sediment types. This diversity of habitat, and the variable estuarine environment where fresh river water meets the sea, mean that these systems support a unique and abundant mix of species.

Although the condition of these environments depends largely on their proximity to population centres, agriculture and industry, events since 2016 have highlighted the increasing threats of climate change and extreme conditions. The condition of estuaries, bays, and coastal lakes and lagoons is poor overall, despite many initiatives to remediate and restore catchments, and variations between locations. The poor condition of coastal waterways has stressed many important habitats (see 'Marine and coastal ecosystems').

This has negative consequences for human society. For coastal Indigenous people, the waterways that run through sea Country underpin all aspects of their living cultures and communities, and their connections to each other, to ancestors and to Country. Waterways are also a focal point for many cultural activities, including leisure and food (Stronach et al. 2019). Connections to these waterways are observed through many artworks, stories, dances and ceremonies.

Islands

Australia contains numerous diverse kinds of islands, such as equatorial tropical atolls (e.g. Cocos–Keeling); coral cays; tropical, subtropical and temperate continental islands; sea stacks; the world’s largest sand island (K’gari–Fraser Island); seamounts forming oceanic islands (e.g. Lord Howe and Norfolk islands); and subantarctic islands (e.g. Heard and Macquarie islands). Many of these islands provide ecosystem services that underpin the lifestyle, economic development and cultural practice for those who live there or have a connection with them. For Traditional Owners of islands, their entire Country, sense of connection and identity are attached to the health of their island home. Many islands are essential locations for a staggering amount of Australia’s biological diversity; islands support more than 35% of threatened species listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The overall state and trend of Australian islands are difficult to determine because we lack adequate ecosystem inventory information, and they are typically overlooked. Where information is available, the condition of islands varies enormously – from highly altered (e.g. some residential islands in south-east Queensland and north-eastern Australia) to largely unmodified (e.g. the Kimberley islands in north-western Australia) to almost pristine (e.g. subantarctic Heard Island). All are threatened by invasive non-native species and the effects of climate change, and many are threatened by overexploitation by people and industries. Larger islands are more resilient, but some have been badly affected by extreme events, such as the 2019–20 bushfires that devastated Kangaroo Island, South Australia.

Marine

As an island nation, Australia’s 13.86 million square kilometres of marine waters – including significant areas of 3 of the world’s 4 major oceans – are deeply connected to our modern national identity, and integral to our economy and way of life. Marine waters hold deep meaning for the Traditional Owners of sea Country. Since the 2016 state of the environment report, the major threat to the health and resilience of Australia’s marine environment has been climate change and associated weather extremes. Climate change is responsible for warming water temperatures, increasing acidification and salinity, changes in ocean circulation, and declines in the availability of nutrients and dissolved oxygen, all of which negatively impact vulnerable habitats and ecosystems (see ‘Marine and coastal ecosystems’).

The key processes that underpin the state of marine ecosystems are generally in good condition. Australia’s oceans are among the clearest in the world (Doblin et al. 2021), enabling relatively deep light penetration. This facilitates photosynthesis in microalgae or phytoplankton, which are the primary producers that form the foundation of the marine food web. Increases in the biomass of both phytoplankton (van Ruth & Matear 2021) and zooplankton have been reported since 2016 (Richardson et al. 2021b). However, changes in ocean currents and the distribution of habitats, communities and species in response to climate change – as well as other major disturbances such as historical declines in large predators, and the historical or current exploitation of various commercially valuable fish and other species – are disrupting the connectivity of ecosystems and the structure of food webs (Condie et al. 2021).

Demand for food, energy and other resources from the marine environment is growing, resulting in the rapid development of our blue economy, which is increasing at 2–3 times the rate of the rest of Australia’s gross domestic product (AIMS 2021). Consequently, Australia’s seascapes are becoming increasingly crowded and noisy. These changes, in combination with pollution (e.g. plastics, marine debris, petrochemicals, excess nutrients, sediments, pesticides) are challenging the management of marine ecosystems and the protection of the many ecosystem services they provide (Costanza et al. 2014, Beaumont et al. 2019, Smale et al. 2019).

However, the sustainability of the commercial harvesting of Australia’s diverse wild-caught marine fisheries has improved over the past 5 years, with 86% of stock assessed in 2020 classified as not overfished. These fisheries catch scallops, prawns, crabs, squid, rock lobster, abalone, coastal fish such as whiting and flathead, reef fish such as coral trout, shelf and deepwater fish such as ling and blue-eye trevally, and oceanic tuna and billfish, contributing some \$1.79 billion to the economy in 2017–18 (ABARES 2020a). The risks associated with oil and gas exploration and extraction activities – with an estimated combined value of \$36.3 billion in 2017–18 (AIMS 2021) – are being effectively managed and having a low impact on environmental condition.

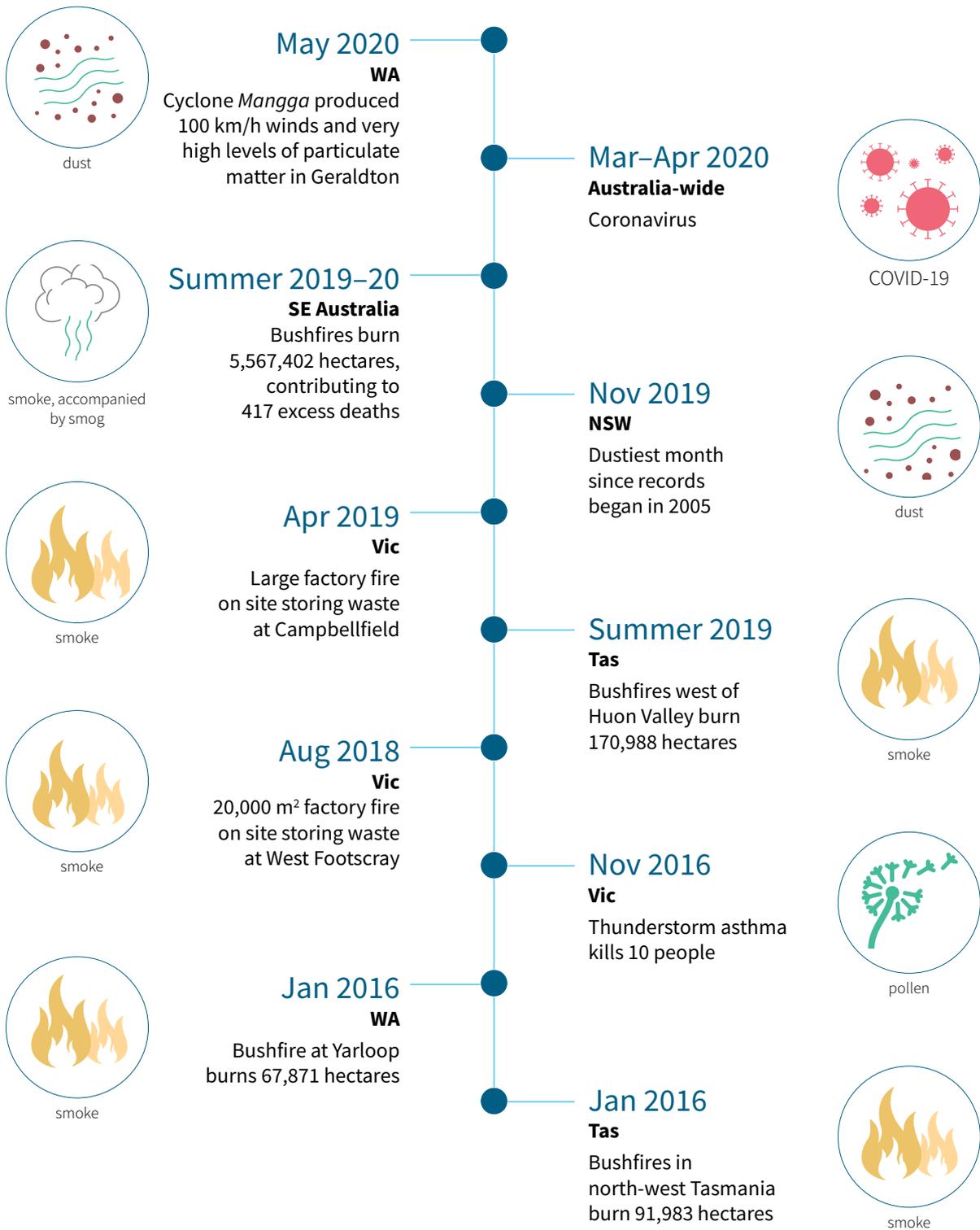
Air

Australia generally enjoys good air quality; however, bushfires, drought, high winds, industrial fires and thunderstorms over the past 5 years have intensified extremes and highlighted the pressures on future air quality as the population grows and the climate changes (Figure 2). For the first time, the

unprecedented bushfires that burned across 6 states over 6 months in 2019–20 made fires (including bushfires and prescribed burns) the single greatest pressure on Australia’s air quality.

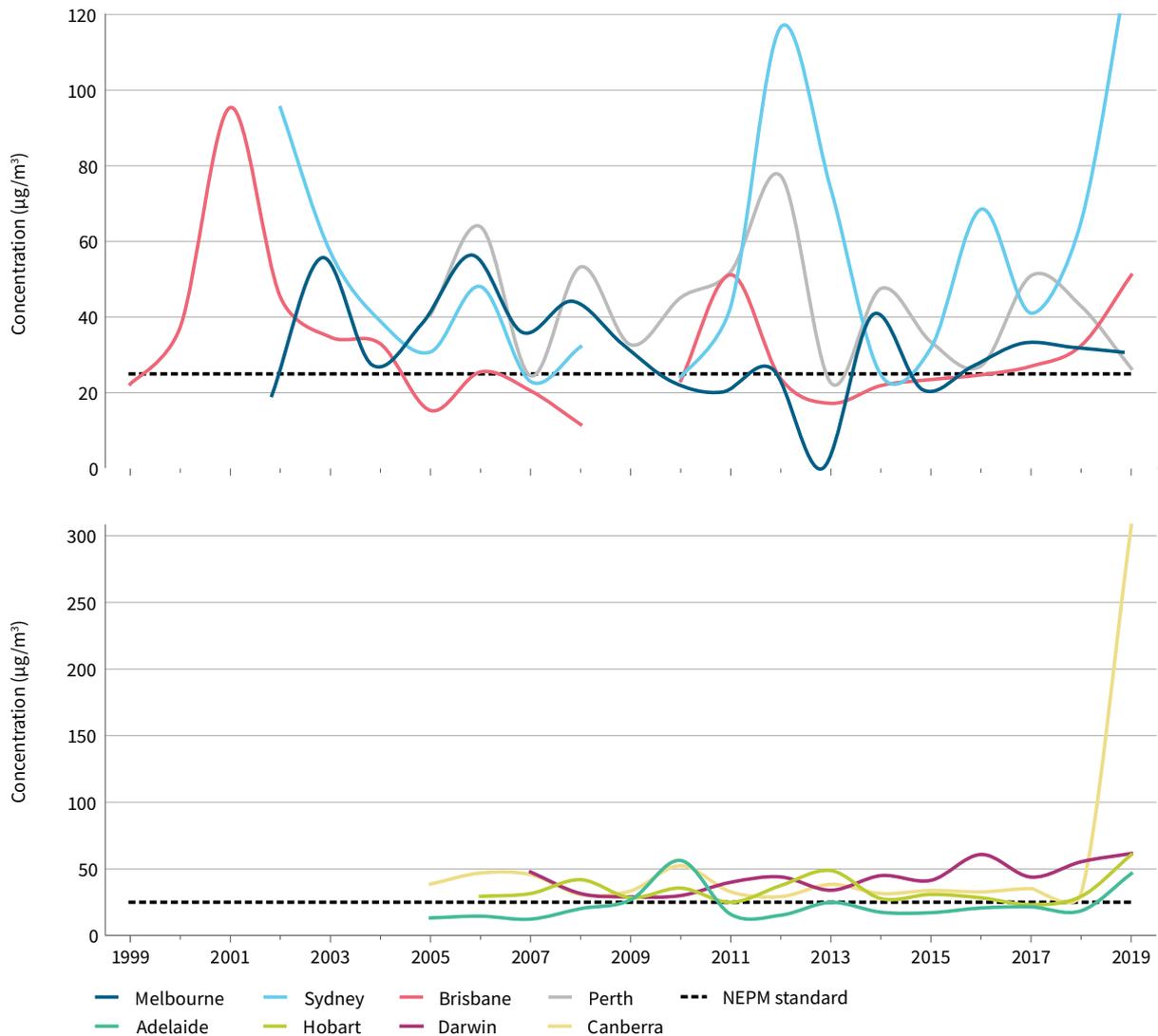
The extreme impacts on air quality began when Melbourne experienced the world’s most severe thunderstorm asthma episode in 2016, causing acute breathing difficulties in thousands of people sensitive to pollen and resulting in 10 deaths. Then, following a prolonged period of drought and high temperatures associated with changing weather patterns, the summer 2019–20 bushfires created high levels of smoke for many weeks, with concentrations of PM_{2.5} (particulate matter with a diameter of 2.5 micrometres or less) well above recommended air quality limits; for example, in Canberra, daily PM_{2.5} concentrations on 1 January 2020 were 38.5 times the 24-hour National Environment Protection Measure (NEPM) standard. During this same extended dry period, New South Wales experienced the dustiest month (November 2019) since records began. In March 2020, the COVID-19 pandemic then triggered a dramatic shift in human activity patterns with the first of Australia’s urban ‘lockdowns’. The result was visibly improved air quality and a glimpse into a cleaner world.

Business-as-usual periods, outside these extremes, were just as important. Fine particulate matter (PM_{2.5}) is one of the pollutants of most concern in terms of human health, linked to 2,616 deaths in Australia each year between 2006 and 2016, or 2% of all deaths (Hanigan et al. 2021). Although all cities have maintained a ‘very good’ assessment for PM_{2.5} since 2016, peak PM_{2.5} levels remained above NEPM levels in all capital cities in Australia every year (Figure 3). PM_{2.5} levels



km/h = kilometre per hour; m² = square metre

Figure 2 Timeline of major events affecting air quality since 2016



µg/m³ = microgram per cubic metre; NEPM = National Environment Protection Measure

Figure 3 Maximum PM_{2.5} (fine particulate) concentration in capital cities, 1999–2019

were stable in Darwin, Hobart and Melbourne, but deteriorated elsewhere.

For concentrations of coarser particulate matter, PM₁₀, most capital cities maintained their ‘very good’ assessment grade of 2016, and Adelaide and Darwin fell just short, moving to ‘good’. Mean PM₁₀ concentrations decreased on average. The 5-year trend in PM₁₀ assessments improved in Brisbane, Hobart, Melbourne and Perth; Canberra and Darwin were stable; and PM₁₀ levels increased in Sydney.

Indigenous communities and other vulnerable subpopulations are inequitably exposed to poorer air quality (Clifford et al. 2015). While it is well known that marked health disparities are prevalent between Indigenous and non-Indigenous Australians, understandings of environmental factors that may significantly compound health problems are under-recognised, with a recent study stating:

Socio-economic disadvantage, existing chronic cardiovascular and respiratory disease, and diabetes have all been shown

to modify the effect of particulate air pollution on health outcomes. Aboriginal Australians have a high prevalence of these health risks and have been recognised as more likely to be at greater risk from poor air quality than other Australians.

Australia's cities are hotspots for ozone, a secondary pollutant formed by chemical interactions between volatile organic compounds and nitrogen oxides (from sources such as motor vehicles, industry, stove tops and gas heaters). With the exception of Brisbane, all capital and regional cities assessed have experienced worsening levels of ozone pollution since 2016. In the 2016 assessments, Darwin, Melbourne, Perth and Sydney were 'very good' for ozone but were downgraded to 'good' in this report. Although the assessment grades in most cities remained 'good' and are below the air quality NEPMs, the increasing trend suggests that it will be harder to maintain this 'good' assessment in future.

Lead exposure has decreased in Australia in recent decades as a result of national initiatives that have restricted the addition of lead to paint and petrol, and the use of lead in consumer goods. Australia's industrial emissions are generally well controlled, and emissions of hazardous substances such as lead and mercury have decreased. However, the National Pollutant Inventory showed that industrial emissions of many pollutants such as PM₁₀, sulfur dioxide, volatile organic compounds and mercury that had decreased since 2009 increased again in 2019, despite attempts to control them.

Urban

Australia is a highly urbanised country. As at 30 June 2021, Australia has more than 1,853 urban environments, 96% of the Australian population (around 24.5 million people) live in cities and towns, and 68%

of Australians live within the greater metropolitan areas of Australia's 8 capital cities (see also 'Livability'). Over the past few decades, the population of major Australian cities has increased, whereas the population in remote and very remote areas has decreased. Australia's Indigenous people make up 3.3% of the population, and many Indigenous people live in urban areas; 37.4% of Indigenous people live in capital and major cities (ABS 2017a).

The COVID-19 pandemic has substantially impacted urban environments, reducing population growth and travel, and changing lifestyles. Working from home has increased rates of walking, cycling and digital interactions (through online shopping), and travel patterns have changed. Green spaces and the desire for larger homes have also increased the demand for more suburban, urban fringe and regional development. Population growth rates are expected to return to pre-pandemic rates, along with other pressures such as consumption, pollution, congestion and waste. New technological innovations are required to move us towards a zero carbon and circular economy.

In 2020, Australia's population density was only 3.3 people per square kilometre (people/km²), with Greater Sydney and Melbourne having the highest population densities of all Australian capital cities (estimated at 433 people/km² in Sydney and 516 people/km² in Melbourne). Australian homes are among the largest in the world; the average size increased by 6% between 2008 and 2018, from 234 to 248 square metres. The average number of occupants within an Australian home has remained relatively constant over the decade, at 2.6 people per dwelling (ABS 2019).

Indigenous communities, knowledge and aspirations are rarely reflected in the built environment, but this is changing as urban planning professionals and government

planning authorities are increasing efforts to meaningfully partner with Indigenous communities to empower their rights and interests in urban settings (Parris et al. 2020). The Planning Institute of Australia developed accreditation in 2016 for ensuring Indigenous knowledge as part of planning qualifications, but, although these moves towards recognition are growing, they remain limited.

Recognising Indigenous perspective in the built environment gives back to Indigenous people, and in turn benefits all aspects of management through deeply expanded understandings of the cultural significance of waterways, past uses of Country and management practices, and sacred sites. Key to the wellbeing of Indigenous people in cities is ensuring that Traditional Owner groups are empowered to speak for Country. Connections to land and waters continue in urban areas, including in big cities (see 'Connection to Country').

Urban areas support critical components of biodiversity, including providing habitat for endangered species. Around 25% of all nationally listed threatened plants and 46% of nationally listed threatened animals are found in Australia's cities and towns (ACF 2020). Indeed, 39 EPBC Act-listed species (37 plants and 2 animals) are thought to have their entire remaining distribution within only 1 or 2 cities or towns (Soanes & Lentini 2019).

Recent shifts in policy towards more green cover are countering some of the losses that occurred before 2016, yet the extent and quality of green cover in urban areas are still declining as urban areas expand. Green cover will become even more important under climate change (see 'Livability'). Increasingly, state and local governments, communities, Indigenous people, and nongovernment organisations are playing a key role in managing and improving the green and blue

networks in our urban environments by working collaboratively to reintroduce native species and plants, create urban forests and living shorelines, and instil principles of biodiversity-sensitive urban design into the design phase of urban infrastructure.

During La Niña years (see 'Climate'), rainfall is higher than the long-term average, and in the north we experience earlier onset of the monsoon and a greater likelihood of cyclones earlier in the season. This results in increased likelihood of major damage and flooding related to strong winds, high seas and heavy rains for most of our urban environments that are located along the eastern seaboard, as experienced along the east coast of Australia in 2021. Flooding particularly affects areas built close to waterways, in low-lying areas and where there is a large amount of impervious groundcover (e.g. concrete pavements, bitumen roads). For example, Western Sydney has a high probability of flooding owing to its topography and infrastructure.

Flooding is also a challenge for many Indigenous communities, whose urban environments have been pushed to urban outskirts or land that was not claimed by others because it was prone to flooding. Many Indigenous communities may experience multiple evacuations over the course of a year, disrupting employment and education routines that are often already inconsistent. Many lower socio-economic urban areas may also be at greater risk because they may have less green cover where water can be absorbed by the soil.

Antarctica

The Antarctic region is widely regarded as of special significance because of its key role in the global climate system, its importance in oceanic food production, and its wilderness and aesthetic values. Since 2016, the overall

state of the Antarctic environment has remained good, but the trend is deteriorating. Changes have continued in the range and abundance of iconic species, regional patterns in sea ice formation have shown increased variability, and the rate of melt of glaciers and ice sheets has increased. At the same time, the Antarctic region has demonstrated the effectiveness of concerted, long-term global action, with the annual hole in the ozone layer showing slow but continued evidence of shrinking following international restrictions on the use of ozone-destroying chlorofluorocarbons (Kramarova et al. 2020).

Climate change poses the most serious threat to Antarctica, the Southern Ocean and the subantarctic islands. The most important factors contributing to physical changes in the Antarctic region are the warming of the upper ocean and the lower atmosphere, and changes in atmospheric circulation, as global concentrations of greenhouse gases increase. Some aspects of surface changes have been mitigated by alteration of winds during

summer through effects from the stratospheric ozone hole.

Since the 2016 state of the environment report, signals of significant change in the physical environment of the Antarctic region have been evident. Regional patterns in sea ice cover have increased in variability, and the Antarctic ice sheet and glaciers have increased their contribution to sea level rise. Additionally, important changes have continued in the state of the Southern Ocean with general freshening and warming of surface waters. Ocean acidification is of particular concern, as it threatens the long-term viability of some soft-shelled organisms that play a critical role in food webs (see ‘Other climate-related changes’).

Particular extremes of variability were apparent over the past 5 years. In 2016, Antarctic sea ice experienced a sudden and rapid decline in its seasonal cycle. By 2021, overall sea ice coverage had increased, but remained mostly below average (Figure 4). Understanding of physical processes in the Antarctic region remains incomplete, and the precise cause of



Photo: Alison McMorrow; © Australian Government Department of Agriculture, Water and the Environment

Figure 4 New sea ice forming near Casey Station in Antarctica

this variability is still under investigation. In the 2019–20 summer, surface temperatures spiked during a record-breaking heatwave across parts of the Antarctic continent. In this case, it is apparent that large-scale climate modes played a role in the extremes, which had other widespread effects across the Southern Hemisphere, particularly in Australia.

The current rate of change in the physical environment of the Antarctic region appears to be faster than the rate at which organisms can adapt, especially those of a higher order (e.g. fish, birds). The Antarctic species most at risk are those that have adapted over millennia to a very specific and narrow range of environmental conditions, such as emperor penguins (*Aptenodytes forsteri*), as well as species that grow and develop slowly, or have limited capacity to move as conditions change. The potential for substantial and abrupt ecosystem shifts as a result of changing sea ice cover has been identified for nearshore Antarctic marine invertebrate-dominated communities (Clark et al. 2015).

Moss and lichen beds that have adapted over millennia to a specific, narrow range of physical conditions are the forests of Antarctica (Kennedy 1993), occupying the most extensive vegetated areas, and offering vital habitats for terrestrial invertebrates and microorganisms. But species composition is changing. In some areas, the abundance of mosses is declining, reducing habitat for associated micro-invertebrates. During the 2019–20 summer, the heatwave in parts of coastal Antarctica (Robinson et al. 2020) raised concerns about impacts on the oases of terrestrial biodiversity that inhabit the fragmented mosaic of ice-free areas, which make up just 0.44% of Antarctica's land surface (Brooks et al. 2019).

Species adapted to warmer conditions and historically not found in the Southern Ocean are moving south and may displace subantarctic

and Antarctic species through competition for food or breeding habitat. Australia's subantarctic islands (Macquarie Island, and Heard Island and McDonald Islands) are at risk of climate-driven invasions of non-native species, particularly as increasing temperatures allow a wider range of plant species to establish themselves and may enhance plant growth. However, Macquarie Island has remained free from non-native invasive rabbits and rodents since their eradication in 2011.

Direct human impacts on Antarctica are also increasing. Before the COVID-19 pandemic, more ships and aircraft were visiting Antarctica than ever before, increasing risks of pollution with hydrocarbons (fuel, oil) through leakage and spills (Polmear et al. 2015); wildlife disturbance, including through visits to breeding areas; and noise pollution from aircrafts, ships and machinery. Just walking can cause compaction that alters the surface structure and nutrient cycles of soil and plant communities (Tejedo et al. 2014). However, management plans are in place for all protected sites in Antarctica and the subantarctic areas under Australian management.

Australia maintains 3 permanent continental Antarctic research stations (Casey, Davis and Mawson), and 1 station at subantarctic Macquarie Island. Remote field bases operate during the summer, including Wilkins Aerodrome 70 kilometres inland from Casey Station. Station populations range from 40 to 100 expeditioners over summer, and 15 to 20 over winter; some 500 expeditioners visit each season with the Australian Antarctic Program. In 2017, 29 nations collectively occupied 40 Antarctic stations year-round, and another 36 facilities operated from October to March (COMNAP 2017). Around Antarctica, the environmental footprint of stations has increased since 2016, mainly through redevelopment and expansion of existing stations.

Ecosystems

Within the living fabric of Australia’s diverse landscapes and seascapes is a complex system of ecosystems of living organisms intertwined with the physical environment they inhabit. Ecosystems are the basis for life – they provide habitat, promote food chains and webs, and control ecological cycles and processes.

The disruption and degradation of ecosystems can lead to irreversible collapse, when key defining features and functions of the ecosystem are lost. At least 19 Australian ecosystems have been reported to show signs of collapse or near collapse, although none has yet collapsed across the entire distribution (Bergstrom et al. 2021). Ecosystems experiencing collapse span the

Australian continent, and include Antarctic and subantarctic ecosystems.

Across Australia, our ecosystems contain elements that are vital for Indigenous people as food and medicine. It is estimated that around 4,000 different plant species are used, which is around 20% of named Australian vascular plants (Isaacs 1987 in Ens et al. 2017). Evidence from the Madjedbebe rock-shelter in northern Australia in the form of charred plant food remains dated to 65,000–53,000 years ago indicates that Australia’s earliest known human population exploited a range of plant foods, including those requiring processing (Florin et al. 2020). Many more plant species were used as materials for tools, shelter and ceremonial items.

Assessment Ecosystems



Assessments of state range from poor to good
Assessments of trend range from deteriorating to stable

Assessment Terrestrial ecosystems and native vegetation



Environmental values of terrestrial ecosystems continue to decline as native vegetation and above-ground carbon stocks are lost through human pressures such as land-use practices and clearing.

Assessments of state range from poor to good
Assessments of trend are deteriorating
Related to United Nations Sustainable Development Goal target 13.2

✓ **Assessment** Freshwater ecosystems



Freshwater ecosystems have been significantly impacted by human activity, generally in the south; habitats have degraded; and breeding grounds and refuges have declined. Drought has had significant impacts on water-dependent ecosystems and culturally significant sites.

Assessments of state are poor
Assessments of trend range from deteriorating to stable
Related to United Nations Sustainable Development Goal targets 6.6, 15.1, 15.6

✓ **Assessment** Marine and coastal ecosystems



Most marine habitats and communities are in a good and stable condition; however, seamounts and reef ecosystems are in poor condition, reefs are deteriorating, and the reorganisation of communities and disruption of ecological connectivity as a result of climate change and cumulative impacts is increasingly apparent. Coastal ecosystems are generally in poor and deteriorating condition in the south-east. Traditional Owners assessed marine habitats and communities as generally in poor and deteriorating condition.

Assessments of state range from poor to very good
Assessments of trend range from deteriorating to stable
Related to United Nations Sustainable Development Goal targets 14.1, 14.2, 14.4, 14.5

Terrestrial ecosystems and native vegetation

Native vegetation is crucial for the health of Australia's environment – it stabilises soil, supports beneficial pollinators and other animals, purifies water, stores carbon, and provides food and habitat for biodiversity. Vegetation and fungi together provide the foundation of the food chain for land-based ecosystems.

The Australian continent supports a vast array of ecosystem types, which have been aggregated at the national level into 89 bioregions and 419 subregions based on climate, geology, landform, native vegetation and species information, described in the Interim Biogeographic Regionalisation for Australia (Thackway & Cresswell 1995, DAWE 2021b). The bioregions and subregions are the reporting unit for assessing the level of protection in the National Reserve System (see 'Protected areas').

Historically, native vegetation has been cleared or degraded by human activity to enable other uses of the land; 13.2% of Australia's native vegetation has been replaced by urban, production and extractive uses of the land (see 'Land clearing'). Native vegetation has been mapped by each state and territory, and has been aggregated into 28 major native vegetation groups and 78 subgroups, through Australia's National Vegetation Information System. Almost half of Australia's major vegetation types have lost at least 20% of their original extent, and one (casuarina forests and woodlands) has lost more than 40% of its original extent. Woodlands have been extensively cleared, with only 53% of casuarina forests and woodlands, and 67% of the original eucalypt woodlands remaining (DAWE 2020c,f).

From 2015 to 2019, nearly 290,000 hectares of primary forest were cleared and a further 343,000 hectares of secondary forest

(regrowth) were re-cleared (DISER 2021e). In addition, extensive areas of sparse woody and nonwoody vegetation have been cleared and converted to other uses, principally pastures; the full extent of this conversion is not well documented. Clearing has been implicated in the listing of 60% of Australia's threatened species under the EPBC Act (Kearney et al. 2018). The most intensively used areas of Australia have the most fragmented native vegetation, such as our major agricultural areas, and the urban and peri-urban areas of Australia's major cities and towns.

Significant areas of native vegetation have been extensively impacted by the grazing activities of sheep and cattle, as well as the destructive activities of introduced species such as pigs, goats, camels, buffalo, horses and donkeys.

Changes to ecosystems from human influences can also result in subtle changes to our native species. For example, many species are highly sensitive to changes in water quality; in Moreton Bay in Queensland, the composition of the diatom community has shown distinct changes in relation to floods, increasing urbanisation and agriculture in the large catchment. The growth of bloom-forming marine planktonic diatoms has increased since the mid-20th century compared with the dominant benthic diatom. This transition is most likely due to a shift in the quality of run-off entering the bay; run-off events of the latter half of the century were characterised by increased fine sediment, nitrogen and pollutant loads (Coates-Marnane et al. 2021).

Most Australians live close to the coast, which puts immense pressure on our coastal ecosystems. The biodiverse coastal areas of south-eastern and south-western Australia continue to see a decline in dune vegetation and ecological function. For the whole of Australia, 11% of coastal dune vegetation from 2014 to 2019 was lost, mainly because

of the 2019–20 bushfires (see ‘Bushfires’), land clearing and reduced rainfall. Coastal vegetation in northern and north-western Australia ranges from poor to good condition. Extensive transformation of native systems to monocultures of introduced species has occurred, as well as loss of significant zones of vegetation across large areas of tropical Australia due to the unseasonably dry wet season in 2019–20 that left coastal dunes exposed to erosion from high winds and cyclonic activity (Babcock et al. 2019b, Duke et al. 2020).

However, although clearing is ongoing, there is also investment in sustainable use and conservation of native vegetation, including efforts to manage and protect natural areas, and restoration of degraded landscapes.

Restoration efforts include those aimed at protecting and restoring our soils. The living part of soil is a critical part of every ecosystem, and is vital for maintaining fertility, species diversity and resilience in natural ecosystems (see ‘Land’). Soil biodiversity is increasingly recognised as being important for human health and wellbeing because healthy soils can suppress disease-causing soil organisms and positively influence the quality of food, air and water (Wall et al. 2015).

Freshwater ecosystems

In much of southern Australia, the greatest threat to freshwater ecosystems and biodiversity is the modification of water processes that has occurred as a result of changes to river and stream flow, surface water and groundwater extraction (primarily for agriculture), and land-use change. Altered water flows, of both surface water and groundwater, have also caused changes to water and soil quality, including salination, sedimentation, and acidification due to the exposure of sulfidic sediments (Capon et al.

2017). Other pressures include barriers to fish movement, invasive species, habitat loss and alteration, and commercial and recreational fishing (Koehn et al. 2020a).

Since 2016, periods of historically low rainfall have significantly affected inland water environments. Australia experienced its lowest-on-record 24-month rainfall period over 2018–20. Climatic extremes – our ‘droughts and flooding rains’ – are a natural feature of Australia’s hydrology. However, their impact on aquatic ecosystems and species is compounded by the continuing pressures of water extraction and development, loss of refugia and deteriorating catchment condition, which may themselves be amplified by climate change. Future changes in the global climate system are likely to have an even more profound impact on hydrology.

The overall assessment of Australia’s freshwater ecosystems in southern, eastern and south-western Australia since the 2016 state of the environment report is that they are generally in very poor condition with reduced ecological function. In northern Australia, they are generally in good condition and are able to maintain minimum expected function (with reduced function, or even persistent transformation, in some localised areas).

Aquatic ecosystems are recognised as being among the most vulnerable to climate change. They experience both local changes and the cumulative effects of changes in the surrounding landscape (see ‘Cumulative pressures’), as well as exposure to a wide range of extreme climatic events such as floods and droughts (see ‘Extreme events’).

Freshwater ecosystems are particularly vulnerable to pressures from climate change, which is predicted to cause substantial changes to the mix of species in Australian rivers well before the end of this century (James et al. 2017). Altered water quality

and quantity, as a result of climate change and resource extraction, are having major detrimental effects on freshwater biodiversity. Extreme hot and dry weather events in the northern Murray–Darling Basin between 2017 and 2019 have been amplified by climate change. The combination of hot conditions, low flows and significant algal blooms during the 2018–20 major drought resulted in mass fish deaths in the Basin (Koehn et al. 2020b). In 2015, a new, unknown disease caused the near extinction of an Australian freshwater turtle, the Bellingher River snapping turtle (*Myuchelys georgesii*), as a result of deteriorating water quality and climate change (Spencer et al. 2018). Future changes in the global climate system are likely to have an even more profound impact on hydrology.

In other waterways, there is an increased risk of algal blooms. The 2019–20 drought and bushfires reduced vegetation cover, and increased the levels of dry soils and ash. This means that following rains could wash large amounts of sediments and nutrients such as phosphorus into waterways, triggering blooms. Algal blooms can produce toxins and reduce the oxygen content of water, affecting fish and other oxygen-dependent organisms (Productivity Commission 2021b).

Murray–Darling Basin

In the Murray–Darling Basin – home to 16 internationally significant Ramsar wetlands, 35 endangered species and 98 species of waterbirds – rivers and catchments are mostly in poor condition, and native fish populations have declined by more than 90% in the past 150 years: a trend that appears to be continuing today (Koehn et al. 2020b).

The drier conditions of a changing climate, coupled with constraints on environmental water management, have meant that the flooding of wetlands (particularly at Ramsar sites) has not met objectives even in wetter

periods. For example, the extent, magnitude and duration of flooding of wetland woody vegetation communities is considered to be inadequate to meet their ecological requirements for the maintenance of extent and condition in most cases (Chen et al. 2020). Low-flow provisions in extreme conditions have not been adequate to protect critical environmental connectivity and refugia in many systems. Reduced water availability also affects water quality, which in turn degrades aquatic ecosystems and causes loss of habitat for flora and fauna, followed by a decline in populations (Productivity Commission 2021b).

The 2020 evaluation of the Murray–Darling Basin Plan found that its implementation over the previous 7 years was ‘having a significant and positive impact on the Basin environment’ (MDBA 2020). Others submit that these effects are highly localised and short term in nature, the amount of environmental water available is too little to have a sustained and widespread benefit (see also ‘Environmental water’), and there is little peer-reviewed evidence of systemic improvement of any flow-dependent matter of national environmental significance or any tributary river system (Wentworth Group of Concerned Scientists 2021).

Assessments of the state and trend of threatened species in the Basin are limited to flow-dependent fish and waterbirds, and tend to focus on particular species or regions. Recent assessments have shown positive outcomes for some threatened species (in some locations at some points in time), but monitoring and reporting on the state and trend of threatened species in the Basin are largely inadequate to assess whether the Basin Plan is achieving its environmental objectives (Ryan et al. 2021).

The Echuca Declaration 2007 reinforced the rights and aspirations of Indigenous people in water management, including the importance

of cultural flows as water entitlements that are legally and beneficially owned by Indigenous communities. Indigenous people in the Murray–Darling Basin own 0.17% of water access entitlements and water licences, despite being nearly 10% of the population (Hartwig et al. 2020). The 2021 final report of the Cultural Water for Cultural Economies project states the clear message of Traditional Owners that water should not be traded or piped out of the Murray–Darling Basin river system, and water should be transferred to Indigenous people through a process determined and designed by them (O’Donnell et al. 2021) (see also ‘Water resources’).

Wetlands

Australia has nearly 34 million hectares of wetlands, covering 4.4% of the continent (Bino et al. 2016), half of which are floodplains and swamps. Australia has 66 Ramsar wetlands that cover more than 8.3 million hectares; Ramsar wetlands are those that are included on the List of Wetlands of International Importance held under the Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat. Wetlands provide important environmental, social, cultural and economic services. They are often significantly affected by changes in agricultural and urban landscapes through extensive clearing, introduction of non-native species, alteration to flows and concentrated grazing pressure. They are also vulnerable to further hydrological changes and drying under future climate change scenarios (Finlayson et al. 2017). Drought conditions, in conjunction with increased consumptive water use, result in a decrease in flows into wetlands and reduction in inundation. The 2019 Aerial Survey of Wetland Birds in Eastern Australia (Porter et al. 2019) found that the wetland area index was the lowest since surveys began in 1983.

Grazing, pests and weeds are also having a significant impact on wetland health,

emphasising the need for integrated management of land-based pressures as well as inundation. For example, nest predation by invasive foxes has been implicated in declines in freshwater turtles in the Murray–Darling Basin (Van Dyke et al. 2019).

Several major indices for waterbirds continued to show significant decline as drought conditions and consumptive water use resulted in a decrease in flows into wetlands. The 2019 Aerial Survey of Wetland Birds in Eastern Australia (Porter et al. 2019) found that the wetland area index was the lowest since surveys began in 1983. Impacts were not confined to eastern Australia – on 30 June 2020, Lake Argyle in Western Australia, a listed Ramsar wetland, was at its lowest end-of-year level in almost 30 years (BOM 2021b).

Wetland ecosystems underpin all aspects of living Indigenous cultures, and hold significant ecological, recreational, spiritual, cultural and economic significance for Indigenous Australians. In some areas of central and northern Australia, wetlands and billabongs are particularly threatened by invasive feral hoofed animals, including water buffalo, pigs and cattle. For example, Indigenous knowledge holders tell us that, historically, yarlbun (water lily) grew in billabongs year-round and was a staple part of people’s diets. However, since the introduction of hard-hoofed ungulates, and their subsequent proliferation and spread, there have been substantial declines in the yarlbun cover of billabongs in the late dry season when water resources become scarce, and animals concentrate around the persisting billabongs. Indigenous knowledge suggests that some billabongs have passed an eco-cultural threshold, shifting from a yarlbun-dominated system to a turbid, sediment-dominated system driven by feral animals (Ens et al. 2016, Russell et al. 2021).

Groundwater species

Although groundwater systems and their dependent ecosystems are generally slower to respond to climatic conditions, they are also under significant pressure from drought and prolonged dry periods. This is because lower rainfall means that groundwater levels are not replenished, and because extraction may increase when surface water resources are depleted. The lower-than-average groundwater levels experienced in 2018–19 in many parts of Australia persisted in 2019–20.

Many Australian ecosystems are dependent on groundwater, and all states and territories have recognised the need for common arrangements in managing significantly interconnected surface water and groundwater resources (Productivity Commission 2021b). Ecosystems that depend on groundwater include terrestrial ecosystems that access subsurface groundwater; the subterranean fauna of cave and aquifer systems; nearshore marine environments that receive groundwater discharges; and springs, wetlands and rivers that rely on groundwater for base flow, particularly in dry conditions. Examples of ecosystems in Australia that depend entirely on groundwater are the Great Artesian Basin spring ecosystems, the Pilbara spring ecosystems, and the permanent lakes and wetlands of the Swan Coastal Plain (Harrington & Cook 2014).

Groundwater access can also be pivotal in supporting urban ecosystem function in prolonged droughts, and in buffering the impacts of climate variability (Marchionni et al. 2020). Of ongoing concern is our lack of adequate knowledge of Australia's diverse and unique subterranean aquatic fauna (stygo fauna) that populate our underground water systems in very restricted ranges, particularly in relation to the assessment of impacts from large-scale developments.

Marine and coastal ecosystems

Australia's rich marine ecosystems span from nearshore reefs to the soft-sediment communities of the abyssal plains at depths of more than 5,000 metres (m), encompassing the vast waters of open ocean that lie between the surface and the sea floor. Coastal ecosystems encompass dunes, saltmarsh, mangroves and estuaries that provide the essential connection between land and sea.

Marine habitats assessed in this report are currently in a range of conditions, from very good to very poor, and their trajectory ranges from stable to deteriorating. Coastal habitats and species were generally assessed as poor and deteriorating. Notably, Traditional Owners assessed marine habitats and communities as in worse condition than reflected by the western science assessments, although Indigenous assessments relate to different spatial scales (local, regional) that can be in a poorer state than the overall national scale.

Climate change continues to drive long-term shifts in the key physical characteristics of Australia's marine and coastal zones, highlighted by recent record-breaking marine heatwaves (Santoso et al. 2017) and enduring changes in marine ecosystems documented over the past 5 years.

Australia's marine waters are undergoing 'tropicalisation', as rising water temperatures drive warmer-water species to extend their ranges poleward into cooler temperate waters (see 'Range shifts and extensions'). Both coral and rocky reefs have experienced changes in the composition of local reef fish communities in recent years and declines in the abundance of species on large scales (Stuart-Smith & Edgar 2021b). Temperate species declined at the warm edge of their distribution. Likewise, some coastal fish communities declined because of coral bleaching and cyclones in the

tropics, and losses of canopy-forming kelps in some parts of the temperate zone (Richardson et al. 2018; Stuart-Smith et al. 2018, 2021). Since 2003, at least 198 Australian marine species have undergone long-term shifts in their geographic distributions, and range shifts are becoming more frequent (Gervais et al. 2021, Gervais & Pecl 2021). Changes in some microbial assemblages of temperate waters have also been observed, favouring smaller phytoplankton (Brown & Bodrossy 2021); this shift could reduce food availability higher up the marine food chain.

Coral reefs

Coral reefs are immensely valuable marine ecosystems, acting as spawning and nursery grounds for many fish species; as magnets for tourism and recreation areas; and as buffer zones against high tides, rising sea levels and storms for coastal areas and communities. Coral reef ecosystems are generally in poor condition and deteriorating. Unprecedented marine heatwaves in 2016, 2017 and 2020 resulted in the first-ever consecutive years of coral bleaching and widespread coral losses, both within and beyond the Great Barrier Reef (Figure 5). Since 2016, coral cover has decreased across the northern Great Barrier Reef (Stuart-Smith et al. 2017, AIMS 2020), at some locations in the North-west Marine Region, and in the Coral Sea (Harrison et al. 2019). Reefs along Western Australia's Pilbara coast experienced repeated heatwaves that resulted in extensive coral mortality (Babcock et al. 2020, Evans et al. 2020).

Tropical cyclones also had substantial, but localised, impacts on Ningaloo Reef in Western Australia and the reefs of Queensland's Whitsunday Islands. However, most offshore (oceanic) reef systems are in good condition, with fewer signs of human impacts than inshore reef systems, but may become threatened by warmer waters (Edgar et al.

2014). Southern parts of the Great Barrier Reef and Coral Sea have experienced increases in coral cover following previous disturbances. This variability indicates the dynamic responses of reef communities to climate change-driven pressures. Deepwater corals and sponges (from 30 m to more than 150 m in depth) remain in good condition; however, trends are unclear because ocean warming is posing an increasing threat.

Australia's extensive string of shallow coastal rocky reefs and kelp (algal) beds that characterise temperate waters are economically, socially and ecologically significant. These have also been affected by rising temperatures. Across Australia, marine heatwaves have led to the loss of species from affected areas; the loss of major habitat types, including corals (Hughes et al. 2018), algal forests, seagrasses and mangroves (Wernberg et al. 2016, Babcock et al. 2019a); and the closure of fisheries (Caputi et al. 2019). Waters of south-eastern and south-western Australia are hotspots, with rates of warming above the global average.

Overall, the condition of the 8,000 kilometres or so of rocky reefs that run (southwards) from Brisbane to Perth is poor and deteriorating (Stuart-Smith & Edgar 2021a). The pressures on these ecosystems include rising ocean temperatures and marine heatwaves, nutrient and pH variations associated with changing currents, overgrazing by sea urchins and other species – due to climate change-driven range shifts and the removal of predators through fishing – and declining water quality due to coastal run-off.

However, conditions vary across regions. Reefs in southern (remote) regions remain in generally good condition, but those in the east and around major cities are poor. Large canopy-forming seaweeds are dominant in many locations in south-western Australia, and western Victoria and Tasmania, but



Photo: Shutterstock

Figure 5 Coral bleaching on the Great Barrier Reef

overgrazing by sea urchins has had major impacts on natural rocky reef habitats in New South Wales, and eastern Victoria and Tasmania (Crozier et al. 2007, Ling & Keane 2018, Glasby & Gibson 2020). Overall, the condition of algal habitat nationwide is good but deteriorating as a result of warming waters and the cascading impacts of fishing (Barrett et al. 2021).

Water column and seabed habitats

Water column habitats in the open ocean extend from the relatively shallow waters over the continental shelf (0–200 m) to the deep offshore abyssal zone at depths of more than 4,000 m. The levels of chlorophyll-*a* (representing an index of phytoplankton biomass), zooplankton biomass and fish

larval abundance (Richardson et al. 2021a,c; Trebilco 2021) indicate that these habitats are currently healthy. However, the water column is vulnerable to climate change–driven acidification and declines in dissolved oxygen, as well as fishing and pollution.

Marine canyons and seamounts are key ecological features: canyons provide pathways for the transport of sediments and nutrients (and pollutants) from the continental shelf to the deep sea and, likewise, the upwelling of cold, nutrient-rich waters from the deep ocean towards the shelf (Kämpf 2010, Currie et al. 2012). The health of these ecosystems varies widely, from very good to very poor, depending on historical levels of damaging bottom fishing and slow recovery rates (Althaus & Williams 2021, Nichol et al. 2021).

Ocean acidification linked to climate change is an emerging threat (see ‘Other climate-related changes’), particularly for vulnerable corals and other calcifying organisms, as is pollution.

Other seabed habitats and communities include those found on silt, sand and gravel sea floors at all depths, as well as reef habitats and communities deeper than 30 m in both temperate and tropical waters. These include ‘twilight’ reefs (30–150 m depth, where small amounts of light still penetrate) and ‘dark’ reefs (below 150 m) formed by deepwater corals (both hard and soft corals), sponges and bryozoans. These habitats are generally in good condition, but again conditions are highly variable across and within regions, largely linked to historical and current commercial bottom fishing (Pitcher 2016, Pitcher et al. 2018). As there is little monitoring of the deep sea floor in Australia (apart from subsea pipelines), biodiversity or oceanographic trends are unknown, as are the impacts of plastics, dissolved pollutants and underwater cables.

Coastal habitats

Along Australia’s coasts, mangroves, saltmarshes, seagrasses, algal mats and native terrestrial vegetation provide habitat for numerous species; their health and extent are important for their own and other species’ survival. Saltmarshes are also efficient carbon sinks, storing an estimated 200 million tonnes of organic carbon (Macreadie et al. 2017). Australia-wide, 47–78% of saltmarshes and mangroves have been lost since European settlement, and they continue to deteriorate (Serrano et al. 2019).

Although mangroves have occupied Australian shorelines for more than 50 million years, and are increasing their range and cover in many areas, the past 5 years have demonstrated that they are not immune to the impacts of extreme events. Cumulative impacts, such as marine

heatwaves, severe drought and a temporary drop in sea level due to a strong El Niño event (Duke et al. 2017), have been linked to massive mangrove dieback in northern Australia.

Many species of grasses, herbs, rushes, sedges and shrubs are found in Australian saltmarshes, mostly growing between mean sea level and the inundation limits of the highest tides. These have experienced losses over the past 5 years. Recent southwards encroachment of mangroves, due to warming temperatures, has driven the ongoing decline of saltmarshes. Flood control measures installed in eastern Australian estuaries from the 1950s to the 1970s isolated mangroves and saltmarshes from tidal waters, with a loss of some 65,000 hectares of saltmarshes in New South Wales and 35,000 hectares in Queensland (Rogers et al. 2016, Wegscheidl et al. 2017). In more recent years, the expansion of solar salt fields in north-west Western Australia has also impacted areas of mangrove and associated algal mats, and saltmarsh communities. The Western Australian Environmental Protection Authority has determined that consideration of any new developments should be in the context of the reasonably foreseeable impacts from all proposals and past developments. Understanding the cumulative impacts from existing and new proposed operations will be critical to minimising the overall impacts.

Australia boasts about 40% of the world’s seagrass species, which form meadows on intertidal and subtidal sediments around Australia. These include several species only found in Australia, and some of the world’s largest meadows. Seagrasses form the base of the food web; stabilise sediments; provide vital nursery habitat for important commercial, cultural and recreational fisheries (Unsworth & Cullen-Unsworth 2014); and are a globally significant reservoir of carbon (Serrano et al. 2019). Historical seagrass losses are extensive

(20–26% loss since European arrival) (Waycott et al. 2009) and ongoing. Although healthy seagrasses largely remain in low-population areas, combined pressures from water quality changes, climate change, weather extremes and the movement of species into new areas have seen declines in seagrass in developed areas. Although there have been some areas of seagrass recovery in the past 5 years (e.g. in some parts of the Great Barrier Reef region), both the general extent and the condition of seagrasses remain poor relative to historical records.

Biodiversity

Biodiversity – the variability among living organisms, including within species, between species and of ecosystems – is essential to the natural environment, and to human survival, wellbeing and economic prosperity (Convention on Biological Diversity Article 2).

Our continent and surrounding seas support 600,000–700,000 native species, and a very high proportion of these are found nowhere else in the world. For example, about 85% of Australia’s plant species are endemic to the continent, and Australia is home to half of the world’s marsupial species. The rate of discovery and formal description of new species has slowed considerably over the past decade, even though, in many species groups, there are many more species that are unknown than known. The best estimate is that 70% (or 400,000) of all Australian species of plants, animals, fungi and other organisms have yet to be discovered, documented, named and classified (Cassis et al. 2017). Although some ‘unnamed’ species can be conserved effectively through conservation of habitats, this is not always the case, and they may be rare or threatened and therefore at threat of extinction before they can be recognised.

Taxonomists are continually discovering and describing new Australian species.

In 2020, 763 new species were named, including 297 insects, 166 fungi, 77 plants, 57 spiders and 21 vertebrates (Taxonomy Australia 2021). However, this is significantly fewer than in previous years. The significant reduction in the annual rate of naming of new species is likely due to reduced investment in taxonomy in many parts of Australia. Although citizen science is rapidly improving our ability to collect information on our wildlife (see ‘Citizen science’), being unable to correctly determine all our species is a massive impediment to best-practice conservation (see ‘Research funding’).

Indigenous Australians attribute tremendous knowledge, spiritual, cultural and symbolic value to our plants and animals, as well as to the broader environment. Many species are spiritually or culturally important, including as totems, sources of food or medicine, materials for tools or implements, and indicators of health of Country. Culturally significant species feature prominently in Indigenous knowledge, including language, ceremonies, stories, lore, identity and narratives.

Wildlife species that are highly visible (and attractive to humans) tend to be better understood. In general, species that are prominently visible (e.g. vertebrates, flowering plants) are well known, and groups that are rarely noticed (e.g. most invertebrates, fungi) are poorly known. This can lead to biases in our overall understanding of diversity, and whether species and groups are threatened. Birds, which are both visible and attractive, make up the single largest proportion of identified threatened fauna species in all areas except the Northern Territory (where mammals make up the largest proportion).



Assessment Biodiversity

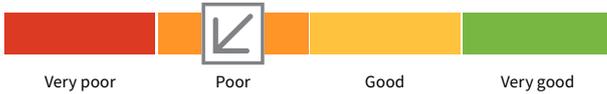


Overall grade: **Poor**
Overall trend: **Deteriorating**

Assessments of state range from very poor to good
Assessments of trend range from deteriorating to unclear



Assessment Threatened species



Overall grade: **Poor**
Overall trend: **Deteriorating**

Threatened plants and animals are generally in a poor and deteriorating state due to increased land clearing, urban expansion and invasive species. The positive exceptions are crocodiles, and some marine mammals and fish in northern and central Australia.

Assessments of state range from very poor to poor
Assessments of trend range from deteriorating to improving
Related to United Nations Sustainable Development Goal targets 14.4, 14.5, 15.1, 15.2, 15.4, 15.5



Assessment Threatened ecological communities



Overall grade: **Poor**
Overall trend: **Deteriorating**

The number of nationally listed threatened ecological communities has been increasing. Approximately half are Critically Endangered, and most of the new listings since 2016 are Critically Endangered.

Assessments of state range from very poor to poor
Assessments of trend are deteriorating
Related to United Nations Sustainable Development Goal targets 13.1, 14.2, 14.5, 15.1, 15.5

✓ **Assessment** Migratory species



Populations of many migratory species, including most migratory shorebirds, have been declining for several decades, with a complex range of pressures affecting them both within Australia and in other parts of the world. Most migratory shorebirds are threatened. Seabirds and marine mammals are assumed to be in good condition, with some known improvements in focal species, but population data are unavailable for many species.

Assessments of state range from poor to good
Assessments of trend range from deteriorating to unclear
Related to United Nations Sustainable Development Goal targets 14.2, 14.5, 15.1, 15.5

Species decline

Over the past 2 centuries, Australia has lost more mammal species than any other continent and continues to have one of the highest rates of species decline among countries in the Organisation for Economic Co-operation and Development. For some species, it is too late, with more than 100 Australian species listed as Extinct or Extinct in the Wild under Australian national, state or territory legislation. The true number of extinctions is likely to be significantly higher, since many species are poorly surveyed or poorly described, or both.

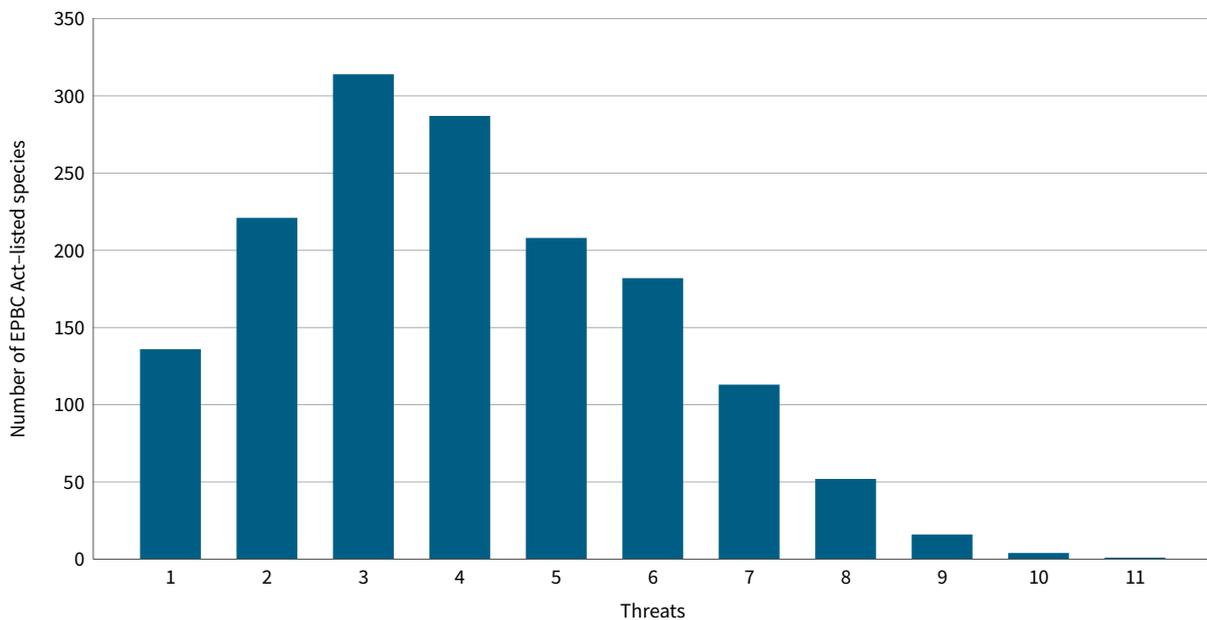
The 2 pressures that have caused the most extinction of Australian terrestrial species since the beginning of colonisation are introduced species (causing the loss of 64 species), and habitat loss and clearing (62 species). In an analysis of all nationally listed threatened terrestrial and aquatic plants and animals in Australia as of July 2018, the same 2 threats were most frequently listed: habitat loss, fragmentation and degradation (1,210 taxa); and invasive species and disease (966 taxa) (Ward et al. 2021). In

more recent times, known extinctions have been associated with introduced disease, sea level rise, and introduced reptiles and fish (Woinarski et al. 2019).

More than 1,900 Australian species and ecological communities are known to be threatened or at risk of extinction. In 2021, more species are listed as threatened, or are listed in a higher category of threat (e.g. from Vulnerable to Endangered to Critically Endangered) than 5 years ago – an increase of 8% since 2016.

The multiple threats faced by Australia’s threatened species may interact and be cumulative, such that the impacts are increased (see ‘Cumulative pressures’). On average, each threatened species faces around 4 different threats (Kearney et al. 2018) (Figure 6). In the past decade, climate change in the form of more severe drought, extreme weather events, fire and habitat modification is becoming a new driver for habitat change and species loss.

There is a growing trend in Australia of ‘local extirpation’, where species may still survive in protected locations (such as islands or fenced



Source: Kearney et al. (2018)

Figure 6 Number of threatened species subject to one or more threats

exclosures) but are no longer present across much of their former range. This insidious change can happen slowly over decades and centuries. The mammals considered most at risk from extinction in the next 20 years are the central rock-rat (*Zyromys pedunculatus*), the northern hopping-mouse (*Notomys aquilo*), the Carpentarian rock-rat (*Zyromys palatalis*), the Christmas Island flying fox (*Pteropus natalis*), and the black-footed tree-rat (*Mesembriomys gouldii gouldii*) from the Kimberley and the Northern Territory (Geyle et al. 2018).

Changes in climate that have been recorded across the Australian landmass are associated with a range of biodiversity responses, including decreases in some species and increases in others. Alpine ecosystems and biodiversity in Australia are particularly vulnerable to climate change that affects snow depth, and the spatial and temporal extent of snow, which have all declined since the late 1950s (CSIRO & BOM 2020). Long-term monitoring (35 years) of alpine vegetation in Australia has shown shifts in the composition and diversity of plant species, changes in the

timing of flowering, and significant declines in endangered fauna such as the mountain pygmy possum (*Burramys parvus*, which is a specialised alpine species) (Hoffmann et al. 2019). Conversely, long-term monitoring in the same region revealed that the average number of bush rats (*Rattus fuscipes*, which is a generalist species that lives in many regions) has almost doubled (Greenville et al. 2018).

Some species may cope with climate change by moving or extending their range to find more favourable conditions (see ‘Range shifts and extensions’). Range shifts and extensions on land can be very complicated because different species have markedly different abilities to shift their location and range in order to cope; many terrestrial species are unable to shift their distribution because of the loss of connecting habitats.

Long-term monitoring data from a wide range of Australian ecosystems confirm that there has been an increase in extreme climate events in the past decade. Coupled with more gradual climate change shifts, extreme events

have resulted in lifecycle shifts, changing species abundances, and range expansions and contractions. Approximately two-thirds of threatened species in Australia are threatened by changing fire regimes (usually in concert with other pressures) (Kearney et al. 2020).

Threatened species

The number of threatened species listed under the EPBC Act has risen for almost all taxonomic groups over the past 5 years, by an average of 8%, with listings increasing the most for invertebrates and frogs (22% and 21%, respectively), and the smallest increase being for reptiles and birds (around 5% increase). Although efforts are underway to better align the international, national, and state and territory lists, there are still many discrepancies and differences between the listing processes. The differences between the lists may be justified for wide-ranging species, but should be the same for a species that occurs only in a single state or territory. The adoption (in October 2015) and implementation of a common listing process (known as the Common Assessment Method) for listing threatened species and ecological communities by most Australian jurisdictions allows the outcome of that assessment to be adopted by other relevant jurisdictions, and is helping to improve management and regulation. But this alone is not enough to address the underlying threats. There is concern that our current listing processes are failing to keep up with the actual rate of biodiversity loss.

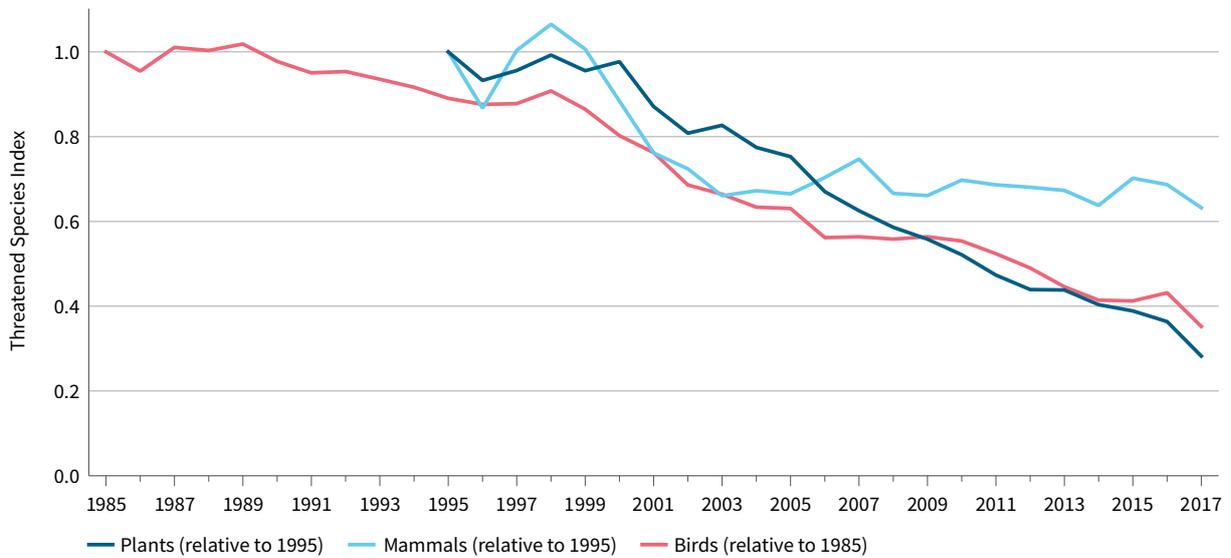
Long-term timeseries of the populations of threatened species collected by many agencies and collated into the Threatened Species Index, funded through the Australian Government's National Environmental Science Program (NESP) with National Collaborative Research Infrastructure Strategy support from the Terrestrial Ecosystem Research Network,

provides valuable insight into startling trends of ongoing loss of habitat and species.

The index has collated thousands of datasets for multiple species across hundreds of sites, and the results show a worrying trend. For example, monitoring of 112 threatened plant species at more than 600 sites for more than 20 years shows, on average, a 72% decrease in Australian threatened plant populations (TSX 2020) (Figure 7). There is also an overall negative trend for threatened (and near-threatened) mammals and threatened birds, with decreases of 38% and 52%, respectively (TSX 2020).

Lists of threatened species are maintained at different spatial scales: the International Union for Conservation of Nature (IUCN) maintains its 'Red List' at a global scale; the EPBC Act lists at a national scale; and each state and territory maintains lists for their jurisdiction. The number and trend of our lists of threatened species is one measure of the health of Australia's biodiversity. As at June 2021, nationally 533 animal and 1,385 plant species were listed under the EPBC Act, more than half of which were listed as Endangered or Critically Endangered.

The top 3 threats that affect the largest number of listed species are invasive species (82% of all threatened species), ecosystem modifications including changed fire regimes (74% of listed species), and agriculture (57%) (Kearney et al. 2018). All of these major threats that cause population declines for threatened species are associated with different forms of habitat destruction or modification. These can result in fragmented populations in small remnants of habitat, which then become vulnerable to further pressures (e.g. invasive predators), resulting in ongoing population declines. The greatest number of threatened plant species and those at most risk of extinction are concentrated in highly modified agricultural and urban landscapes.



Note: The Australian Government’s NESP Threatened Species Index is based on data from multiple monitoring programs of population trends.

Source: National Environmental Science Program (NESP) Threatened Species Recovery Hub

Figure 7 Threatened Species Index plant populations (1995–2017), mammal populations (1995–2017) and bird populations (1985–2017)

Some threatened species may be considered ‘functionally extinct’, having fallen below the critical number to sustain their populations in the long term. Of the 660 plant species listed as Critically Endangered or Endangered at a national level, 62 are known from fewer than 50 individuals, and 300 from fewer than 250 individuals. These are often restricted to tiny remnants that are vulnerable to further degradation and where population growth is unlikely, with a high risk of extinction within the next 10 years (Silcock et al. 2020).

Threatened ecological communities

Threatened ecological communities are ecosystems that are in danger of being lost and are listed under national and state and territory legislation.

The number of threatened ecological communities listed under the EPBC Act has risen by 20% over the past 5 years. As of June 2021, 88 are listed, of which 41 are

Critically Endangered, 44 are Endangered and 2 are Vulnerable. Fourteen new listings have occurred since January 2016, including 9 in the Critically Endangered category. Threatened ecological communities occur mostly in areas that have been heavily modified for agriculture or urban development. Ten of those 14 new listings since 2016 occur in New South Wales. There are 27 recovery plans in place; all EPBC Act-listed ecological communities have either a recovery plan or a conservation advice.

Fauna

Many native animal species in many ecosystems across Australia are in decline.

Terrestrial fauna

Terrestrial mammals across Australia have experienced high rates of extinction, with 10% of endemic species becoming extinct over the past 200 years. Mammals are subject to ongoing population declines, and the numbers of threatened species, including

those at high risk of extinction, are increasing. Approximately 21% are now assessed as threatened (Woinarski et al. 2015, 2019). Most mammal extinctions in Australia have been driven by predation from introduced species, especially the feral cat and European red fox; extinction rates are particularly high in arid and semi-arid regions of Australia.

The 20 mammal species most at risk from extinction over the next 20 years mostly occur in northern Australia and south-west Western Australia (Geyle et al. 2018).

Many of Australia's birds are suffering population declines and are at risk of extinction; the most at-risk bird species are found only on islands or in southern Australia (Geyle et al. 2018). The NESP Threatened Bird Index indicates significant declines in abundance of threatened birds for which monitoring data are available. Between 1985 and 2018, the relative abundance of threatened birds decreased by an average of 60%.

Many of Australia's reptiles also show rates of decline, and the past decade saw the first Australian reptile extinctions in the wild. The proportion of species assessed

as Critically Endangered nationally is increasing. Two species currently listed as Critically Endangered – the blue-tailed skink (*Cryptoblepharus egeriae*) and Lister's gecko (*Lepidodactylus listeri*) – are only known to exist in captivity. The Christmas Island forest skink (*Emoia nativitatis*) was officially declared Extinct in March 2021 and was last seen in the wild in 2010; the last known individual died in captivity in 2014. Reptile experts suggest that, by 2040, up to 11 snakes and lizards, all with restricted ranges and threatened by invasive plants and animals, could become extinct (Geyle et al. 2020).

About half of the 25 species of Australian freshwater turtles are in serious population decline and are listed as Vulnerable, Endangered or Critically Endangered. Nest predation by invasive foxes has driven declines in freshwater turtles in the Murray–Darling Basin (Van Dyke et al. 2019). Turtle declines of up to 91% have also been observed in sections of the Murray River, linked to drying climate and nest predation.

A recent assessment of all our frogs against the IUCN Red List criteria found 18.5% as



Photos: Grasswren – Babs and Bert Wells (Department of Conservation and Land Management, Western Australia); rock-rat – Dr Colin R Trainor; quail – Brian Furby collection

Figure 8 Threatened fauna, from left to right: thick-billed grasswren; Carpentarian rock-rat; painted button-quail

either extinct or threatened. Most of the threatened frog species occur along the east coast of Australia and the Great Dividing Range (Heatwole & Rowley 2018, Gillespie et al. 2020). Most threatened species of amphibians are restricted to the south-east, the wet tropics and the south-west of Australia. Disease is a persistent pressure in eastern Australia (see ‘Diseases’). Drought and fire are increasing pressures.

Coastal and marine species

Most Australians live within 50 kilometres of the coast, and more than half of all Australian species listed as nationally threatened occur within the coastal zone; 56% of the species listed under the EPBC Act were coastal, based on data released in 2019. Of these, 94% were impacted by habitat loss, fragmentation or degradation; invasive species, including weeds, and predators; disease; and fires (Ward et al. 2021). The highest density of threatened species was found along the east coast of Australia, particularly around the urban centres of Brisbane, Cairns, Melbourne and Sydney, and along the increasingly populated coast between Sydney and Brisbane.

Nationally, 88 species and 4 ecological communities with marine and coastal distributions are listed under the EPBC Act. In the past 5 years, 2 species and 1 ecological community were added to the threatened list, including the cauliflower soft coral (*Dendronephthya australis*), which was listed as Endangered in 2020. No marine species have been removed from the EPBC Act list during this period.

Some marine species are restricted to particular latitudes, such as the endemic Australian sea lion (*Neophoca cinerea*) which is listed as Endangered in Australia under the EPBC Act and globally on the IUCN Red List (Goldsworthy 2015), and has been assessed as in a very poor and deteriorating state. Some

species are limited to bays and estuaries within specific regions – for example, the endemic Australian snubfin dolphin (*Orcaella heinsohni*), which has been noted as having decreasing population trends under the IUCN Red List. There were no national estimates for dolphins, but Australian humpback (*Sousa sahalensis*) and snubfin dolphins are considered declining in the North-west Marine Region (Raudino et al. 2019).

All 6 Australian species of marine turtle are also listed under the EPBC Act, half of which are Endangered: loggerhead (*Caretta caretta*), olive ridley (*Lepidochelys olivacea*) and leatherback (*Dermochelys coriacea*). The pressure of greatest concern for marine turtles and sea snakes is climate change and resultant habitat loss from coral bleaching, seagrass loss, mangrove dieback, sea level rise and extreme weather events. Marine debris, pollution, fisheries bycatch, light pollution, and the harvesting of eggs or their consumption by predators also threaten Australian turtles.

Sea snake populations are considered to be poor and declining, with recent dramatic reductions in the spatial distributions of some species (Udyawer et al. 2020). Two endemic sea snake species are listed as Critically Endangered under the EPBC Act and the IUCN Red List; a further 2 endemic species are listed as Endangered and Near Threatened on the IUCN Red List but have not been assessed under the EPBC Act (Eifes et al. 2013). There is limited information on the resilience of sea snakes; however, as they spend most of their lives foraging in surface waters (Udyawer et al. 2016) where temperatures are increasing the fastest, they are potentially vulnerable to climate change (Udyawer et al. 2018).

Fishes

Currently, 62 Australian fish species are listed under the EPBC Act; of these, 38 are freshwater

fish (see ‘Freshwater ecosystems’). This is considered an underestimate because recent analysis shows that 20 freshwater fish species have more than a 50% risk of extinction in the next 20 years, but only 3 are currently listed. The freshwater Pedder galaxias (*Galaxias pedderensis*) is known to be extinct in the wild (Chilcott et al. 2013), and the marine smooth handfish (*Sympterychthys unipennis*) was listed in the IUCN Red List as extinct in 2018, but this is not yet reflected under the EPBC Act listings.

Since 2016, several major fish deaths occurred in our waterways, most prominently in the lower Darling, and both surface water and groundwater ecosystems were affected. Major bushfires also impacted water quality and aquatic species. The long-term decline in populations of Macquarie perch (*Macquaria australasica*), once the most abundant native fish in the Murray–Darling Basin, was showing signs of stabilising in late 2019 in the Snowy Mountains region. But as the rains followed the bushfires in early 2020, ash and mud were washed into the river system, suffocating much of the remaining population (Productivity Commission 2021a).

Our estuaries and coastal bays are highly productive environments and provide essential nursery grounds, migration routes, and refuge and feeding opportunities for many species. They also suffer immense pressure and, in general, estuarine fish populations remain in poor condition. The pressures of local human activities and climate change (Warwick et al. 2018, Gillanders et al. 2021), combined with legacy contamination in many places (e.g. heavy metals) and emerging contaminants (e.g. pharmaceuticals, microplastics, perfluoroalkyl substances), pose an ongoing threat to estuarine fish populations, particularly near urban and industrial areas (Taylor et al. 2018c, Anim et al. 2020).

In Antarctica and the surrounding Southern Ocean, fish are the most diverse vertebrate

group. Evolving over millions of years in subzero temperatures, Antarctic fish (around 200 species) have many physiological and biochemical traits (e.g. antifreeze in their blood) that enable them to thrive in their chronically frigid environment (Beers & Jayasundara 2015) in the vast and variable Southern Ocean, which covers about 10% of Earth’s oceans and is up to 5,000 m deep. Little is known about their capacity to adapt physiologically to increasing ocean temperatures and acidification, but experimental research has shown that heat stress can cause changes in metabolic processes and enzyme activity (Forgati et al. 2017). Annual surveys, stock assessments and tagging studies of species fished within catch limits provide some indications of the state of fish populations since 2016. Populations of schooling mackerel icefish (*Champsocephalus gunnari*) and the large deep-sea Patagonian toothfish (*Dissostichus eleginoides*) are assessed as good, comparable to 2016. The population of the deep-sea Antarctic toothfish (*Dissostichus mawsoni*) is good and has improved since 2016.

Invertebrates

It is estimated that Australia has approximately 320,465 invertebrate species, of which about 35% have been described. Many invertebrates are of significant cultural importance to Indigenous Australians, particularly those that were, and are, valued as a nutritional food source (entomophagy) or used for medicinal purposes.

A total of 285 invertebrate species are listed as threatened under various state and territory conservation Acts, the EPBC Act and the IUCN Red List (Taylor et al. 2018a), but this is considered an underestimate because a vast number are undescribed, and knowledge of their distributions is poor. Most threatened species have been listed from the wetter areas of Australia, with particularly high

concentrations of species in coastal regions of eastern Australia.

However, little data are available in either the marine or terrestrial domains to be able to describe trends in species abundance and diversity. Major threats to insect biodiversity come from habitat loss through broadscale clearing of native vegetation, invasion by weeds, habitat fragmentation, loss of natural corridors and inappropriate fire regimes (Braby 2019). Other threats include disturbance of plant communities on hilltops, on creek embankments and in water courses; pesticides; trampling and grazing by stock and feral animals; and non-native predators (Sands 2018). Invertebrates are an important food source at many levels of the food chain. However, this role means that they can also facilitate the transfer of contaminants, such as heavy metals and pesticides, to other species. Climate change affects insects that have limited thermal and moisture tolerances. Changes in temperature and rainfall potentially affect their distribution, development and reproduction (Sands 2018).

Subterranean fauna

Subterranean ecosystems form important ecological communities in Australia. The diversity of Australian subterranean fauna is extremely high. Living underground, they are an inconspicuous but important part of biodiversity that represent outstanding examples of adaptation and ongoing evolutionary processes, with many ancient lineages of high scientific value and conservation significance. More than 4,100 species are estimated to occur in Western Australia alone, based on the rate of species discovery in the early part of last decade (Guzik et al. 2011). At least 3 fish species also occur in groundwater systems. The blind cave gudgeon (*Milyeringa veritas*) and the blind cave eel (*Ophisternon candidum*)

are both listed as Vulnerable freshwater fish species under the EPBC Act.

Knowledge gained in the past decade shows that much of the Australian subterranean fauna occurs nowhere else (Mokany et al. 2019) and has highly restricted ranges (Hyde et al. 2018). This makes these species extremely vulnerable to extinction from environmental changes and human impacts. For example, in south-west Western Australia, unique stygofaunal communities are associated with mats of submerged rootlets of trees in limestone caves underneath the Leeuwin–Naturaliste Ridge. Several of these communities have been listed as Endangered under the EPBC Act.

Plants

More plant than animal species are listed as threatened under national, state and territory legislation. As of June 2021, 1,385 plant species are listed under the EPBC Act, compared with 533 animal species. The number of plant species listed nationally increased from 1,252 in 2015 to 1,344 in 2020, a marked increase from the previous 5-year period. Orchids are the most threatened group of flowering plants in Australia, with 10% (184 species of a total of around 1,794) of our orchid species listed as threatened under the EPBC Act (Wraith & Pickering 2019). In 2017, the NESP Threatened Plant Index was 0.28, indicating that, on average, the size of threatened plant populations decreased by 72% between 1995 and 2017.

Overall, the major pressure causing population declines for threatened plant species is habitat destruction. Declining species and those at most risk of extinction are concentrated in highly modified agricultural and urban landscapes. Changes in fire regimes – fires that are either too frequent or too infrequent – are also a significant pressure for many plant species.



Case study Australian sandalwood – native forest product or threatened species?

Richard McLellan, Charles Sturt University

The Australian sandalwood (*Santalum spicatum*), also known as walarida (Wajarri), waang (Noongar) and dutjahn (Martu), is a tree native to semi-arid and arid areas in southern and western Australia. This important tree is in dramatic population decline – it is estimated that only around 10% of its original extent remains, and it appears that virtually no new trees have emerged in the wild for 60–100 years.

Indigenous people revered the tree for thousands of years, using it, for example, in smoking ceremonies and bush medicine. Commercially harvested since the 1840s, forest products from Australian sandalwood have been widely used as aromatics and cosmetic products. Over the past 175 years, it has become one of the world's most valuable timbers. Although extensive plantations have been established for domestic use and export, wild populations continue to be commercially harvested because of commercial expediency and the fact that old-growth trees produce the best-quality oil.

The species is being affected by the cumulative impacts of commercial harvesting, land clearing, altered fire regimes, overgrazing (mainly by introduced herbivores) and lack of regeneration, all compounded by the effects of climate change. Sandalwood seedlings require 3 consecutive good years of rainfall to establish from seed, which, in the current climate regime, is a rarity in arid and semi-arid Australia. The loss of commensal species, such as burrowing bettongs that provided seed dispersal services, has also impacted the recruitment of new individuals.

The fate of the Australian sandalwood tree demonstrates the combination of land-use and climate stressors that are currently impacting many old-growth, slow-growing native species. Dramatic declines are overlooked until the population crash becomes unequivocally evident, requiring immediate and reactive responses. Yet often the cascading signs of collapse in many species can be predicted decades earlier by understanding their biology, ecology, land-use history, and altered climate and disturbance regimes that lead to changes that adversely impact the species' persistence.



Source: McLellan et al. (2021), republished from *The Conservation*

Figure 9 Dead sandalwood tree

Fungi and microorganisms

Despite the very important roles that fungi and microorganisms play in ecosystems and ecological processes, the overall level of knowledge about Australian nonvascular flora (algae, liverworts, mosses), fungi and lichens is very limited. Thirty-six Australian fungi species are listed under the global IUCN Red List, including 1 Critically Endangered and 4 Endangered species, most of which occur in temperate forests. No fungi are currently listed under the EPBC Act, and only a few are listed under state or territory legislation.

Migratory species

Australia's migratory species include birds, turtles, marine mammals (such as whales

and dugongs) and fish, including the world's largest shark. Many of these are listed under international agreements (see 'International obligations and treaties') and protected under the EPBC Act. The EPBC Act's Migratory Species List as at June 2021 includes 114 birds, 20 marine mammals, 17 fishes (including sharks and rays) and 7 marine reptiles.

Understanding the state and trend of migratory species and the pressures affecting them is complex and requires collation of data from different sites across multiple countries.

Millions of migratory shorebirds fly from breeding grounds in northern China, Mongolia and Russia to East Asia and Australia each year, traversing more than 20 countries while migrating. Thirty-seven species regularly

and predictably visit Australia during their nonbreeding season, from spring to autumn. Some shorebird populations are in severe decline, and future extinctions are expected without urgent management interventions. Loss and degradation of ‘stopover habitat’ on tidal mudflats in the Yellow Sea region of East Asia has reduced this habitat by more than 65% in recent decades. Consequently, the populations of migratory species that rely heavily on this region to rest and refuel show significant declines. For example, populations of the great knot (*Calidris tenuirostris*) and far eastern curlew (*Numenius madagascariensis*), both of which are listed as globally threatened taxa, have declined more than 5% per year on average since 1993 (Studds et al. 2017).

Twelve out of 19 migratory shorebird species (and 17 out of 19 species in southern Australia) have been declining nationally for several decades. Since 2016, as new trend analyses became available, 4 populations of migratory shorebirds have been listed as Critically Endangered, 5 as Endangered and 3 as Vulnerable under the EPBC Act. Four additional populations that use Australia are listed globally as Near Threatened.

Around 60 species of seabirds are known to breed in and around Australia and its external territories, including albatrosses, boobies, cormorants, frigatebirds, gulls, noddies, pelicans, penguins, petrels, prions, shearwaters, storm petrels, terns and tropicbirds. Their overall state is good and stable (Woehler 2021); however, there have been widespread decreases in the populations of some species of petrels, shearwaters and tropicbirds (Garnett & Baker 2021, Woehler 2021). Many species of seabirds are listed as Threatened under the IUCN and are also listed under the EPBC Act.

Threats to seabirds include the ingestion of marine debris; fisheries bycatch (although this is decreasing); the redistribution of their

prey in response to climate change; and competition for breeding habitat as a result of development, feral predators, and the southwards movement of some species due to climate change.

Few surveys have been done of the 7 species of migratory flying seabirds on the Antarctic continent; more is known about the 13 species on the subantarctic Heard, McDonald and Macquarie islands, which include albatrosses, diving petrels, cormorants and shearwaters. Because these islands support threatened and endangered seabird species, they are declared Important Bird Areas (IUCN). Some populations have benefited from the eradication of introduced predators, rabbits and rodents (McInnes et al. 2019), and the management of commercial fishing.

All of Australia’s 48 species of cetaceans (whales and dolphins), 3 species of pinnipeds (seals) and a single sirenian, the dugong (see ‘Coasts’), are listed under the EPBC Act. Key pressures include bycatch in commercial fishing operations, interactions with vessels (tourism operations and recreational vessels), ship strike, entanglement in debris and fishing gear, coastal habitat loss from development, temporary disturbance caused by vessels and noise, and changes to breeding and feeding habitats and marine food webs associated with climate change (Speakman et al. 2020).

Information on the status of most whales and dolphins is not available (Evans & Harcourt 2021, Evans & Raudino 2021), but their state is assumed to be good. Available Australian estimates are generally positive. Population growth rates for northward-migrating east coast humpback whales (*Megaptera novaeangliae*) are estimated at 10% per year (Pirodda et al. 2020). The population has likely fully recovered from commercial whaling and may soon surpass original population levels (Noad et al. 2019). Population growth rates of southern right whales (*Eubalaena australis*)

in south-eastern Australia were estimated to be 4.7% per year, but with no significant change in the numbers of cow–calf pairs at the only recognised calving ground in the region (Stamation et al. 2020). There are no national estimates for dolphins, but Australian humpback and snubfin dolphins are declining in the North-west Marine Region (Raudino et al. 2019).

Blue whales (*Balaenoptera musculus*) are the largest creature on earth, reaching 27 m in length. The Antarctic blue whale population is only 3% of the population in the pre-whaling era and is recovering slowly, despite prohibitions on hunting in the Southern Ocean from 1965–66 and elsewhere from 1972. The greatest threats the whales now face are declining food sources associated with ocean warming and increasing ocean acidification (Cooke 2018). Blue whales are among 6 species of baleen whales found in Antarctica that sieve or filter krill, plankton and crustaceans from sea water through a hairy plate in their mouth (baleen). Baleen whales include humpback whales, the majority of which migrate to Antarctic waters. Recent surveys indicated that populations of the 7 breeding groups of humpbacks that use the Southern Ocean are increasing, and consultation is in progress on the possible delisting of humpback whales from the EPBC Act (DAWE 2021c).

The 9 species of tuna and billfish that migrate through Australian waters support valuable fisheries (Mobsby et al. 2020). All species are wide-ranging, with populations that extend well beyond the Australian exclusive economic zone. The main pressure on populations is the harvesting of wild stocks. Populations of southern bluefin tuna (*Thunnus maccoyii*), one of 8 fish species identified as Conservation Dependent under the EPBC Act, have increased as a result of the implementation of a rebuilding strategy that includes harvest limits.

Human society and wellbeing

The state of the environment has direct implications for human wellbeing. Humans depend on nature for life-sustaining services such as provision of food and water, climate regulation and cultural connection (Rendón et al. 2019). These are collectively described as ecosystem services, or ‘nature’s contributions to people’ (Díaz et al. 2018). The ongoing delivery of these services or contributions is founded on healthy, well-functioning ecosystems, and the sustainability of natural capital ‘stocks’ (see ‘Natural capital accounting and environmental–economic accounting’).

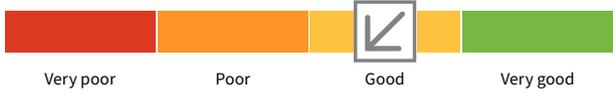
Human wellbeing goes beyond physical health. In this report, wellbeing is defined as the life quality and satisfaction of people and communities, comprising (Yap & Yu 2016, Rendón et al. 2019):

- health
- living standards
- community and social cohesion
- security and safety
- freedom, rights, recognition and self-determination
- cultural and spiritual fulfilment
- connection to Country and nature.

The Indigenous worldview recognises that the health of the environment and health of people are inextricably intertwined – healthy Country means healthy people (see ‘Connection to Country’ and ‘Indigenous wellbeing and economy’).



Assessment Human society and wellbeing



Overall grade: **Good**
Overall trend: **Deteriorating**

Assessments of state range from very poor to good
Assessments of trend range from deteriorating to stable



Assessment Food, water and air quality



Overall grade: **Good**
Overall trend: **Deteriorating**

Most urban residents experience high wellbeing in built environments. Regional and remote areas have lower access to services, including water supplies, which are impacted by drought. Air quality is generally good but declining in cities, and has limited numbers of monitoring stations.

Assessments of state range from poor to good
Assessments of trend range from deteriorating to stable
Related to United Nations Sustainable Development Goal targets 1.4, 1.5, 2.4, 3.9, 6.1, 6.6, 6.b, 14.2, 15.1



Assessment Impacts of changing climate and extreme events

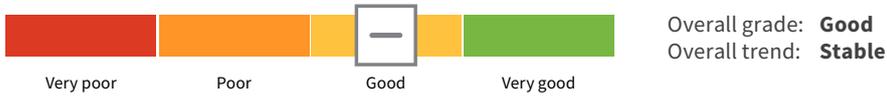


Overall grade: **Poor**
Overall trend: **Deteriorating**

Many of the effects of extreme events on wellbeing can currently be managed. However, bushfires, drought and heatwaves are all impacting negatively on wellbeing. Impacts are increasing in all cases under the influence of climate change.

Assessments of state range from poor to good
Assessments of trend are deteriorating
Related to United Nations Sustainable Development Goal targets 1.5, 2.4, 11.5, 13.1, 13.3

✓ **Assessment** Livability



Livability is good in large urban areas but decreases in peri-urban and smaller urban centres and remote communities. Livability factors, such as access to jobs and public transport, are highly variable across towns and cities. Inequities in access to resources continue, especially for Indigenous people and communities, and some essential supplies such as water are further impacted by climate change and lack of rights.

Assessments of state range from poor to good
Assessments of trend range from deteriorating to stable
Related to United Nations Sustainable Development Goal targets 6.1, 6.5, 6.b, 7.1, 11.7, 13.1

✓ **Assessment** Indigenous wellbeing and heritage



Barriers exist to Indigenous wellbeing in terms of involvement in decision-making, connection with Country, disempowerment and adequacy of support. Some aspects of Indigenous wellbeing are improving, such as recognition of languages, culture and rights, but perspectives vary across Indigenous groups. Regional variation is also high.

Assessments of state range from very poor to poor
Assessments of trend range from deteriorating to improving
Related to United Nations Sustainable Development Goal targets 11.4, 15.6

✓ **Assessment** Historic and natural heritage



Wellbeing outcomes from the management of natural heritage, historic heritage and World Heritage are generally good; however, management of cultural heritage, Indigenous heritage and geoheritage is inadequate.

Assessments of state range from poor to good
Assessments of trend range from deteriorating to stable
Related to United Nations Sustainable Development Goal targets 11.4, 14.5, 15.1, 15.5

Assessment ratings

For wellbeing assessments

- **Very good:** The wellbeing of people and communities is in very good condition, with enhanced social values.
- **Good:** The wellbeing of people and communities is in good condition, with stable social values.
- **Poor:** The wellbeing of people and communities is in poor condition, with reduced social values.
- **Very poor:** The wellbeing of people and communities is in very poor condition, with very degraded social values.

Trend

- ↗ **Improving:** The situation has improved since the previous assessment (2016 state of the environment report).
- ▬ **Stable:** The situation has been stable since the previous assessment.
- ↘ **Deteriorating:** The situation has deteriorated since the previous assessment.
- ? **Unclear:** It is unclear how the situation has changed since the previous assessment.

Food, water and air quality

Quality, affordable food is one of the key material contributions of nature to people (Diaz 2018). The competition for land area in Australia caused by urban sprawl, combined with the impacts of climate change, are putting increasing pressure on fresh food provision and security. Local responses such as urban gardens provide some relief from this pressure, as well as a connection to nature and culture. The Waraburra Nura rooftop garden at the University of Technology Sydney features many native plants used for nutrition and medicine by Indigenous people. The CERES Community Environment Park includes a community garden and urban farm on Wurundjeri Country, Melbourne (CERES 2021).

Australia's high levels of food production through agriculture, for both local and

overseas consumption, result in high pressures on our environment from land clearing, grazing, cropping and water use for irrigation. Hence our native vegetation, soil and carbon stocks in intensive land-use zones are in poor condition and deteriorating (see 'Land').

Climate change and extreme events are having an increasing impact on our agriculture. Pressures include the chronic effects of drought and heat, and changing rainfall patterns, which are driving changes in the type and location of crops.

Increasing extreme events caused by climate change have affected food, water and air over the past 5 years. The loss of vegetation in many catchments following major bushfires meant that subsequent rains caused erosion and the movement of sediment loads into drinking water catchments, compromising water quality. Multiple extreme events have imposed

significant stresses on agricultural production, from extensive damage to tree and other crops caused by storms and cyclones to the effects of heat stress on farm and domestic animals, and more insidious impacts that disrupt the lifecycles of pollinators and beneficial predatory insects.

Intense events such as hailstorms can damage infrastructure and equipment, and large volumes of smaller hail can strip leaves from plants or cause surface imperfections on fruit. Severe hailstorms across New South Wales, South Australia and Victoria in November 2016 affected vineyards, almond crops and stone fruit crops, along with 21,000 ha of field crops (AIDR 2017). Tropical cyclones also pose a risk to agricultural production, damaging or felling trees, and stripping leaves, flowers and fruits from plantings (see ‘Storms, floods and cyclones’).

Commercial fishing and increases in aquaculture are also important for food security. These are not without environmental cost, such as bottom-trawling impacts on sensitive marine habitats and pollution from fish farms. Fish stocks are generally in good condition; however, inner-shelf reef species are in poor condition and declining. Recreational fishing pressures remain high, posing a threat to fish stocks and biodiversity.

Fresh water is precious in Australia – the driest inhabited continent on Earth. Low rainfalls in recent years, combined with water use for agriculture, have depleted surface water. This is leading to inequity between stakeholders, increased reliance on groundwater and increasing water restrictions. Overall, the state and trend of water are deteriorating as a result of pressures from climate change, increasing development and only partially effective management, including the exclusion of Traditional Owners from rights to cultural water.

Although water quality in Australia is generally high, it is declining in many areas due to increased salinity, algal blooms, bushfire ash run-off and pollutants. Indigenous people are being affected by the diminished availability of water for cultural and environmental flows (see ‘Environmental water’). This has a deep impact on Indigenous wellbeing, which is intimately connected with water as a being, spirit and ecological entity.

Air quality is also essential to human wellbeing, as poor air quality affects respiratory and cardiovascular health, birth outcomes and deaths. The latest burden of disease assessment by the Australian Institute of Health and Welfare estimates that 2,566 deaths were caused by air pollution in 2015, or 1.6% of all deaths in Australia (AIHW 2019). Air pollution also reduces life expectancy. The number of years of life lost as a result of air pollution has increased by 1,000 years since the previous burden of disease report (AIHW 2016). Although Australia’s air quality generally meets global standards, recent research indicates that there is no ‘safe’ level of air pollution, particularly for sensitive populations exposed to ozone or particulate matter (see ‘Air’). The health of Indigenous communities is being impacted from changes in air quality (Patel et al. 2019), and poor air quality can also lead to impacts on Indigenous people’s lifestyle, cultural resources and cultural stories.

Impacts of changing climate and extreme events

Climate change impacts are increasingly affecting human wellbeing; marginalised individuals and communities are at greater risk.

Many of the most direct impacts are caused by heatwaves. Heatwaves cause more deaths in Australia than any other single extreme weather event (Steffen & Hughes 2013).

Australia's vulnerability to heat exposure is high, and lost working hours and mental health outcomes both increased over 2016–21 (Beggs et al. 2019). Presentations at hospital emergency departments peak on heatwave days, and there is a significant increase in presentations for up to 2 weeks after a heatwave event. Age, health status and socio-economic disadvantage all contribute to heatwave vulnerability (Beggs et al. 2019).

Climate change exacerbates dust levels and natural emissions from plant and animal sources, through rising temperatures and more frequent droughts. Temperature-driven chemical reactions in the atmosphere are likely to cause more summertime smogs in urban areas. This poor air quality will affect health, especially in vulnerable individuals and populations. The predicted increase in extreme heatwave events will also lead to increased summer bushfire activity, meaning that extremely poor air quality due to smoke may be a recurrent feature of future Australian summers.

Extreme events such as tropical cyclones, hailstorms, flooding rains, storm tides, heatwaves, bushfires and blizzards have always been part of Australia's climate, but increasing intensity and frequency of these events are impacting more heavily on human wellbeing. Extreme events may last only hours or days, but can change natural and urban landscapes, and sometimes have irreversible impacts on ecosystems and individuals or communities. Emerging engineering solutions aim to improve the resilience of infrastructure, homes and other buildings, and to protect people, but impacts of extreme events are still considered to be increasing.

When severe tropical cyclone *Seroja* crossed the Western Australian coast on 11 April 2021 as a category 3 cyclone, 70% of buildings in Kalbarri and Northampton were damaged, causing widespread power outages (BOM

2021c). This crossing was unusually far south for a cyclone of this intensity, and thus the minimum building standards required for buildings and infrastructure were lower than for areas more usually exposed to cyclones of such intensity, indicating one of the many social impacts of climate change.

Improved forecasting and warning systems mean that communities are usually aware of approaching storms, cyclones, floods and bushfires, and have time to act to avoid risk to life. However, the intensity and speed of extreme events did not entirely prevent loss of life between 2016 and 2021. For example, the Black Summer bushfires of 2019–20 caused the death of 33 residents and firefighters, the loss of more than 3,000 homes, and months of thick smoke that affected an estimated 80% of the Australian population at some time during the fire season, contributing to 417 additional deaths (Borchers-Arriagada et al. 2020). The bushfires also caused property, farm, livestock and wildlife losses, and affected local tourism and economies (see 'Bushfires').

Extensive, damaging floods across Queensland in early 2019 resulted from a monsoon trough and embedded tropical lows that delivered record-breaking rainfall to the north and west, affecting 56% of the state (IGEM 2019). Some areas received more rain than their average annual rainfall, and there was significant flooding, impacting large areas of pastoral holdings, and multiple cities and towns.

Livability

The state of Australia's urban environment affects wellbeing through access to jobs and services, travel times, access to green and blue spaces, urban heat, connection between people and with Country, security (e.g. against extreme weather events), and flow-on effects on physical and mental health (see 'Urban').

Australian cities are consistently ranked as some of the most livable in the world based on personal security, lifestyle, health care, crime, work–life balance and access to green space. Sydney is ranked 7th and Melbourne 11th in the world (Knight Frank 2020).

However, livability is not uniform across Australia. Urban fringe areas have lower livability than inner city and more established areas as a result of reduced access to resources, long travel times and less tree canopy cover. Inland areas have lower livability than coastal areas, and smaller urban areas are often more impacted by extreme events and limited access to services. Indigenous people are disproportionately affected through dispossession, loss of cultural identity and loss of connection to Country.

Access to public transport that is consistent and reliable is a key factor in urban livability. Travel-to-work distances have at least doubled since 1977 in every capital city except Adelaide. Although most local councils are adding bike and pedestrian paths, most of Australia's largest cities remain dependent on cars. Indigenous and small regional and remote communities are often far from services such as shopping and health care, and transport problems make it hard to get to employment venues and to undertake cultural commitments (e.g. getting to funerals and out on Country).

Urban congestion has eased during the COVID-19 pandemic. However, demand for travel across urban environments may return to the former growth trend. This will place greater pressure on road and rail infrastructure, exacerbating existing levels of congestion and demand for new or augmented transport infrastructure, which has ever-increasing financial costs. Growing congestion translates into longer commutes and travel times, which increases carbon dioxide emissions. Road vehicles contributed

85% of direct greenhouse gas emissions that were generated from all transport modes in 2019–20 (BITRE 2020).

The structure and layout of our urban areas has a critical influence on their walkability and cyclability. Six major cities in Australia rank as 'somewhat walkable': Sydney, followed by Melbourne, Adelaide, Geelong, Brisbane and Perth. Walking Country is an essential part of Indigenous people's ability to connect to Country. Connecting to Country promotes the sense of belonging that Indigenous people have to their environment, whether this environment is urban or regional.

Resource security in urban areas is generally poor and deteriorating. Areas of high population growth and vulnerability to climate change are placing increasing pressure on scarce resources such as water and energy, and producing high levels of waste.

Equity of digital access also remains a challenge, as does cybersecurity. Digital infrastructure is important for access to employment, health and education. Digital connectivity varies across the country, as does reliability of connection. The COVID-19 pandemic has brought about discrepancies in digital access, disproportionately affecting low-income households.

Climate change has a very high and increasing impact on our urban environments. Warmer temperatures, bushfires, floods, drought and sea level rise are challenging the livability, resilience and sustainability of our homes and workplaces. Most of our urban areas are on the coast, and coastal erosion, recession and inundation are expected to increase substantially as a result of sea level rise, resulting in financial and safety impacts.

Urban heat is forecast to increase substantially, impacting human health, sleep patterns, productivity and other social factors, and thereby leading to increasing deaths

and illness. Rising temperatures particularly affect cities because of the ‘urban heat island effect’, where urban areas are warmer than the surrounding land. This is a result of the presence of roads, pathways, buildings and dark roofs that trap and absorb heat more than green surfaces (e.g. gardens, parks) and blue surfaces (e.g. rivers, creeks). With the urban heat island effect, temperatures in our urban areas can be 1–7 °C higher than surrounding areas, particularly at night (Soltani & Sharifi 2017).

Indigenous wellbeing

Indigenous people’s wellbeing is intrinsically connected with Country. Changes in Country alter and disrupt Indigenous people’s connection with land, seas, plants and animals (see ‘Connection to Country’). Mining and agriculture have been identified by Indigenous people as causing degradation to Country. Destruction of Indigenous heritage is detrimental to Indigenous people. Encroaching development and tourism also have impacts, although there are examples of Indigenous tourism ventures that promote ecological responsibility, such as the Mossman Gorge Centre in the World Heritage-listed Daintree Rainforest, operated by Voyages Indigenous Tourism Australia on Kuku Yalanji Country (VITA 2021).

The ongoing and intergenerational impact and trauma of colonisation continues to adversely affect Indigenous people’s connection to Country and manifests in unacceptable rates of imprisonment, suicide and unemployment (PM&C 2020). Indigenous people are leading the development of frameworks to strengthen their health and wellbeing through caring for land and sea Country. For example, the Strong Peoples – Strong Country framework was developed in 2019 by the Indigenous Heritage Expert Group as part of the Reef 2050 Integrated Monitoring and Reporting Program

(Figure 10). Strong Peoples – Strong Country reflects the world view of Traditional Owners that their quality of life is connected to their health and the condition of the Great Barrier Reef (Jarvis et al. 2019). These connections between Country, people and culture are reflected in 6 strongly connected ‘hubs’.

Caring for Country

Indigenous people are custodians of Country, with deep responsibilities to actively care for and manage all aspects of Indigenous culture, lands and waters. Although Indigenous peoples are extremely diverse, with more than 300 language groups across Australia, there are many shared foundational aspects to Indigenous culture – caring for Country as kin is one of these.

Connection to Country covers all landscapes and seascapes, including deserts, rainforests and urban areas. Concepts such as urban and wilderness have tended to undermine Indigenous people’s custodianship of Country. However, all Australian lands and waters have Traditional Owners and Custodians.

Land management work enables Indigenous people to practise culture. There is a wealth of evidence that engagement and collaboration benefit the wellbeing of Indigenous people and communities, and provide much benefit for Country. Knowledge of keeping Country strong can heal land and sea management, and enable Indigenous people to carry out their stewardship or custodial obligations. For example, the Ngadju people have a joint management arrangement with the Western Australian Government that allows them to protect the environment by hunting, burning and managing sacred sites (Prober et al. 2013, Woodward et al. 2020).

The rapid growth of Indigenous sole and jointly managed protected areas over 2010–20 suggests that equitability of management



© Mallie Designs
Source: Jarvis et al. (2019)

Figure 10 Strong Peoples – Strong Country framework, grounded in Traditional Owner values, showing the connections between Country, people and culture

has increased, but several issues remain. Although Indigenous Protected Areas (IPAs) are recognised as part of the National Reserve System, the Australian Government offers only short-term grants to establish and manage IPAs, and invests in them at a much lower level per hectare than in other protected areas (Taylor 2020). IPA ‘projects’ are funded through multiyear funding agreements to fulfil their management plan commitments. Government protected areas, on the other hand, have permanent staff, ongoing salaries and operational budgets. The increasing reliance on Indigenous communities to shoulder the burden of building the National Reserve

System requires an increasing and appropriate investment in management and security. Short-term contracts, financial insecurity and tenure insecurity impose a high administrative burden and constrain the aspirations of Traditional Owners to care for their land over the long term.

The *Strong women on Country* report (Country Needs People 2018) pointed to the positive impacts for Indigenous people and the environment flowing from meaningful expression of culture and caring for Country. In particular, the report highlighted the powerful and influential role of Indigenous women in

caring for Country initiatives. The contribution of Indigenous women in this context is often overlooked, but Indigenous women's engagement with Country can produce many reciprocal benefits for entire communities. Land and cultural activities have been identified as priority outcomes for health and supportive family environments (Productivity Commission 2020a).

Indigenous languages are interlinked with Country and the stewardship role of Indigenous peoples. Complex ecological knowledge is embedded within Indigenous languages (see 'Indigenous heritage'). The impact of colonisation on Indigenous language use has been highly detrimental to the wellbeing of Indigenous Australians. The revitalisation of languages is considered an important Indigenous cultural priority. There is a positive relationship between Indigenous language use and participation in land-based activities. Overall, the National Aboriginal and Torres Strait Islander Social Survey found that Indigenous language speakers are more likely to participate in hunting, fishing and gathering, and caring for Country, and such activities are known to markedly improve health outcomes in Indigenous communities (DITRDC et al. 2020). The Living Languages website of the Australian Institute of Aboriginal and Torres Strait Islander Studies expresses language as imperative to cultural belonging and strength.

Climate change impacts

While climate change impacts are becoming apparent in our environment, what is less apparent is the profound impact on Indigenous people's traditional practices and knowledge systems, which have been in place for tens of thousands of years. The ways in which Indigenous people read and predict weather and climate systems are based on their knowledge and connections

to Country, which are based on observed patterns. Natural indicators of climate and environmental patterns are being overlaid by rising temperatures, sea level rise and ocean warming, shifting or delayed rainfall patterns, and extreme weather. As a result, the Indigenous seasons are changing or delayed, putting Indigenous people's knowledge and culture at risk. As natural indicators continue to undergo extreme change and shift from what the cultural baseline used to be, we will see Indigenous people's knowledge at risk of loss or transforming to a new norm of adaptation.

Temperature extremes can have health and wellbeing implications for human communities across Australia. For Indigenous people, extreme temperatures can force them to migrate away from their traditional lands for long periods into an urban setting or to seek cooler climates. Temperature extremes place environmental change stresses on traditional knowledge, Country and biodiversity. Rising land temperatures can also reduce the availability and growth of plants used for a traditional purpose such as food and medicine; this can affect the health of Indigenous people who rely on traditional plants for their nutritional and healing properties.

Extreme events, which are increasing with climate change, are continuing the incremental destruction of Indigenous places and cultural values. Many cultural sites and values are unidentified or undocumented because of population displacement, lack of access to Country, and impacts on traditional knowledge and practice. Environmental changes wrought by extreme events are also affecting the abundance and distribution of native plants and animals of cultural significance, further threatening the persistence and application of cultural knowledge and people's cultural connections to Country.

Indigenous, historic, natural and geoheritage

Australian heritage is those aspects of the cultural and natural environment that we wish to look after and pass on as an inheritance. Heritage is distinguished from the everyday because it has special importance or value, and tells the story of the evolution and special nature of Australia's environment and culture. It includes aspects of the natural environment as well as aspects of the cultural environment, and these elements are often interlinked. Much of Australia's natural and cultural heritage is globally significant.

Indigenous heritage

Indigenous heritage is fundamental to all aspects of Indigenous cultures. It has spiritual, historical, cultural and social value, through connecting Indigenous people to their Country, and thereby also to particular social relationships and custodial obligations.

Indigenous cultures, and the heritage that underpins them, are living. They do not reside only in the past; they are a vital aspect of the lives and cultures of Australia's Indigenous people today. Heritage is integral to the health and wellbeing of Indigenous communities, and is the foundation of spiritual and cultural connection and vitality for future generations of Indigenous people.

In recent years, there has been a shift towards acknowledging that Indigenous heritage includes intangible heritage and is not restricted to physical sites. Cultural landscapes are increasingly being recognised in Indigenous heritage and systems of management. 'Cultural landscape' refers to the dynamic interactions between people and Country. It includes the natural environment, the spiritual and traditional knowledge of that environment, and the cultural practices and activities applied there. It reflects the

management and modification of Country over many thousands of generations for the benefit of all.

Major achievements in Indigenous heritage management and protection since June 2016 include:

- inscription of the Budj Bim Cultural Landscape (Figure 11) on the World Heritage List in 2019; this is the first Australian World Heritage property to be listed for its Indigenous values alone, and the first to be wholly nominated by an Indigenous community (Gunditjmarra)
- inclusion of the Murujuga Cultural Landscape (Burrup) on Australia's World Heritage Tentative List
- development of *Dhawura Ngilan: a vision for Aboriginal and Torres Strait Islander heritage in Australia*, which was adopted by the Heritage Chairs of Australia and New Zealand in 2020 and, through its best-practice standards, is an important step in improving Australian Indigenous heritage legislation
- the introduction of the first intangible cultural heritage laws in Australia in 2016 as amendments to the Victorian *Aboriginal Heritage Act 2006*.

However, these achievements need to be balanced against the highly visible failures of the past 5 years, which include:

- the unnecessary and shocking destruction by mining of the irreplaceable 46,000+ year-old Juukan Gorge rock-shelters in the Pilbara, Western Australia, against the wishes of the Traditional Owners, the Puutu Kunti Kurrama and Pinikura (PKKP). This event brought into sharp focus the extensive damage that is occurring to Indigenous heritage across Australia. *A way forward*, the final report of the inquiry into the destruction at Juukan Gorge (JSCNA 2021), was released in October



Courtesy Gunditj Mirring Traditional Owners Aboriginal Corporation. Photo: Ian McNiven, republished from *The Conservation*

Figure 11 Budj Bim Cultural Landscape

- 2021 and found that heritage legislative frameworks enabled Rio Tinto to exercise excessive power over the PKKP peoples
- the findings of the review of the EPBC Act (Samuel 2020), which were highly critical of Indigenous heritage protection in Australia
- the lack of progress in intangible heritage protection; as of June 2021, Victoria remains the only state with any provision to protect intangible cultural heritage through legislation.

The outlook for Indigenous heritage is poor, given the ongoing pressures that affect Indigenous heritage, particularly cultural landscapes, from development and non-Indigenous land management. Major changes to Indigenous heritage legislation and governance are required, especially regarding free, prior and informed consent; self-determination; and access to Country. Indigenous people should be empowered in the identification

and management of Indigenous land and sea heritage, including cultural mapping. A way forward recommended that a new national legislative framework be co-designed with Indigenous people.

Historic heritage

As currently recognised and protected in Australia, historic heritage is the tangible evidence and places associated with Australia's inhabitants and visitors since the arrival of the first European migrants, also including evidence and places related to explorers and other visitors since 1606. It can also include heritage that has shared history or meanings between Indigenous and non-Indigenous people. Heritage provides an important sense of place and connection, and can contribute to individual and community wellbeing. Historic heritage can also generate economic benefits through tourism and re-use, although such

use requires a well-managed and sustainable approach.

Historic heritage is primarily at risk from rural and urban land development, and resource extraction. Considerable amounts of historic heritage are being destroyed or significantly affected by economic development and redevelopment. Inadequate management and protections are contributing to the impacts of development pressures.

Historic heritage on land is primarily recognised and protected through inclusion on heritage lists. At the national level, the EPBC Act provides for significant historic heritage to be listed on World Heritage, National Heritage or Commonwealth Heritage lists. At the state and territory level, heritage is protected through inclusion on state or territory heritage registers. At the local level, protection is generally provided through inclusion in a local planning scheme code or overlay. Listed places represent a diversity of types of places and geographic coverage of Australia; however, they do not include all Australia's significant historic heritage that is worthy of recognition and protection, and there are significant imbalances and regional or thematic gaps in what historic heritage is listed, requiring more effort in historic heritage identification.

Underwater cultural heritage is managed separately from terrestrial cultural heritage. The *Underwater Cultural Heritage Act 2018* (replacing the *Historic Shipwrecks Act 1976*) provides protection in Commonwealth waters, and various state and territory legislation protects underwater cultural heritage in other Australian waters and in inland waters. Underwater cultural heritage is generally at less risk from the various pressures than terrestrial heritage; however, Australia's underwater cultural heritage is also poorly understood, and requires greater heritage identification effort and monitoring.

Natural heritage and geoheritage

Australia's natural heritage includes protected areas, natural systems and significant landscapes, and elements of these. The biological aspects of natural heritage include endangered and iconic species, significant plant and animal populations and habitats, and high-quality ecosystems. Most 'natural' heritage is interrelated with Indigenous heritage because, apart from Australia's remote offshore territories, there is no place in Australia that does not belong to one or several Traditional Custodian groups.

Natural heritage is at risk from various pressures – in particular, climate change impacts, bushfires and other burning, development pressures, introduced species, and inadequate management and protections. These pressures have been increasing over the past 20 years, and are forecast to further increase (see 'Landscapes and seascapes', 'Ecosystems' and 'Biodiversity'). Although many of Australia's natural systems are resilient to disturbances such as fire, the diverse nature and high levels of these pressures that have been experienced since 2016, including the effect of cumulative or sequential pressures (e.g. drought followed by fire followed by heavy rain), have had negative impacts.

In Australia's current heritage protection systems, natural heritage includes geoheritage. As an extremely old, relatively stable landmass, Australia has a wealth of very old geological and geomorphological features rarely preserved elsewhere. Geoheritage helps define Australia, regions or local areas through iconic landscapes and particular landscape features, and can be of economic importance, particularly through tourism. The Australian landscape and many of its individual features are of great significance to Indigenous Australians, as part of Creation stories and integral to interactions with Country (see

‘Indigenous heritage’). However, geoheritage is generally not recognised or protected separately from natural heritage, and this leaves much of Australia’s geoheritage at risk.

The condition of natural heritage in protected areas (see ‘Protected areas’) is not well understood because it is inadequately monitored and evaluated and, in the case of geoheritage, poorly understood generally. There is a lack of data to evaluate the present level of impacts of stresses and pressures on Australia’s natural heritage as a whole, at either the national or regional scale. In general, the ‘biodiversity’ elements of natural heritage are better understood and managed; however, understanding and management are not complete and are not adequate to slow current rates of decline. Climate change – with rising temperatures, increasing extreme events and altered fire regimes – is considered to be the greatest pressure on natural heritage.

World Heritage

Some of Australia’s unique natural heritage is recognised in 20 World Heritage properties, listed for their outstanding universal natural and cultural heritage values. Twelve are listed for their outstanding natural values, 4 for outstanding cultural values, and 4 for both cultural and natural values. The rate of inscription of Australian World Heritage properties has fallen significantly in the past 10 years, with only 1 new property added to the list since 2011.

In Australia, natural and cultural heritage are intertwined. For example, in 2019, the Budj Bim Cultural Landscape was added to the World Heritage List (Wettenhall & Gunditj Mirring Traditional Owners Aboriginal Corporation 2010, DAWE 2021d), and another 4 sites were added to the Tentative List, including 2 new properties: the Murujuga Cultural Landscape and the Flinders Ranges. Murujuga is the Indigenous

name for the Dampier Archipelago and surrounds in Western Australia. With more than 1 million images in an area of more than 37,000 hectares, Murujuga is home to one of the most significant and diverse collections of petroglyphs in the world, which documents the transition of an arid maritime cultural landscape through time. The Flinders Ranges is proposed to be listed for its natural values, as its geological formations provide a record of the environment and habitable conditions that started animal life some 350 million years ago.

While the physical state of Australia’s World Heritage properties is not routinely evaluated, the most recent IUCN World Heritage Outlook 3 report (Osipova et al. 2020) concluded that no properties in Oceania have improved their conservation outlook since 2017, and 5 properties, all Australian, have deteriorated: Great Barrier Reef, Gondwana Rainforests of Australia, Greater Blue Mountains Area, Ningaloo Coast and Shark Bay. However, the Outlook 3 report also noted that, for Oceania generally, including Australia, the natural and mixed World Heritage properties have ‘mostly effective’ (64%) to ‘highly effective’ (32%) protection and management.

The 2019–20 bushfires (see ‘Bushfires’) affected 24 of the 50 Gondwana Rainforests of Australia World Heritage Area reserves, which protect the largest stands of remnant rainforest in subtropical eastern Australia, and support a high diversity of endemic and threatened rainforest biota (DAWE 2020b). Following the fires, assessments and monitoring indicate a remarkably high resilience and recovery of subtropical, littoral, dry and warm temperate rainforest. Several threatened species showed signs of recovery, although the future of some species remained unclear.

Antarctica’s unique heritage includes sites of outstanding environmental, scientific, historic and wilderness values. Pressures on these

values are increasing as a result of climate change and greater human presence. The Mawson's Huts Historic Site remains Australia's only National Heritage site in Antarctica. Heard Island and McDonald Islands, as well as Macquarie Island, are Australian subantarctic World Heritage places, listed for their outstanding universal value.

There has been ongoing action and success in relation to the control of invasive species, notably the control of rats and rabbits on Macquarie Island and the near elimination of mice and rats on Lord Howe Island.

Macquarie Island lies in the Southern Ocean, approximately halfway between Australia and Antarctica. It was originally inscribed on the World Heritage List in 1997 for its outstanding wild and natural beauty and for its geology, being the only place on Earth where rocks from Earth's mantle are being actively exposed above sea level. In 2007, it was further inscribed as having 'Outstanding Universal Value of its natural environment'. The diverse vegetation of Macquarie Island (91 species of moss, many lichens and liverworts, and 47 species of vascular plants, including the world's most southerly-occurring orchids) is now in its best shape for more than a century, following the eradication of rabbits and rodents in 2011. However, the Macquarie cushion plant (*Azorella macquariensis*) – a keystone species of the island – has suffered a catastrophic population collapse since 2009, attributed to climate change-related changes in soil conditions and, potentially, an unidentified pathogen. Up to 90% of plants have been affected, and the species has been listed as Critically Endangered since 2010. There is limited understanding about the actions required to abate the threat of dieback, and a dynamic and coordinated approach is required to address this threat.



Pressures

Climate change and extreme events

Over the past 5 years to 2021, climate change and extreme weather events have highlighted the vulnerability of human society; ecosystems and biodiversity, including freshwater and marine systems and other natural resources; industry, crops and agriculture; and urban, rural and coastal communities. Climate shifts that affect temperature and weather patterns, increased frequency and severity of extreme events, and other climate-related changes such as sea level rise are all having profound effects.

In 2021, Australia updated its nationally determined contribution to the United Nations Framework Convention on Climate Change, affirming a target of net zero emissions by 2050.

Australia also reaffirmed its 2030 target of 26–28% reduction in greenhouse gases on 2005 levels and stated that it will exceed this target by 9% (DISER 2021a). The nature and concentrations of future global emissions will have a major effect on the trajectory of climate change in the second half of the 21st century.



Assessment Climate change



Overall grade: **High impact**
Overall trend: **Deteriorating**

There is a general shift across Australia towards higher land, air and sea temperatures; more acidic oceans; rising sea levels; and less rainfall in southern Australia. Bushfires and heatwaves (both land and sea) are increasing in frequency and intensity. Other extreme events are changing in their frequency, intensity and distribution. It is anticipated that pressure from climate change will continue to increase.

Assessments of impact range from high to very high

Assessments of trend range from deteriorating to stable

Related to United Nations Sustainable Development Goal targets 6.1, 6.5, 7.2, 11.4, 11.b, 13.1, 13.2, 14.3, 15.5

Assessment ratings

For assessments in the 'Pressures' section

-  **Very low:** Pressures do not degrade or only negligibly degrade the state of the environment.
-  **Low:** Pressures minimally degrade the state of the environment over a small extent and/or with low severity.
-  **High:** Pressures moderately degrade the state of the environment over a moderate extent and/or with moderate severity.
-  **Very high:** Pressures strongly degrade the state of the environment over a large extent and with a high degree of severity.

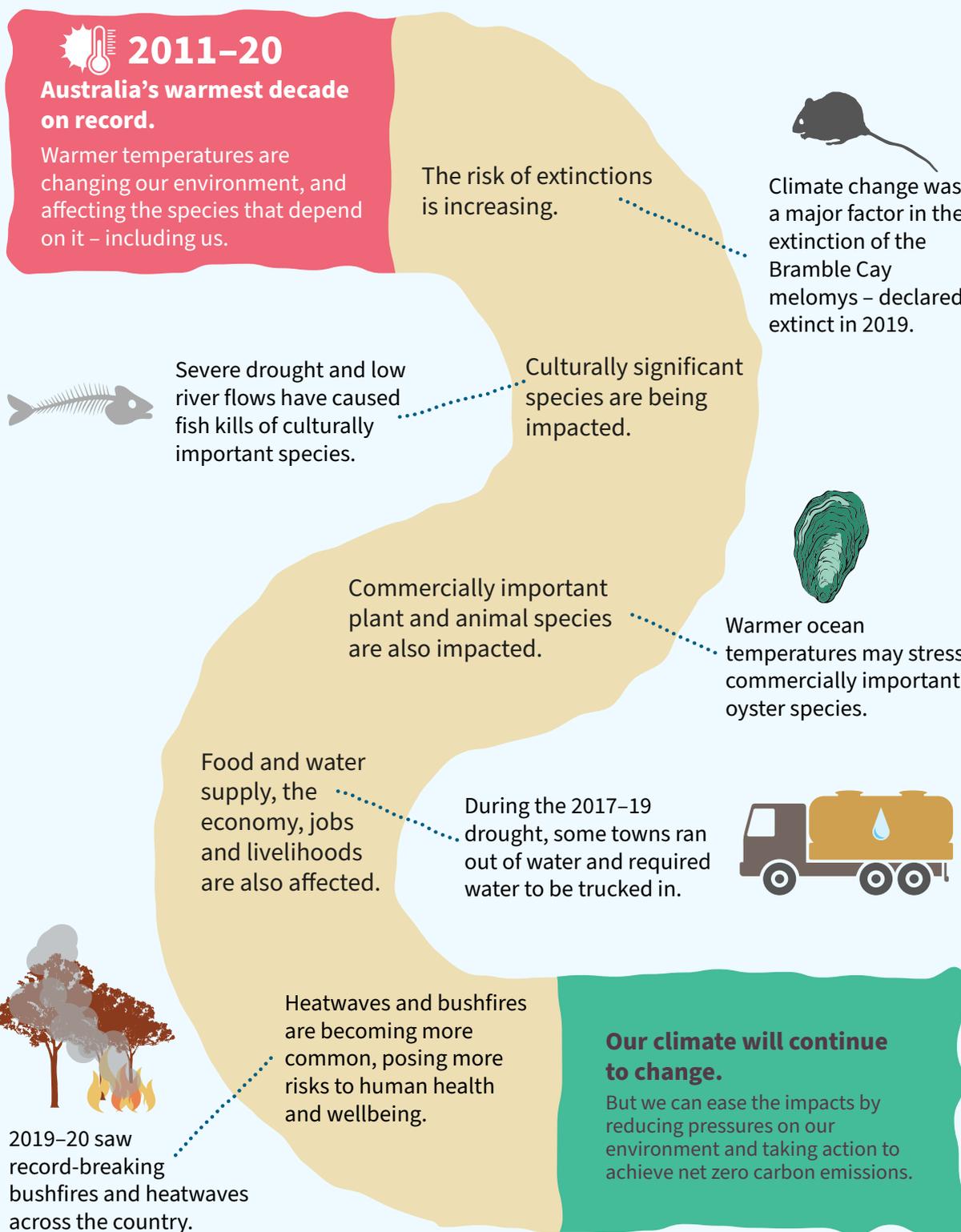
Trend

-  **Improving:** The situation has improved since the previous assessment (2016 state of the environment report).
-  **Stable:** The situation has been stable since the previous assessment.
-  **Deteriorating:** The situation has deteriorated since the previous assessment.
-  **Unclear:** It is unclear how the situation has changed since the previous assessment.

Climate change

Climate change continues to affect our environment and people.

Because every part of our environment and society is connected, changes in our climate have significant flow-on effects.



Greenhouse gas emissions

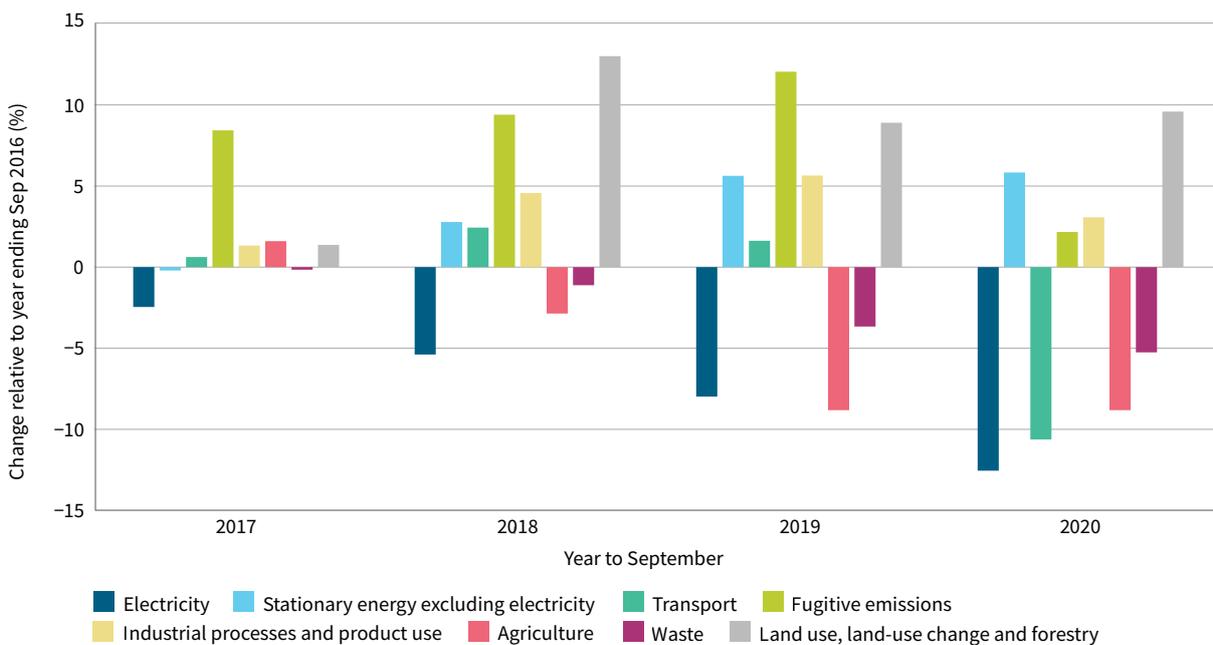
Warming of the Australian climate, and associated changes in the climate system, are driven by increased concentrations of greenhouse gases in the atmosphere. Changes to the climate are inevitable, based on greenhouse gases that have already been emitted, but further changes in the second half of the 21st century will depend on the level of future global emissions.

Globally, atmospheric concentrations of greenhouse gases continue to increase, driving climate change, warming on land and in the oceans, and, in turn, rises in sea levels as warmer water expands and polar ice caps melt. Although Australia’s emissions have decreased from their 2007 peak, mostly due to changes in land use and the rapidly increasing share of renewables in electricity generation, progress on emissions reductions has stalled since 2013 (DISER 2020a). A sudden drop in emissions due to restrictions on human activity and travels during the COVID-19

pandemic is expected to be temporary. Before the pandemic, transport-related emissions grew steadily, especially as a result of increases in diesel use and the uptake of larger light commercial vehicles.

Australia contributes approximately 1.2% of global emissions. This places us among the top 15 total emitters, and we are among the world’s largest per-person emitters (Global Carbon Project 2019). It is not clear whether the current trend will enable Australia to meet its current nationally determined contribution of a 26–28% decrease by 2030 and our recent commitment to net zero emissions by 2050 (Figure 12).

Emissions from electricity generation are the largest source of emissions in Australia (34%), but have been falling since 2016 driven by large amounts of renewable capacity entering the market (DISER 2021c). Stationary energy emissions have increased since 1990 at an average rate of 1.4% per year but are projected to remain relatively stable until 2030 (DISER



Source: Australian Government Department of Industry, Science, Energy and Resources

Figure 12 Changes in greenhouse gas emissions, by category, 2017–20

2021c). Emissions trends in the energy sector are rising, mainly driven by liquefied natural gas production, which accounted for 70% of emissions in the energy sector in 2019 and is projected to increase to 75% by 2030 (DISER 2021c) (see Figure 18 in 'Energy production').

Climate shifts

Climate change comprises long-term, gradual shifts in climate together with changes in episodic extreme events. Gradual shifts in climate are occurring across a range of parameters, including land, sea and air temperatures, and rainfall patterns. These changes are causing high pressures on the environment, and the situation is deteriorating.

The warming of the Australian continent and sea surface has continued unabated, accompanied by unprecedented weather extremes and associated disasters, with devastating consequences for the environment, the economy and the Australian people.

The Australian climate has warmed by a mean of 1.4 °C on land and 1.1 °C in the oceans since consistent national records began. Most of the increase in temperatures over Australian land areas has occurred since the 1950s, and temperatures have continued to increase over the past 5 years. Australia's warmest year on record was 2019, with temperatures 1.52 °C above the average for the standard 1961–90 reference period. The decade from 2011 to 2020 was Australia's warmest on record, and every individual year from 2013 to 2020 ranks in the 10 warmest on record nationally. Although some parts of Australia are warming faster than others, almost all areas are warming in all seasons (BOM 2020a).

On land, the strongest warming has occurred in the central and eastern interior of Australia, and the slowest in north-eastern Australia and

some south-eastern coastal regions, including Tasmania (BOM 2020a). Marine warming was slightly higher in eastern Australian waters than in the west, and the western Tasman Sea has warmed especially quickly (Blunden & Boyer 2020). Many natural systems face major challenges from temperature increases, with species and ecosystems forced to move, adapt or die.

Rainfall has decreased since 1970 in southern Australia; the decreases have been strongest in the cool season, placing substantial stresses on water availability in these regions. Over the same period, rainfall has increased in north-western Australia. In other parts of Australia, a clear trend has not emerged beyond the range of natural interannual to decadal variability.

While these changes are occurring against a backdrop of Australia's climate and system variability, climate change is also having a high impact on that variability, including the seasonal, interannual, decadal and longer changes in key factors such as water temperature, rainfall patterns, surface winds and oceanic currents (Evans & Hobday 2021). Continued climate change is expected to exacerbate such variability, leading to more intense extremes (Matear et al. 2021).

Climate change disproportionately affects Indigenous communities, which have reported seasonal changes, rising seas, temperature increases, reduction of food and water resources, and loss of Country and access to Country. Climate change impacts Indigenous people's ability to practise culture (Seed 2021). In 2021, Torres Strait Islanders from Boigu and Saibai islands commenced the first climate change class action against the Australian Government, alleging failure to protect them and their low-lying islands from climate change that now threatens their homes (SBS News 2021).

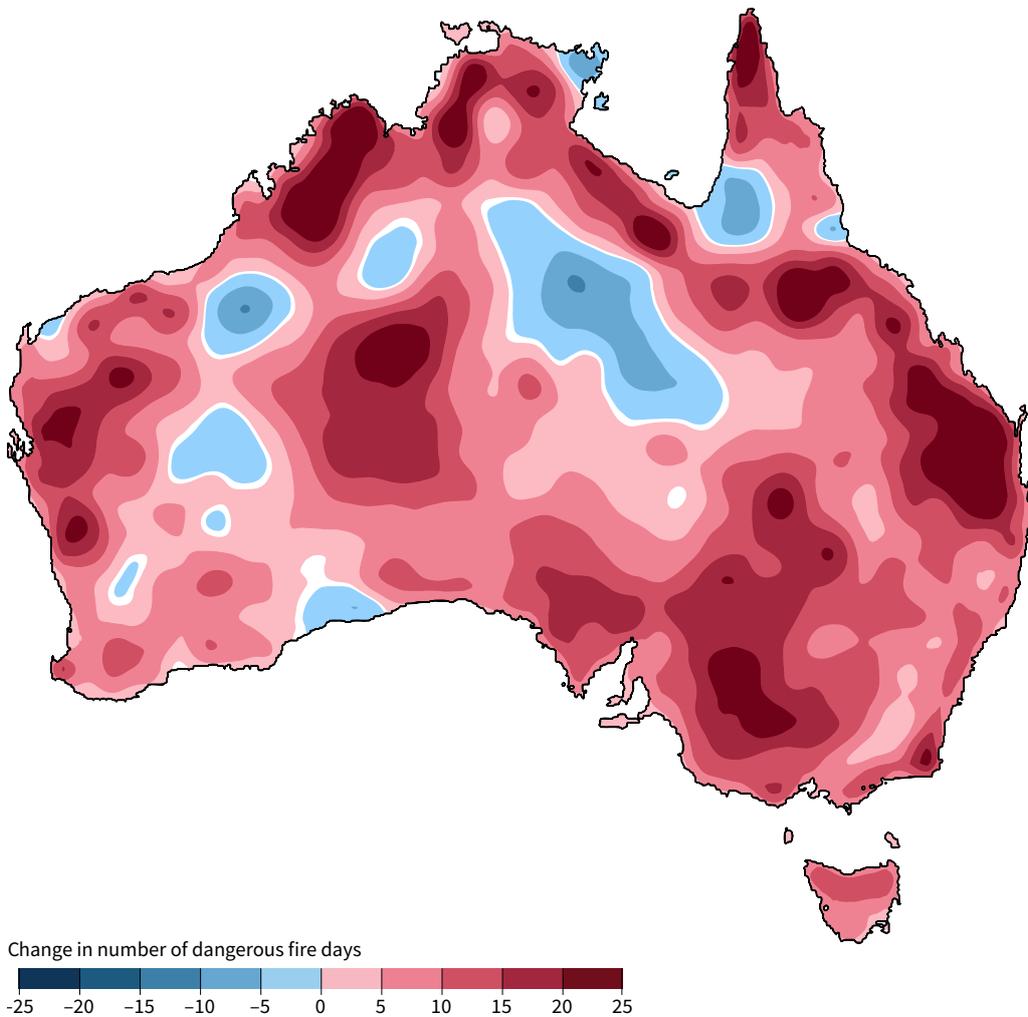
Other climate-related changes

Other profound environmental changes are occurring that are related to the changes we are seeing in our atmosphere and climate.

Climate change is influencing the potential for fire in the landscape. Seasonal fire periods are becoming longer; in New South Wales, for example, the bushfire season now extends to almost 8 months, not including hazard reduction burning (OEM 2018). Climate change is also resulting in a greater frequency, severity and overall unpredictability of bushfires. The

number of days with very high or above fire danger has also generally increased (Figure 13) (CSIRO & BOM 2020). The exceptional 2019–20 fire season in temperate Australia occurred during a period when numerous indicators of fire weather aggregated over the season were at record highs.

Our oceans are absorbing about 25% of the annual global carbon dioxide emissions (see ‘Greenhouse gas emissions’). This is changing the chemistry of the ocean, reducing its alkalinity (increasing its acidity – known as ocean acidification). Ocean acidification



Source: CSIRO & BOM (2020)

Figure 13 Changes in the number of dangerous fire weather days between 1950–85 and 1985–2020

influences the ability of marine animals to build their calcium shells or skeletons (such as a coral's hard skeleton). Conditions on the inner-central Great Barrier Reef are approaching a tipping point, forecast to cause a decline in coral juveniles and increased macroalgal cover (Fabricius et al. 2011, 2020; Smith et al. 2020).

Because Australia is an island nation with much of its development on the coast, sea level rise caused by the expansion of the warming ocean and the melting of polar ice is a significant threat. One of the most significant predicted impacts of sea level rise on Australia's coasts is erosion and the movement of beaches, and the permanent inundation of low-lying areas.

Pressures from sea level rise are currently low, but the situation is deteriorating. Sea level rise at Australia's coastline is above the global average of 3–3.5 millimetres per year (Green et al. 2010, Suppiah et al. 2011, TSRA 2014, Rainbird 2016). Globally, sea levels have risen by 19 centimetres since 1901. In Australia, the rate of rise varies around our coast and is accelerating, with some parts of Australia seeing rises of 4–6 millimetres per year. Over 2014–2100, it is projected that global sea levels will rise by 28–55 centimetres relative to the average level if greenhouse gas emissions are low, and by 63–102 centimetres if emissions are high (IPCC 2021). The predictions for Australia are similar or slightly higher, but also vary regionally around Australia (IPCC 2014).

Although sea level rise itself is not an extreme event, it can exacerbate the impact of extreme events, such as storms and heavy rainfall, on Australia's highly populated coastal plains. Sea level rise caused by global climate change is a chronic change facing all coastal communities.

Climate change is of significant concern for many Indigenous communities around Australia, especially the low-lying islands

of Torres Strait (O'Neill et al. 2012) that are vulnerable to rising sea levels. Indigenous peoples have acquired knowledge about the environment and its changes for more than 60,000 years, including adaptation responses (Bird et al. 2013). The survival of Indigenous peoples over this time means that cultural and traditional knowledge has been passed down during some periods of rapidly changing climate conditions (Charles & O'Brien 2020); however, this knowledge has remained largely undervalued (ESCC Hub 2021). Recently, a number of national Indigenous events were convened to talk about climate change and the threats to Country. The National First Peoples Gathering on Climate Change 2021 noted impacts on seasonal weather patterns, cultural practice, resources and sea levels. In October 2021, the Lowitja Institute, in partnership with the National Health Leadership Forum and the Climate Change Alliance, held a Climate Change and Aboriginal and Torres Strait Islander Health Roundtable discussing the impacts of climate change on health and wellbeing (HEAL Network & CRE-STRIDE 2021).

Extreme events

The intensity and frequency of extreme weather-related events – including heatwaves, droughts, bushfires and floods – are changing. Since the 2016 state of the environment report, ongoing increases in land and sea temperatures across Australia driven by climate change have coincided with multiple extreme weather events. These have had devastating impacts on many of Australia's unique natural ecosystems and caused the death of many individuals of many species, while also bringing new growth and stimulus for reproduction. For example, floods associated with massive rainfall in northern Australia in early 2019 caused extensive social and economic cost in northern and western Queensland (estimated at \$5.68 billion), but

also reached the Kati Thanda–Lake Eyre system and filled the northern lakes, triggering large pulse-breeding responses in wildlife such as birds, and freshwater fish and frogs.

Modelling based on historical and archaeological events and climate scenarios suggests that many extreme events will increase in intensity and frequency, with a potential expansion in their distribution, changes in their duration, and increasing complexity of linked impacts. Some events, such as tropical cyclones and east coast lows, are forecast to become less frequent but potentially more intense (CSIRO & BOM 2020). Research into the relationship between human-induced climate change and extreme weather events suggests that the risk of most observed extreme heat and cold events has been significantly altered by climate change. Although extreme events can have positive effects on some systems, their increasing intensity may overwhelm systems, leading to a more negative overall impact. It may also negate the positive impacts of occasional disturbances, which can stimulate colonisation, growth and reproduction.

The effects of extreme events on all aspects of the natural and urban environments are well known (see ‘Landscapes and seascapes’). Perhaps less well understood are the cumulative effects of multiple forms of extreme events on other stressors of the environment (see ‘Cumulative pressures’). For example, the impacts of feral animals can inhibit recovery of different species and communities after fire; increased mortality of some species after bushfires is primarily due to increased predation by invasive predators (cats, foxes) as a result of loss of groundcover.

There is growing recognition of the role Indigenous people can play in dealing with extreme events and mitigating impacts on their communities, and cultural and environmental values. Significant areas of

land are returning to Indigenous ownership or joint management through land rights, native title and Indigenous Protected Areas (see ‘Indigenous tenure’). The Indigenous population is widespread, and Indigenous communities are disempowered as a result of many factors, such as remoteness, lack of adequate housing and infrastructure, racism, continuing impacts of colonisation, and socio-economic and health disparity with non-Indigenous communities. Despite this, Indigenous communities display great resilience and have longstanding connections to their Country. They hold traditional knowledge and continue customary practices that can assist in planning, response, recovery and resilience to climate change and extreme events.

Heatwaves

There is a broad nationwide trend towards a much higher frequency of very hot days. For example, in Victoria, the average number of days per year on which the temperature has reached 45 °C increased from 0.3 in 1961–2000 to 2.6 in 2011–20. Extreme and extensive heatwaves occurred in many parts of Australia in the 2018–19 and 2019–20 summers, exceeding historical records. The heat was particularly notable for the large area that it covered, which led to unprecedented daily temperatures averaged over Australia.

Elevated temperatures impact all living things and are known to increase mortality in human populations. Heatwaves cause more human deaths in Australia than any other single extreme weather event (Steffen & Hughes 2013). Australia’s potential vulnerability to heat exposure is high and increasing, with total deaths, lost working hours and mental health outcomes all increasing with higher temperatures (Beggs et al. 2019).

Vulnerable ecosystems and native animals are susceptible to both the direct and

indirect effects of heatwaves, and heat stress has been responsible for large numbers of deaths of native species since 2016 – for example, the mass deaths of flying foxes in Queensland in late 2018. Heat stress also affects plant productivity, and agricultural enterprises have already begun diversifying where they grow certain crops for future market resilience. Elevated temperatures also affect freshwater systems and interact with drought, contributing to fish deaths in stressed waterways, and increasing bushfire risk and intensity. Heatwaves played a role in the 3 devastating fish death events in the extensive Menindee Lakes system on the Darling River in western New South Wales in 2018–19, in which more than 1 million fish died.

Ocean warming has contributed to recent record-breaking marine heatwaves (Santoso et al. 2017) – these are events in which seawater temperatures exceed a seasonally varying threshold (the 90th percentile) for at least 5 consecutive days (Hobday et al. 2016). The global annual number of marine heatwave days has risen by 54% over the past century, with 8 of the 10 most extreme marine heatwaves ever recorded occurring after 2010 (Smith et al. 2021b). Marine heatwaves have dramatic impacts on marine life, resulting in major ecological impacts such as changes to species' distribution, reproduction success and persistence in some habitats. This has flow-on effects on industries; it is estimated that economic losses from a single marine heatwave event can exceed US\$900 million (Smith et al. 2021b).

Marine heatwaves were recorded on the Great Barrier Reef in 2015–16, 2016–17 and 2020, and were accompanied by significant coral bleaching events (BOM 2020d). In 2015–16, a northern Australia marine heatwave was the longest on record in the south-east tropical Indian Ocean (Benthuisen et al. 2018), with

coral bleaching off north-western Australia (Gilmour et al. 2019). During 2020, marine heatwaves occurred in most shelf areas around Australia, with many regions reaching category 2 (strong) (WMO 2021). Marine heatwaves have contributed to a decline in environmental state in both temperate and tropical waters on both the west and east coasts. The waters south-east and south-west of Australia are recognised as global hotspots, with rates of warming above the global average (Hobday & Pecl 2014).

Drought

Although there was some recovery following the millennium drought (2000–10), hot, dry conditions resulted in severe drought affecting much of Australia over 2017–19. The most acute dry conditions occurred in the northern Murray–Darling Basin, where annual rainfall in 2019 was 70–80% below normal, and more than 40% below previous record lows. It was also exceptionally dry over much of Australia's interior, where numerous locations had less than 30 millimetres for the year. Although Australia has experienced longer droughts, this event was more intense over a 2–3-year period.

Bushfires

The interaction of drought and heatwaves means that much of Australia is experiencing more extreme fire weather days (CSIRO & BOM 2020); increases in the length of fire seasons; and increases in the frequency, severity and unpredictability of bushfires.

A study of the catastrophic 2019–20 bushfires (known as the 'Black Summer' fires) found that climate change had induced a higher weather-related risk than in previous years (Binskin et al. 2020, BOM 2020c, van Oldenborgh et al. 2021). Several years of severe drought across much of Australia preceded the hottest and driest year on record in 2019. Temperatures exceeded historical

records, particularly during the 2018–19 and 2019–20 summers, when extreme, expansive heatwaves were reported across much of Australia. Numerous high-temperature records occurred at individual sites across southern and eastern Australia.

The hot conditions combined with the dry landscape and strong winds to produce dangerous fires during December 2019 into early January 2020.

The Black Summer fires were exceptional for the scale, severity and synchrony of fires across southern and eastern Australia (Figures 14 and 15). Fires burned simultaneously across multiple Australian states and territories. Thirty-four human lives were lost (Binskin et al. 2020), and some

2,500 homes were destroyed. An estimated 417 additional deaths were attributed to bushfire smoke (Borchers-Arriagada et al. 2020, Johnston et al. 2020) and about 80% of the Australian population was affected by bushfire smoke at some point during the season; smoke travelled 11,000 kilometres offshore to South America and is estimated to have added up to 900 million tonnes of carbon to the air (Filkov et al. 2020). Canberra experienced the worst outdoor air quality measurements of anywhere in the world (Filkov et al. 2020); daily PM_{2.5} concentrations on 1 January 2020 – the worst day during the bushfire period – were 38.5 times the 24-hour National Environment Protection Measures standard.



Photo: Philippe Frost

Figure 14 2019–20 bushfires, Braidwood North fire range

More than 10.3 million hectares of native bushland were burned (ABARES 2021), as well as grasslands, agricultural lands, commercial forest plantations and peri-urban areas (Davey & Sarre 2020). Some 8 million native animals were lost in New South Wales alone, and it is estimated that a total of 1–3 billion animals were killed or displaced during the fires (Dickman et al. 2020, WWF-Australia 2020). The bushfires increased the extinction risk of many plants and animals, including many that were already listed as Endangered or Critically Endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) or state legislation. For example, 486 species of threatened plants (Gallagher 2020), 23 reptiles, 22 crayfish, 20 mammals, 17 birds, 16 fishes, 16 frogs and 5 invertebrates were identified as requiring urgent management intervention following the bushfires (DAWE 2020d,e). Four threatened

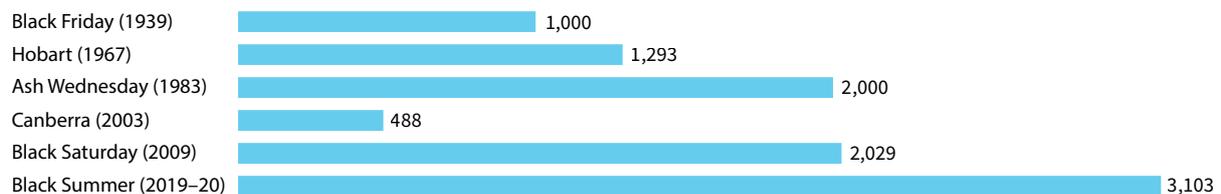
ecological communities had more than 50% of their distribution within the mapped fire extent, and a further 3 had more than 30% of their distribution within the mapped fire extent; 18 Key Biodiversity Areas had 15% or more of their habitat burned (see also ‘World Heritage’) (Todd & Maurer 2020).

Other weather extremes interact with bushfires, exacerbating pressures on natural and human environments. For example, the above-average rainfall that followed drought and fires across much of eastern Australia in 2020 compounded pressures on waterways. Rainfall run-off through burnt firegrounds carried sediment loads rich in ash, nutrients, organics and metals, putting water and sediment quality at risk in inland and coastal ecosystems, including drinking water catchments. In the Upper Murray catchment in south-eastern New South Wales and north-eastern Victoria, nearly one-third of forested and rural regions were burned. When

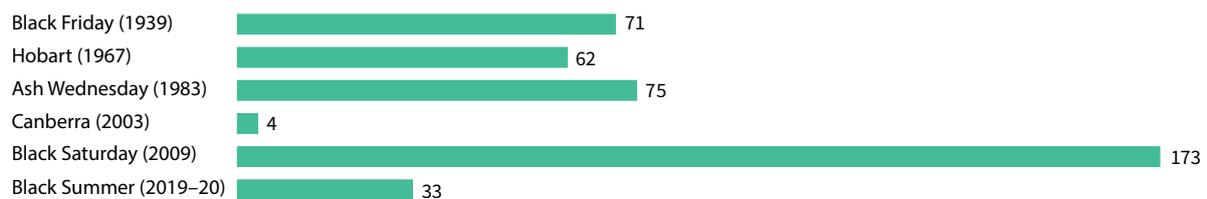
Area burned (ha, thousand)



Homes lost



Lives lost



ha = hectare

Figure 15 Impact of major bushfire events on human lives, homes and area burned since 1939

rain fell, high loads of sediment and ash entered the Murray River and Lake Hume, causing local mortality of fish, reducing the hatching success of key crustacean food sources and causing high mortality of freshwater snails (Joehnk et al. 2020). Mortalities across 15 waterways in New South Wales and Victoria were seen in at least 27 species of fish and 4 crustacean species. The sediment-laden run-off entering coastal waters caused stratification and delayed algal growth in some New South Wales estuaries in response to the increased nutrient and carbon loads. Few studies have yet looked at the impact of the toxins generated from the bushfires on aquatic organisms, although research to fill these gaps was underway in many states by 2021.

Storms, floods and cyclones

An increase was observed in certain types of rainfall extremes over 2017–19 (CSIRO & BOM 2020). The intensity of short-duration (hourly) extreme rainfall events increased by around 10% or more in some regions and in recent decades. Daily rainfall totals associated with thunderstorms have increased since 1979.

Flooding is one of the costliest extreme events because rising water levels can damage agriculture, buildings and infrastructure; disrupt supply chains; displace people; and threaten human life. Floods also cause erosion and deposition in natural environments. For human endeavours, they can be catastrophic; however, floods are also frequently life giving. Floods are essential for groundwater recharge in some systems, and, in natural landscapes and some agricultural contexts, floods are a key part of the lifecycle – some species depend on floods to distribute seeds, fill temporary waterholes and stimulate population explosions.

For example, prolonged rainfall associated with the 2019 northern Australia monsoonal trough caused the most significant flood event in 50 years in Queensland's longest river, the Flinders River, resulting in floodwaters

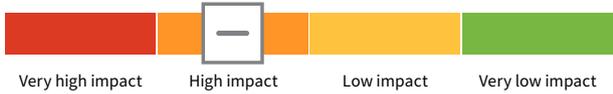
700 kilometres long and 70 kilometres wide (IGEM 2019). The 2019 floodwaters reached the predominantly dry Lake Eyre system in South Australia and filled its northern lakes, triggering a massive wildlife response in freshwater fish, frogs and birds. Floodwaters flowing north into the Gulf of Carpentaria also carried large quantities of organic matter and detritus, which triggered a population boom in some coastal fisheries.

Cyclones reduce productivity in both natural environments and agricultural operations, with flow-on effects on habitats and food resources for wildlife, and on human populations and economies. Disturbances also enable weed species to invade recovering vegetation (Murphy & Metcalfe 2016). Cyclones damage coral and seagrass beds, wash fish and marine mammals ashore, and reshape coastal and intertidal communities such as mangrove forests. For example, because the 2017 category 4 cyclone *Debbie* was slow moving, gale-force winds gusting at more than 200 kilometres per hour persisted near some of the reefs near the Whitsunday Islands for up to 56 hours, resulting in an average loss of coral cover of 70% at a depth of 2 metres, and up to 98% loss in some areas (GBRMPA 2019). Billions of dollars of damage to homes, infrastructure and industries included losses of approximately \$500 million to agriculture.

The pressure imposed by tropical cyclones on natural and human systems is stable but deteriorating. The forecast for Australia is for a similar frequency of tropical cyclones, but their intensity and associated rainfall will increase (Chu et al. 2020, Pepler & Dowdy 2021), and they may track further south (Bruyère et al. 2020). Between January 2016 and December 2020, 35 tropical cyclones occurred in the Australian region, with 16 making landfall on mainland Australia or island territories (BOM 2021d).



Assessment People-related pressures



Overall grade: **High impact**
Overall trend: **Stable**

Population growth (despite reductions due to COVID-19), urban expansion, and associated land clearing and pollution continue to impact our environment, particularly in coastal areas where most Australians live. Habitat modification such as construction of seawalls, and recreational activities such as tourism and fishing can also have substantial negative effects on species and ecosystems.

Assessments of impact range from low to very high

Assessments of trend range from deteriorating to stable

Related to United Nations Sustainable Development Goal targets 6.3, 8.4, 8.9, 11.3, 11.4, 11.6, 11.a, 12.1, 12.4, 14.1, 14.4, 15.1, 15.2, 15.5, 15.8

People

Humans drive many of the pressures on our environment. Our activities, settlements and use of resources all affect the environment and its assets in different ways.

Urbanisation

Australia's urban areas continue to grow. The population grew from 24 million people in 2016 to 25.6 million as at 30 June 2020, with more than 76% living in major cities. It is estimated that Australia's population will exceed 28.7 million by 2021 (Centre for Population 2021). Australia is a highly urbanised country, with most of the population growth in the past decade occurring in Australia's 18 largest cities; 39% of the existing population is located in Melbourne and Sydney. The COVID-19 pandemic has slowed population growth in 2020. Modelling by the Australian Bureau of Statistics indicates that the population will be 31.8 million in 2040, 4% less than predicted, as a result of the impact of the pandemic. Much of Australia's population growth has been driven by overseas immigration. Cities such as Sydney and Melbourne traditionally

experience significant levels of immigration; however, urban planning and economic drivers have meant that many immigrants subsequently move out to other urban areas across Australia (sometimes called 'out migration'). These trends are fluctuating, and Greater Sydney has experienced a lower rate of out migration in recent years. Many Indigenous people live in urban areas, and connecting to Country in these areas remains important (see 'Connection to Country').

Increasing urban density, as well as urban sprawl, puts pressure on the natural environment and heritage. In the case of the urban environment (see also 'Livability'), pressures include increased costs for new infrastructure (Garrard et al. 2015), reduced access to local services and jobs, higher transport and energy costs, reduced space to produce food, reduced walkability and increased social isolation (Garrard et al. 2015). For the natural environment and green spaces, pressures include land clearing, reduced green space, pollution and loss of biodiversity (PIA 2018). Biodiverse urban areas are valuable not only for the ecology that lives within them, but for the identity, health and wellbeing of

urban citizens. The threats to biodiversity in terrestrial urban areas are fragmentation from urban sprawl, logging and agricultural expansion; vehicle strikes and dog attacks; and the impacts of climate change, including more intense bushfires, droughts and extreme heat events (ACF 2020).

Coastal urban areas

Coastal population growth has continued to rise since 2016. This trend has been exacerbated by relocations to coastal towns driven by the COVID-19 pandemic, enabled by new 'work from home' patterns and online communication. This population growth and coastal development are having a high and increasing impact on the coastal environment.

Proliferation of artificial marine structures to support the activities of growing coastal populations has continued since 2016 (Bugnot et al. 2021), from wharfs, jetties, marinas and moorings to coastal defence structures such as seawalls, breakwaters and groynes. Modification and loss of habitats are one of the primary causes of global biodiversity loss (Didham et al. 2007). In coastal environments, replacement of natural habitats such as mangroves, seagrasses, sediments and rocky reefs with artificial structures directly impacts many ecosystems and may also hinder species movement, alter food webs (Clynick et al. 2007), and facilitate the establishment and spread of non-native species (Dafforn et al. 2012). In parts of Australia, more than 50% of estuarine coastlines are modified by artificial structures, most of which are associated with urban growth.

Although more building is forecast, recent innovations in ecological engineering have incorporated the complex topographic features of natural habitats, such as rock pools, crevices and root structures, into new seawalls. Customised habitat modules have also been retrofitted to existing sea walls.

For example, 900 units fitted across Sydney Harbour from late 2018 were inhabited by microscopic life and invertebrates within hours of installation. In just a few months, the modules were crowded with marine life (Strain et al. 2018).

Urban resources

Urban areas are increasingly consuming material and energy resources, requiring investment in associated infrastructure. Despite this, investment in transport, water and energy infrastructure has declined since its peak 8–10 years ago. Conversely, expenditure on telecommunications infrastructure has been steadily increasing over the past 3 decades (BITRE 2020). We are increasingly relying on ageing infrastructure, resulting in less efficient urban services that can waste finite resources such as water. There is a need to invest in new and innovative technology that not only supports the net zero economy but makes our urban areas cleaner and more livable (e.g. new recycled water technology and systems, alternative energy sources, distributed energy networks).

Another significant issue relates to the 'digital and urban divide', where underinvestment in all forms of infrastructure is resulting in lower levels of service in some areas, with significant social impacts. These include educational implications for students during the pandemic, and a lack of water or sewer connections, resulting in substandard living conditions in some regional areas.

Households remain the biggest users of energy in Australia. Although our overall energy consumption rose by 0.6% in 2018–19 (with most of the growth being in the mining sector), household use has declined by 2.2% since 2016–17 (see also 'Energy production'). In Australia, residential energy use, combined with construction, transport, manufacturing, electricity, gas and water, account for 71% of

the nation's greenhouse gas emissions (DISER 2020c).

Australian water consumption rates are some of the highest in the world, and the volume of water required for many of our urban environments continues to grow along with the population. The amount of water that can be supplied to our households depends on climatic conditions and government policy.

Risks to water security associated with climate change present a challenge for both human and environmental wellbeing. Our water supply relies heavily on rainfall to replenish storages, streams and groundwater. Infrastructure Australia's 2019 audit found that the reduction in average winter rainfall in south-western Australia has caused a 50% reduction in urban run-off over the past 50 years, leading to declining streamflows across the southern and south-eastern regions (Infrastructure Australia 2019). As a result of increasing significant drought conditions, river levels have fallen, water storage has significantly decreased, and soils have become drier, reducing agricultural productivity and the livability of communities across Australia. The significant water shortages have placed strain on urban areas, necessitating water restrictions. Water shortages have also led to an increased use of desalination as a water source.

Land clearing

Clearing of native vegetation is a major cause of habitat loss and fragmentation, as well as heritage and biodiversity decline. It has been implicated in the listing under the EPBC Act of 60% of Australia's threatened species (Kearney et al. 2018). Land clearing can also lead to processes that degrade soils, such as erosion, salinisation, loss of organic matter and depleted fertility. The primary drivers of native vegetation clearing in Australia

include expansion of land dedicated mainly to agriculture (see 'Agriculture') and, to a lesser extent, forestry and infrastructure (including urban development; see 'Urbanisation'). Land clearing is also a significant contributor to greenhouse gas emissions, and, conversely, land can absorb emissions through vegetation regrowth.

Between 2000 and 2017, 7.7 million hectares of habitat for terrestrial threatened species was cleared or substantially degraded, including 64,000 hectares of habitat for terrestrial migratory species, and 370,000 hectares of threatened ecological communities (Ward et al. 2019). In total, 1,390 terrestrial threatened species (85%) have experienced some habitat loss since 2000, with some losing substantial proportions of their habitat. Nine of the 10 threatened species that have lost the most habitat to clearing occur in Queensland (Ward et al. 2019). Significant degradation of threatened species habitats also occurs from land use such as grazing of native vegetation.

Land clearing is monitored nationally to inform the National Greenhouse Accounts, in ways that are consistent with Australia's international commitments to reduce emissions, track progress and report each year (DISER 2021g). Current methods of detecting native vegetation clearing tend to focus on woody vegetation, which is more readily detected using satellite and aerial remote sensing, although substantial areas of nonwoody native vegetation (e.g. native grasslands) can also be subjected to clearing.

From 2015 to 2019, nearly 0.29 million hectares of primary forest was determined to have been cleared, as well as a further 1.8 million hectares of secondary forest (regrowth after previous clearing; see also 'Terrestrial ecosystems and native vegetation'). This represents a 15% reduction in the amount of primary forest clearing, and virtually no change in the amount of secondary forest

clearing compared with the previous 5 years (DISER 2021b,h). A small proportion can be attributed to non-native vegetation clearing for forestry or agricultural purposes, or removal of non-native invasive woody species.

Over the same period, extensive areas of sparse woody vegetation losses were also recorded, averaging 2.27 million hectares per year, a loss rate that is 8% greater than in the previous 5 years. Although gains in sparse woody vegetation were greater than losses (averaging 2.35 million hectares per year over 2015–19), these gains were 14% less than in the previous 5 years. This difference is partly due to the recent drought that also impacted extensive areas of inland Australia.

The combined pressures of climate and land-use change, and especially water availability in semi-arid regions, influence woody vegetation gains and losses (Liao et al. 2020). Over the nearly 30 years since 1990, more than 6.1 million hectares of primary forest has been cleared and converted to other land uses or regrown as secondary forest, some of which is subject to re-clearing (sometimes repeatedly). The total area of sustained regrowth as of 2019 was 4.13 million hectares. In addition, extensive areas of sparse woody and nonwoody vegetation have been cleared and converted to other uses, principally pastures, but the full extent of this conversion is not well documented. The ongoing, cumulative impact of native vegetation loss on natural capital values is substantial. It can be many decades before areas of sustained native vegetation regrowth or managed restoration provide good-quality wildlife habitat.

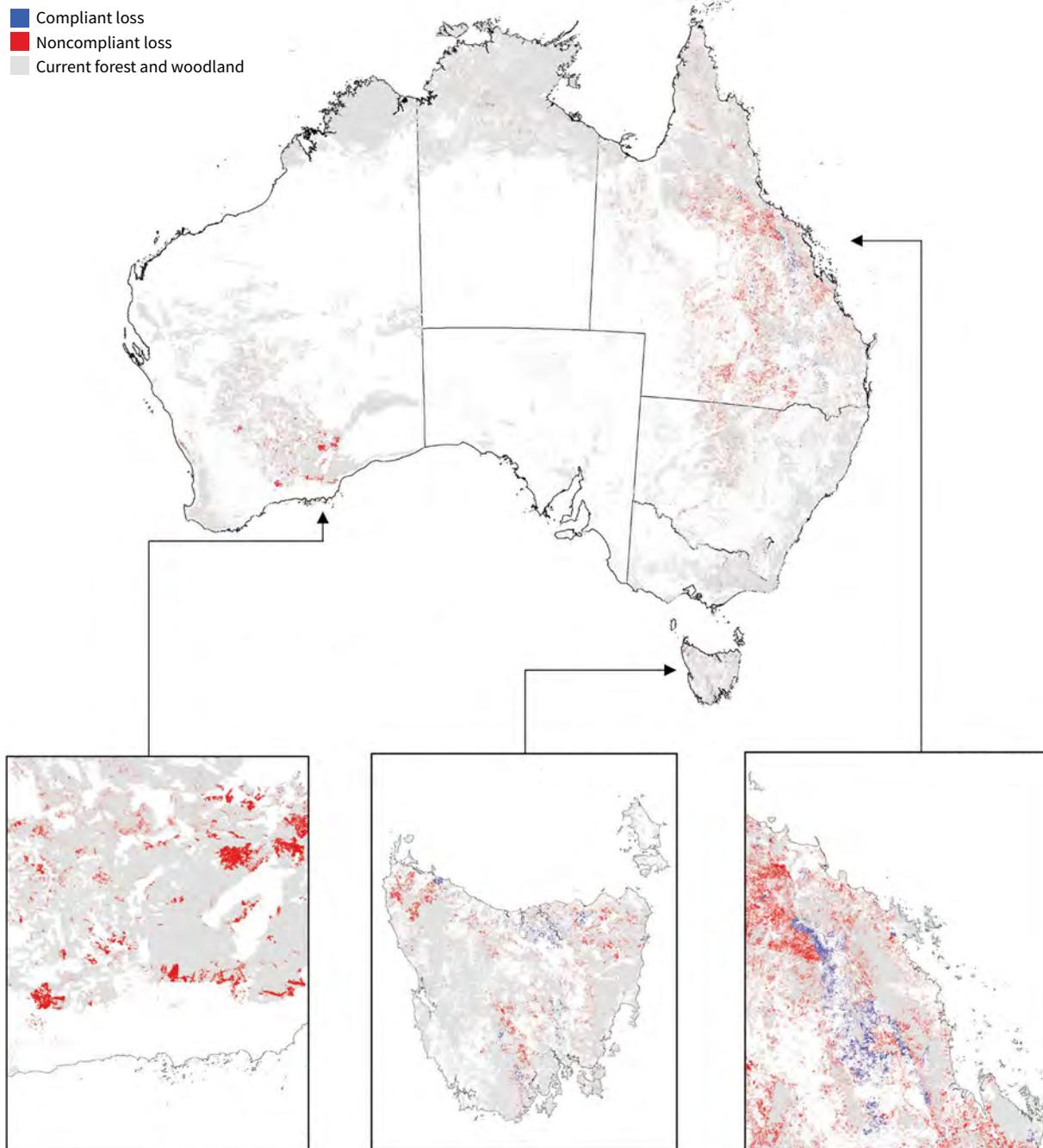
Each state and territory monitors land clearing for the purpose of native vegetation and soil management, land-use planning, and infrastructure or urban development planning. Queensland and New South Wales dominate the pattern of vegetation loss or

gain. Extensive areas of primary forest and regrowth forest were lost in Queensland (64% and 70% of the national total, respectively) and New South Wales (20% and 16% of the national total, respectively) from 2014 to 2019. The majority of forest clearing in Queensland is attributed to agriculture, such as conversion to pasture for stock grazing in the Brigalow Belt and Mulga Lands bioregions (Queensland Government 2021). In New South Wales, there has been a steady increase in clearing, presumably for agricultural purposes, but substantial areas of clearing were not authorised (DPIE 2021). Analysis of data on national forest and woodland loss by Ward et al. (2019) also concluded that substantial areas of nationally important habitats appear to have been cleared without an authorisation under the EPBC Act (Ward et al. 2019) (Figure 16).

In terms of loss of vegetation in areas other than forest, Queensland had the highest loss of sparse woody vegetation from 2014 to 2019 (31% of the national total), followed by the Northern Territory (28%) and Western Australia (26%). These changes relate to a variety of causes, including ‘natural’ reduction of shrub or sparse woody vegetation from changes in rainfall patterns across Australia, as well as land use such as grazing of native vegetation, and fire. For example, 55% of all lost sparse woody vegetation in the Northern Territory was found to coincide with fire events (DISER 2021d).

Pollution

Australia, particularly our urban areas, produces high levels of pollution (see also ‘Industrial pollution’) and waste. Australia has the second-highest rate of annual waste disposal per person (704 kg), behind the United States (771 kg), and our waste production continues to increase. Pollution, as part of overall pressure on the environment



Note: Compliant loss occurs with a referral under the EPBC Act. Noncompliant loss occurs without a referral. Three panels highlight the southern Western Australia coast (left), Tasmania (middle) and northern Queensland coast (right).
Source: Ward et al. (2019)

Figure 16 Areas of potential threatened species habitat and threatened ecological communities that were cleared, classed as compliant and noncompliant loss, 2000–17

from Australia's population, has had a high impact on urban areas over the past 5 years.

There is increasing evidence that the volume of debris is expanding along Australia's coasts, increasing the risks to habitats and fauna, and posing a range of threats to the health and, potentially, survival of organisms and ecosystems. Debris is composed of different materials and items, such as glass and plastic bottles, metal cans, cigarettes, plastic bags, balloons and rubber. Pressures on coastal environments from land-based debris leaking into waterways are very high and increasing.

In Australia's offshore marine waters, plastics and debris are also having a high and increasing impact, with increases in litter flows into oceans (Wilcox et al. 2020). It is estimated that there are at least 25 times more microplastics on the sea floor than floating on the ocean's surface, with some 14 million tonnes of debris across the ocean floor (Barrett et al. 2020). A national map of marine debris has been created based on a decade of citizen science studies, which shows high (but variable) concentrations of marine debris in Australia's coastal beach environments (Gacutan et al. 2021). Although some of Australia's marine plastic pollution is carried on currents from neighbouring countries, most plastic pollution is generated domestically (Hardesty et al. 2016) and then trapped in the coastal environment (Olivelli et al. 2020).

Although the remoteness of Antarctica, the subantarctic islands and the Southern Ocean means that they are less affected by marine pollution than other regions, ocean currents bring urban pollutants into their waters, especially lightweight plastic waste. The COVID-19 pandemic increased plastic pollution significantly worldwide from early 2020 through the use of huge quantities of single-use items (Ammendolia et al. 2021), adding to the danger faced by wildlife. Entanglement in plastics, such as

ropes, nets and monofilaments used in commercial fishing operations, threatens at least 243 species worldwide. Young Antarctic fur seals (*Arctocephalus gazella*) can get caught in plastic materials; as the animals grow, the plastic gets tighter and cuts into their bodies (Pemberton et al. 1992). This is not only a macro-waste problem; microplastic and nanoplastic particles have been detected in the Antarctic food web. The pressure on Antarctic ecosystems posed by marine pollution is high and deteriorating.

Air pollution is produced by a variety of sources, such as transport, commerce, industry and domestic activities, most of which are concentrated in or around urban areas. Levels of key pollutants affecting air quality and health increased in most Australian cities over the past 5 years (see 'Air'). As our cities grow, this is resulting in more pollution, as well as more people being exposed to that pollution. Such population-based pressures on air quality can only be improved by a move to cleaner technologies such as electric vehicles, renewable energy sources and renewables-fuelled public transport.

Since 2016, the pressure on air quality due to smoke from bushfires and prescribed burns has been very high and deteriorating (see 'Bushfires'). Climate change and associated increases in temperature, heatwaves and droughts are also generating more dust and longer summer bushfire seasons. They may also cause more smog; the chemical reactions that cause smog are changing, but it is not clear if there are more, less, faster or different reactions occurring. Although pressures on air quality from industry remain low, some toxic pollutant emissions have increased since 2016, and the trend is deteriorating. Airborne pollen also causes significant health challenges for many sensitive people with asthma and respiratory conditions. Although the pressure

on air quality from wood fire heaters and motor vehicles remains high, levels are stable.

Light pollution – in particular, artificial light at night – can lead to ecological changes. In marine areas close to our coastal cities, these can include decreased reproductive success in fish, shifts in predatory behaviour of invertebrates and fish, and changes to the physiology and biochemistry of reef-building corals and fish. Coastal regions near major Australian cities are likely to be affected, given the ubiquity of global coastal light pollution. Intertidal and shallow subtidal habitats are among the most affected, as artificial lighting is common along beaches, coastal streets and promenades, and within harbours and marinas.

Recreation and tourism

Pressures on the environment include disturbances associated with recreation and tourism, hunting, fishing and collecting, which can impact plants and animals on both land and sea in even the most remote areas of Australia. Public parks, conservation reserves and heritage areas provide valuable recreation opportunities, which are important for people’s mental wellbeing and health. But, although Australians enjoy being part of nature, some of our recreational activities can be extremely detrimental to our environment and heritage.

Impacts on natural and cultural heritage can occur from direct use and the development of supporting infrastructure, or indirectly – for example, through the introduction of invasive species. The nature of the impact depends on where it occurs and the level of interest: small visitor numbers can potentially have a major impact in sensitive areas such as high-quality conservation areas or wilderness areas; large visitor numbers can have significant effects

at any site, especially when this level is not planned for.

Coastal tourism and its associated recreational activities have long dominated Australia’s international and domestic tourism market, particularly at beaches and the Great Barrier Reef. Environmental pressures associated with tourism include trampling, pollution, degradation, habitat loss, erosion, disturbance of wildlife, and increased demands on local resources and infrastructure (Sun & Walsh 1998, Canteiro et al. 2018). Since 2016, major changes in tourism patterns have occurred. These were due to the 2019–20 bushfires and heatwaves, which affected many popular coastal destinations, followed by the closure of Australia’s international borders in early 2020 due to the COVID-19 pandemic, and intermittent lockdowns that temporarily restricted local mobility and domestic tourism.

Many recreational vessels use coastal waters and harbours, providing an important connection to nature for many Australians (see also ‘Aquaculture and fishing’). However, marine vessels can cause environmental damage from anchor dragging, moorings, exhaust, noise pollution, fuel spills and copper pollution from antifouling coatings. They may also carry invasive species in ballast water and on their hulls. Pressure from recreational boating is expected to increase. For example, the number of registered recreational vessels is predicted to increase in areas of population growth, such as New South Wales, where more than 26,000 vessel moorings are currently registered (TfNSW 2015).

Wetland ecosystems hold significant ecological, recreational, spiritual, cultural and economic significance. Although the greatest threat to freshwater ecosystems and biodiversity is the modification of water processes that has occurred as a result of water resource development, recreational pressure from fishing and increased human

interaction can be part of the overall cumulative impact on species. Disturbances associated with recreation, tourism, hunting, fishing and collecting have had negative impacts on biodiversity in even the most remote areas of Australia.

Human activities in Antarctica are intensifying, with increasing numbers of national scientific missions and international tourists until the suspension of cruise ships due to the COVID-19 pandemic in early 2020. Larger numbers of visitors increased pressures on small ice-free areas, as well as risks to fragile ecosystems

from waste, pollution (including plastics and oil spills), non-native species and disease vectors.

Industry

Industry has a variety of impacts on the environment as a result of the resources it uses, the pollution and waste it produces, and the direct footprint of its activities. The nature and extent of the impact depend on the industry itself, where it operates, and how well it is regulated and managed.



Assessment Industry



Overall grade: **Low impact**
Overall trend: **Stable**

Industrial pressures, such as resource use, production of waste, pollution and habitat loss, all impact ecosystems and biodiversity. Land clearing and grazing for agriculture have some of the greatest impacts. Across Australia, however, industrial pressures are generally low, but can be very high at local scales.

Assessments of impact range from low to very high

Assessments of trend range from deteriorating to improving

Related to United Nations Sustainable Development Goal targets 6.3, 8.9, 11.3, 11.4, 11.6, 12.1, 12.2, 12.4, 13.2, 14.1, 14.2, 14.4, 14.6, 15.3, 15.8

Transportation

A major pressure on the environment comes from human activity related to supplying our growing cities and towns with goods and services, in terms of both direct transport of goods and the associated development of transport networks.

As the built environment expands, so too does infrastructure for service networks to support and connect population centres. Often overlooked, the massive infrastructure that makes up Australia's transport routes (roads, rail) continues to expand and have impacts on nearby ecosystems. Australia's road network could wrap around the world 22 times (Infrastructure Australia 2019), making it a significant land use. Since 2016, our road network has continued to increase its footprint, with impacts on adjoining natural areas. These impacts include incremental loss of remnant roadside vegetation, particularly as habitat for biodiversity in agricultural and peri-urban landscapes. The road network can also facilitate the spread of invasive non-native species – for example, poor hygiene protocols in mowing regimes spread weeds and cause degradation of suitable habitats for biodiversity. This pressure is now recognised by many local governments; in Victoria, the Peri-urban Weed Management Partnerships program (a partnership between state and local governments) provides \$4 million of funding over 4 years to protect native plant and animal species in Melbourne's peri-urban areas from high-risk weeds by working with the local community to identify native habitats on public land (including road verges) that have significant environmental and community value.

Millions of animals are struck by vehicles and killed on Australian roads every year. Road mortality is the second biggest killer of Endangered Tasmanian devils, with around

350 killed every year, and the largest cause of death of adult Endangered cassowaries in Queensland. Between 2006 and 2017, there were 31,626 admissions of 83 species of wildlife to the Australia Zoo Wildlife Hospital in Queensland (Taylor-Brown et al. 2019). Car strikes were the most common reason for admission (35%).

Australia relies on sea transport for 99% of its international trade by volume (DIRD 2016). From 2016 to 2020, the number of cargo vessels using Australian waters grew by about 2% per year (BITRE 2020). Sea transport depends on reliable access to our ports and shipping channels, which periodically require dredging. This is a constant pressure and inflicts major environmental damage in the 'dredging footprint'; species within the dredged sediment are physically disturbed as they are removed, and the dumping of dredged spoils can smother or bury seabed habitats. Generally, the overall impact of this pressure in Australia is low, but impacts can be high at local scales. Such impacts include the resuspension of sediment, which increases turbidity and decreases light, jeopardising the survival of photosynthetic organisms. This is particularly important in areas with key primary-producing habitat-forming species, such as coral reefs and seagrasses. Resuspended sediment can also release contaminants such as heavy metals into the water column, affecting filter-feeding organisms. Dredging levels in 2016 were high. Silt curtains usually used to contain suspended sediments are rarely completely effective and can create extremely turbid conditions within the curtains.

International transport is also Australia's main source of introductions of non-native species and diseases (see 'Invasive species and range shifts' and 'Invasive species management'). Annually, as at 2018, more than 18,000 vessels, 1.8 million sea cargo consignments,

41 million air cargo consignments, 152 million international mail items and 21 million passengers arrive in Australia, and numbers are growing every year (Inspector-General of Biosecurity 2019). As a result of the COVID-19 pandemic, international air passenger arrivals declined by 98% in 2020, but freight decreased by only 23% and shipping was much less affected; some Australian ports now exceed 2019 trade volumes (Infrastructure and Transport Ministers 2020). A National Priority List of Exotic Environmental Pests, Weeds and Diseases (the Exotic Environmental Pest List) has been developed to facilitate activities that help prevent entry, establishment and spread of exotic pests, weeds and diseases (ABARES 2020b). Exotic invasive species are those species not yet present in Australia.

As well as commercial vessels, many smaller vessels use Australian waters and provide an important recreational pastime for many Australians. Marine vessels can cause environmental damage from collisions or grounding, exhaust, noise pollution, fuel spills and microplastic pollution from antifouling coatings (Dibke et al. 2021). They can also carry invasive species in ballast water and on their hulls. Anchors can damage seabed habitats, and marine fauna, particularly whales, are at risk of ship strike. Most impacts are local, and risks can be mitigated through effective management. However, indirect impacts from shipping, such as the introduction of invasive pests, remain a substantial pressure. Shipping-related infrastructure and activities (ports and dredging) also represent a substantial and growing pressure as the number of vessels increases.

Resource extraction

For more than 200 years, different forms of resource industry have modified our lands and seas, particularly agriculture, aquaculture, commercial fishing, mineral exploration and

mining. They have also resulted in significant destruction of Australia's heritage, particularly Indigenous heritage. Many of these impacts have also caused a dramatic decline in our biodiversity, and have adversely impacted ecosystem services that provide social, ecological and economic benefits to people.

Agriculture

One of the greatest impacts on the environment caused by agriculture is the land clearing that occurs to convert land from native vegetation to agricultural land use (see 'Land clearing').

Ongoing pressures from agriculture are immense. As of 30 June 2017, approximately half of Australia's land mass was used for agricultural production, mostly for grazing (340.8 million hectares), cropping and improved pastures (66.6 million hectares), and forestry and other practices (0.9 million hectares) (ABS 2018). More than 50,000 agricultural businesses applied 5 million tonnes of fertiliser to 50 million hectares of agricultural land across Australia in 2016–17. Agricultural activity (e.g. cropping, livestock grazing, wood plantations) is the third most commonly listed threat to species listed under the EPBC Act, affecting 57% of taxa (Kearney et al. 2018). For example, land degradation causes a decline in soil microbial activity, and agricultural practices have major impacts on the composition of microbial communities (Gellie et al. 2017).

Australian rangelands experience Australia's most extensive agricultural activities and have been significantly degraded as a result of weeds and overgrazing by introduced herbivores, often combined with drought (Foran et al. 2019). However, they also have active Indigenous cultures, areas of relatively intact biodiversity and mining industries. More than 10% of rangelands are protected in the conservation estate, and more than

one-third is under some form of exclusive Indigenous land tenure. A major ongoing issue is the spread of non-native pasture grass species. For example, buffel grass (*Cenchrus ciliaris*) occurs over 60% of the continent, and directly impacts many native plant and animal species that may be threatened with extinction (Godfree et al. 2017).

Substances such as pesticides and chemical pollutants from agriculture are suspected of causing 8% of fish deaths in coastal and inland catchments in New South Wales over the past 20 years, entering the system through spray drift, vapour transport and run-off. Pollution also impacts the viability of sperm, eggs and larvae, and increases the incidence of abnormalities, skeletal defects, growth reduction and reduced life expectancy (DPI 2021). Overall, there are limited data nationally from which to extrapolate a trend over the past 5 years.

In south-eastern Australia, the greatest impact on freshwater ecosystems is from the modification of water processes as a result of river regulation, surface water and groundwater extraction for irrigation, and other water resource developments. Although water use was lower in many of the past 5 years (due to reduced water availability), and progress has been made in addressing the balance between water use and the environment in overallocated systems, significant issues remain (see 'Freshwater ecosystems' and 'Water resources').

Water temperature affects the spawning, breeding and migration patterns of many aquatic species. Large dams storing water for agricultural and urban use can cause downstream thermal pollution, which can affect many biological and ecosystem processes. When water is released from the cold, bottom layer of a dam, it can result in much colder water temperature than normal, with negative impacts on fish recruitment,

and potentially on ecosystem productivity and carbon cycling. Conversely, the removal of riparian vegetation reduces shading, causing river water temperatures to increase. Higher temperatures can result in increased solubility of salts and decreased solubility of oxygen, and increase the growth rates of microbes, animals, plants and algae. Furthermore, land clearing and erosion can lead to an increase in the turbidity of inland waters, reducing light penetration, negatively impacting some plants and fish, favouring the growth of blue-green algae, and potentially mobilising pollutants such as heavy metals and nutrients.

Aquaculture and fishing

Aquaculture production is growing globally and in Australia; 38% of Australian seafood production is currently 'farmed', including salmon, barramundi, bluefin tuna, rainbow trout, prawns, oysters, mussels, abalone and high-value pearls. Increased nutrient loads from aquaculture, particularly fed fish farming, can have significant impacts on the seabed and surrounding water quality (Black 2001); if not managed effectively, they can result in eutrophication (excess nutrients, which may cause harmful algal blooms). However, impacts depend on many local factors, such as farm site and design management processes. Despite industry growth, the pressures of aquaculture are generally low, and most impacts are confined to small areas.

In Australia, commercial fishing is considered to be well regulated. The sustainability of commercial harvesting in Australia's diverse wild-caught marine fisheries has improved since 2016, with 86% of stock assessed in 2020 classified as not overfished; however, these assessments are based on fisheries-dependent data and are subject to model assumptions. Some Australian jurisdictions are working to implement spatially referenced data collection and develop fisheries management plans for

key species (e.g. mackerel and saucer scallops in Queensland) (Mobsby et al. 2020). Australian commercial fisheries catch scallops, prawns, crabs, squid, rock lobster, abalone, coastal fish such as whiting and flathead, reef fish such as coral trout, shelf and deepwater fish such as ling and blue-eye trevally, and oceanic tuna and billfish, using methods ranging from small-scale netting to large-scale longline fishing and trawling (FRDC 2018, Pitcher et al. 2021).

The impact of commercial fishing varies across regions and with the type of gear used. The greatest fishing intensity occurs in the east and south-east. Bycatch (nontarget) species mostly consist of other fish or invertebrate species but can also include protected or migratory species such as seahorses, sharks, sea snakes, marine turtles, seabirds and marine mammals. Although a framework has been developed and applied for assessing the ecological impacts of fishing on nontarget species (Hobday et al. 2011), a national analysis of the cumulative impacts of commercial fishing on marine habitats has not been completed. Over the past 5 years, fishing effort has declined in Australia's trawl fisheries in all marine regions, consistent with a long-term trend of reduced trawl footprints. Of concern is ongoing foreign illegal, unreported and unregulated fishing in Australia, which mostly occurs in northern Australian waters (i.e. north of Western Australia, the Northern Territory and Queensland), and in the Southern Ocean around Australia's subantarctic Heard Island and McDonald Islands (Vince et al. 2020).

Although fishing is generally considered a pressure on the environment, customary fishing by Indigenous people should not threaten nature and sustainability if the Indigenous principles of lore and custodianship are followed and there are no other major pressures. Customary fishing is hunting, gathering and fishing of marine and

coastal species for personal, subsistence, communal, ceremonial, spiritual or trade purposes. It is also known as traditional use, cultural harvest or cultural fishing. Traditional Custodian groups along the Australian coastline continue an ancient connection with sea Country, and customary fishing occurs over a large area of Australia (Schnierer et al. 2016). Customary fishing practices are not static; they vary between communities and over time in line with changes in lore and customs, as well as with modern practices and environmental changes. Methods are often low-impact activities carried out from shore or from small boats, and customary catch is expected to be relatively small for most stocks (Productivity Commission 2016).

In contrast, the intensity of mainstream recreational fishing activities can pose a threat to both fish stocks and marine biodiversity, at least at a local scale (Henry & Lyle 2003, Stuart-Smith et al. 2008, van Putten et al. 2017, Edgar et al. 2018, Little et al. 2019). Compared with global levels, participation levels for recreational fishing in Australia are high (Arlinghaus et al. 2015, Hyder et al. 2018, Lynch et al. 2021). Furthermore, although participation levels have remained stable or declined, fishing power has substantially increased as a result of continual improvements in technologies (Lynch et al. 2021). Although trends vary across regions, recreational fishing generally has a high impact on the marine environment. For some species, the proportion of the catch taken by recreational fishers can be large, at times rivalling or exceeding the harvest from commercial fisheries. Fishery-independent survey data have shown recent declines of nearshore harvested species (Edgar et al. 2018), which suggest that the impacts of recreational fishing on shallow-water inshore environments should be of concern (Little et al. 2019). Recreational fisheries, although often licensed, are open access with no cap

on participation. Except for a small number of no-take marine reserve and fisheries closures, most coastal and marine waters are available to fishers (Ochwada-Doyle et al. 2014, Kenyon et al. 2018). The distributed nature of this pressure means that further work to understand small-scale variation in fisher behaviour and the consequent pressure on our estuaries and coasts is needed (Griffin et al. 2021).

Antarctica is a productive fishing ground that is closely managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), which sets opening and closing dates for fishing seasons, and catch limits for each fishery and each geographic area. The Antarctic fishery for krill (used in aquaculture, pharmaceuticals and human consumption) is the largest commercial fishery in the Southern Ocean. These tiny crustaceans are a keystone species for Antarctic ecosystems because they graze on micro-size phytoplankton and then become the primary food source for predators such as seabirds, fish, penguins, seals and whales. Krill catches have increased over the past 2 decades, but have been sustainably managed by CCAMLR. However, krill is vulnerable to environmental changes, particularly climate change (Kawaguchi et al. 2013), and any resulting reduction in krill populations, or overfishing, would have major impacts on Antarctic species. Large deepwater Antarctic and Patagonian toothfish and mackerel icefish are also commercially harvested within precautionary catch limits.

Mining

Mining activity in Australia continues to grow. Over the past 5 years, investment in mineral exploration doubled from \$344.7 million in June 2016 to \$878.3 million in June 2021. Beyond the direct footprint of mines, impacts include waste discharge and pollution

(including dust and aerosols), chemical emissions and acids, sediment transport, and rehabilitation. Mining impacts on air quality vary considerably, depending on the operations.

Mining affects biodiversity and natural heritage at scales ranging from the area of mineral extraction to processes operating at landscape to regional scales and beyond. Habitat loss and degradation are the most immediate and direct impacts, with flow-on impacts that change species distributions and ecosystem condition. Mining activities – such as mineral exploration, resource excavation, and groundwater drawdown and reinjection – can threaten the viability of certain species, such as subterranean fauna.

Land-based mining is among the major Australian heavy industries with the largest levels of emissions (DAWE 2020h), including carbon monoxide (CO), sulfur dioxide (SO₂), coarse particulate matter (PM₁₀) and volatile organic compounds (VOCs). In addition, some mining uses nonregulated diesel engines (NRDE). Although NRDE make up only around 3% of on-road vehicle numbers (DAWE 2020g), their much bigger sizes mean that they usually emit much more CO, nitrogen oxides (NO_x), PM and VOCs than other road vehicles. Impacts on air quality from mining can last for centuries because some human-made emissions do not break down easily. Mercury used in goldmining during the mid- to late 1800s is still being cycled through the atmosphere via soil and vegetation processes.

Australia continues to bear the legacy of tens of thousands of orphaned or abandoned mines that pose an ongoing risk to the environment, public health and safety (Campbell et al. 2017). The cumulative impact of past practices, as well as present activities, is substantial and not well understood, with significant legacy issues remaining unaddressed (Roche & Judd 2016).

Much of Australia's mining occurs on land that is subject to land rights and native title. For example, more than 80% of the mineral value extracted in the Northern Territory comes from Indigenous-owned land (NLC 2021). Nationally, more than 60% of operating mines are located near Indigenous communities (MCA 2021). Mining impacts Indigenous caring for Country and can damage Indigenous heritage (Australian Government 2016), as revealed by the 2020 destruction of Juukan Gorge (see 'Indigenous heritage'). Mining activities also impact historic heritage; historic mining heritage is particularly at risk from mine rehabilitation.

Industrial pollution

Mining, steel production, metal processing, power generation and petroleum refining produce the highest air pollutant emissions in Australia (DAWE 2020h), including CO, SO₂, PM₁₀ and VOCs. Agricultural operations such as feedlots emit large volumes of ammonia that react in the atmosphere, forming inorganic particulate compounds such as ammonium nitrate and ammonium sulfate, which contribute to PM_{2.5} levels. Other industries generate airborne toxins such as hydrochloric acid, cyanide, dioxins and furans.

Industrial emissions are generally well controlled across Australia, and there have been recent improvements in the emissions of hazardous substances such as lead and mercury. Industrial emissions of CO and NO_x generally increased from 2015 to 2019, but most others decreased or remained steady. However, the impacts from point sources and industrial air pollutants near regional populations are increasing.

In coastal regions, the naturally nutrient-poor waters of productive, sheltered estuaries and bays are at particular risk from industrial pollution because of high levels of human

activity and growing populations. The resulting nutrient-rich run-off (e.g. wastewater, fertilisers) and other organic pollution can lead to excessive growth of nuisance or harmful algae (Davis & Koop 2006), and deoxygenation of the water in extreme cases. Although nutrient pollution levels have remained high overall across Australia since 2016, there have been reductions in nutrient inflows from wastewater treatment plants. However, results vary considerably between regions.

In Queensland, some 423,000 square kilometres of land drains into the sensitive Great Barrier Reef lagoon. Pollution risks are highly variable, as land use for this area includes cattle grazing (72% of the area); conservation (15%); other agriculture (6%); forestry (5%); mines, wastewater treatment plants, landfills, industrial and commercial sites (2%); and residences for some 1.2 million people (0.3%) (ABS 2017b, Queensland Government 2020).

Anti-fouling paints, coal dust, metals and metalloids, marine debris, pharmaceuticals and personal care products, and petroleum hydrocarbons were recently identified as emerging concerns for Reef waters (Kroon et al. 2020). In 2017, more than 5,000 organic chemicals were detected in green turtle blood samples collected at 3 sites in the Reef lagoon. Although overall pressures from chemicals entering the Reef lagoon are low and stable overall, localised impacts range from very high to low.

Other forms of industry-related marine pollution of national concern include land-based nutrients, pesticides, sediment inputs and hydrocarbons (Gagnon 2021, Trebilco 2021). These pollutants cause a wide variety of impacts on marine plants and animals, including reduced photosynthetic activity, endocrine disruption, reduced immunity, modified behaviour and mortality. The 2 main sources of sediment input are

run-off from land and dredging, including disposal of dredged material at sea. Improvements over the past 5 years have included a shift to land-based disposal of dredged materials; better land management, resulting in some reduction in the flow of land-based sediments and contaminant over inshore reefs; and the mandatory use of low-sulfur fuels by ships in Australian ports from December 2016, and at sea from January 2020. Despite some improvements, poor water quality as a result of land-based run-off remains one of the 3 most significant pressures on the Great Barrier Reef (GBRMPA 2019), and a significant pressure on inland waters in all urban and agricultural environments. Urban environments continue to be sites of substantial pollution that can enter waterways via stormwater run-off. This pressure increases with urbanisation; however, effective management via litter traps and constructed wetlands is reducing pressure in some cities.

New wastes are emerging as a result of new industries, and new chemicals are emerging as contaminants in wastes and with increased regulatory understanding of chemical hazards (Latimer 2019). The most high-profile of these are PFAS (per- and poly-fluoroalkyl substances), a group of human-made chemicals that have been used since the 1950s in a variety of domestic products and in aqueous film-forming foam used in fighting liquid fuel fires (Australian Government 2021b). Increased environmental levels of PFAS have been found near some industrial areas, effluent outfalls and landfill sites (Australian Government 2021b). PFAS are toxic, are highly mobile in water, can travel long distances from their source, and do not fully break down naturally in the environment (COAG 2019, 2020). Although the potential risks of PFAS contamination on the environment and human health are not yet fully understood, all Australian governments have agreed a PFAS National Environmental Management Plan

on the regulation of PFAS-contaminated sites (HEPA 2020). Implementation is undertaken by each jurisdiction as part of its broader environmental regulation responsibilities.

Discharge from power plants or other industrial sites into river systems can increase water temperatures, which can impact the spawning, breeding and migration patterns of many aquatic species (DPIE 2020). Changes in microclimates, contamination from pollutants and hydrocarbons, and increased nutrient loads are added threats to subterranean fauna, especially stygofauna and other entities in groundwater-dependent ecosystems (Hose et al. 2015, Hose & Stumpp 2019, Castaño-Sánchez et al. 2020).

Flaring of waste gas associated with oil and gas remains a contributor to overall greenhouse gas emissions. In 2019, Western Australia became the first Australian jurisdiction to join the World Bank's Zero Routine Flaring by 2030 initiative to manage natural gas resources and reduce greenhouse gas emissions more efficiently. One project on the Burrup Peninsula in Western Australia is set to become the largest single carbon pollution emitter, at 4.4 million tonnes per year, initially increasing Western Australia's total annual emissions by 5% (The Australia Institute 2021). However, the company's Greenhouse Gas Abatement Program commits it to a 30% reduction in emissions by 2030, and net zero emissions by 2050.

Noise pollution is another form of industrial pollution. Human-induced noise in the marine environment can disrupt normal behaviours of marine life; induce stress; and adversely impact foraging, reproduction and overall population health (de Soto et al. 2013, de Jong et al. 2020). Sound is important for communication among species, alerting individuals to predators (or prey) and enabling animals to navigate the marine environment and locate particular features

(Tyack & Clark 2000, Montgomery et al. 2006, Popper & Hawkins 2019). The largest source of persistent, chronic, anthropogenic noise is shipping; oil and gas exploration activities are the main source of acute impulsive noise. However, noise generally has a low impact on the marine environment. Since 2016, noise associated with shipping has increased, and noise associated with oil and gas exploration has decreased (Evans et al. 2021c).

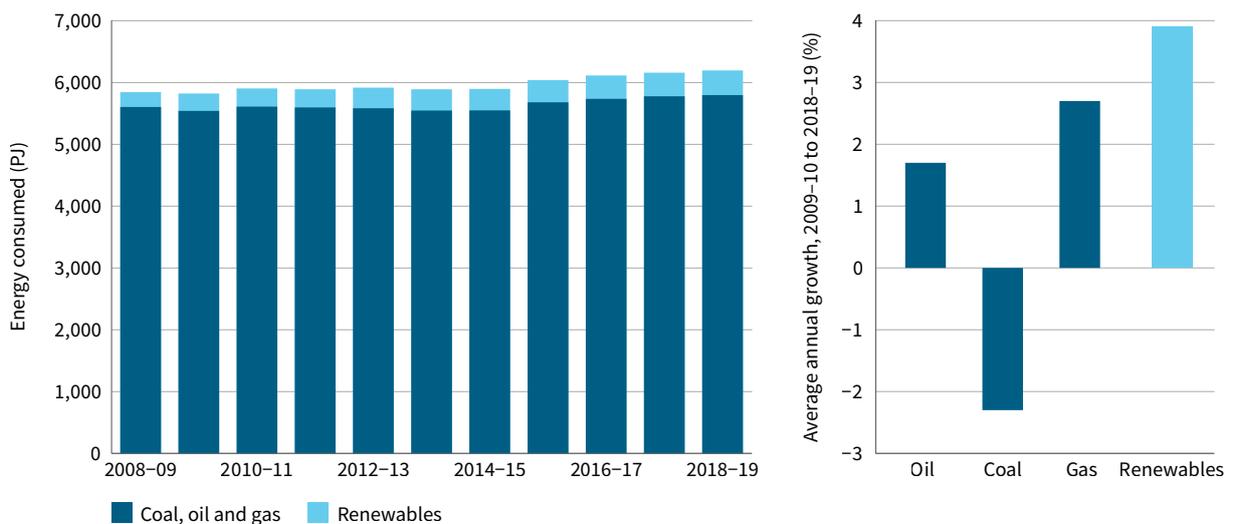
Energy production

Power generation from fossil fuels and petroleum refining are among the major Australian heavy industries with the largest greenhouse gas emissions. Fossil fuels accounted for 94% of Australia’s primary energy mix in 2018–19. The overall growth in energy demand and the cost of electricity is requiring a change in methods of energy generation, with a growing proportion being sourced from renewable sources. In 2020, 33.6% of total emissions nationally were from the electricity sector, making it the largest single contributor to emissions nationally.

However, emissions from the electricity sector have generally been declining since 2009, largely because of an increasing share of renewables in electricity generation and a consequent decrease in the share of other forms of power generation, particularly coal.

Renewables offer opportunities for low-cost, low-emissions energy; however, they present challenges in ensuring the security, reliability and affordability of the power system. The trial and rollout of localised household and industrial batteries is one way of addressing these challenges. There has also been a change in the design of our energy systems, with a move from a centralised model of energy production and storage towards a more distributed approach. This is occurring at the same time as a transition away from a coal-fired energy sector to a more decarbonised one.

Renewable electricity generation in Australia has more than doubled over the past 10 years, and 20.9% of electricity in Australia was generated from renewable sources in 2019 (Figure 17). The average annual growth of wind energy is particularly high (around 15%)



PJ = petajoule

Source: Australian Government Department of Industry, Science, Energy and Resources

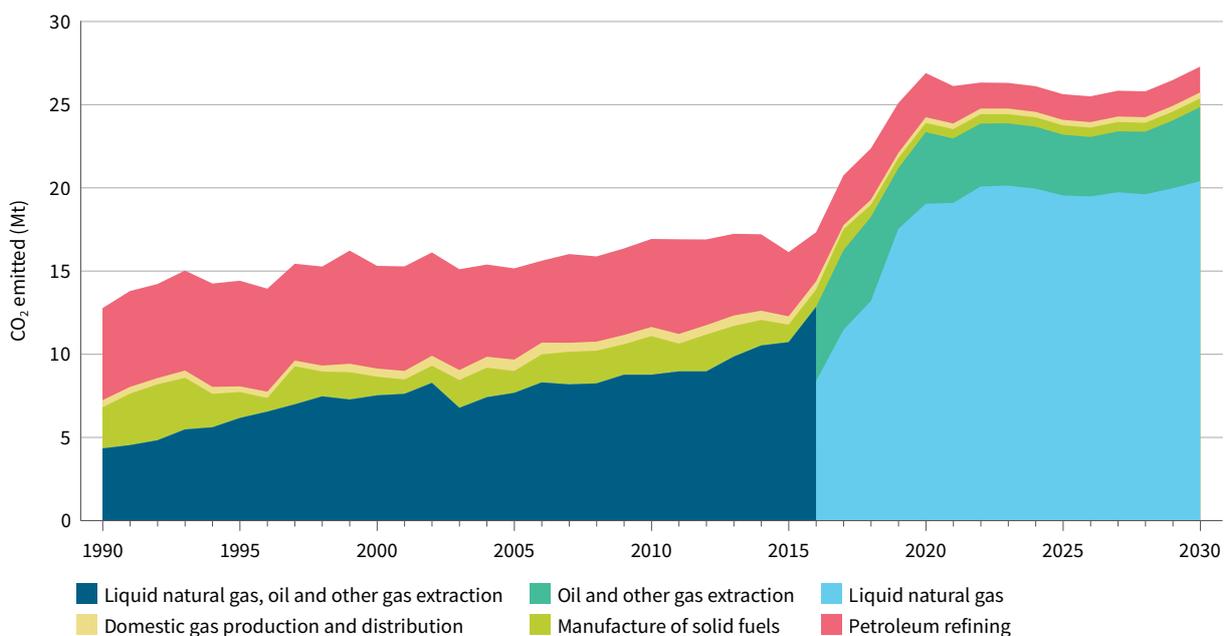
Figure 17 Sources of energy, 2008–09 to 2018–19; and average annual change by category, 2009–10 to 2018–19

(DISER 2021f). At the end of 2018, there were 94 wind farms in Australia, delivering nearly 16 gigawatts of wind generation capacity; a further 8 wind farms were commissioned in 2019 (ARENA 2021). The growth of onshore coastal wind farm developments represents a significant land-use change within the Australian coastal zone. Wind farms contribute to mortality of bird and bat species; however, on average, the impacts appear relatively small compared with other pressures, although consolidated data are very limited. Coastal wind farms could potentially have a detrimental affect on migratory bird species, including Endangered and Critically Endangered species such as the curlew sandpiper, far eastern curlew and red knot; but there are insufficient data at this time to draw any definitive conclusions.

Oil and gas exploration and extraction activities constitute the largest economic sector, by value, of Australia’s marine industries, with an estimated combined value of \$36.3 billion in 2017–18 (AIMS 2021).

Natural gas production is becoming the largest contributor (\$30.3 billion in 2017–18), and oil and gas are decreasing. During 2015–20, oil production ceased at several marine facilities, and natural gas production commenced at 3 facilities in offshore waters. Production of crude oil declined in volume, and production of condensate and liquefied petroleum gas increased in volume (DISER 2020b). As the oil sector continues to mature, it can be expected that oil exploration and production activities will decrease and decommissioning activities will grow (NOPSEMA 2020, Evans et al. 2021b). Figure 18 shows the changing contributions of the different energy subsectors to CO₂ emissions.

Only small-scale (less than 500 kilowatt) experimental or prototype wave and tidal technologies have been deployed in Australia (Hemer 2021a,b). Several development proposals for large offshore wind farms (more than 100 megawatts) are in progress, the most mature of which is for offshore eastern Victoria. Given the limited deployments,



CO₂ = carbon dioxide; Mt = megatonne
Source: DISER (2021c)

Figure 18 Energy sector CO₂ emissions between 1990 and 2020, with projections to 2030



Case study The 10 Gigawatt Vision

Source: Monica Tan and Jane Carter, Beyond Zero Emissions

Published in 2019, the 10 Gigawatt Vision is a comprehensive plan to use abundant sunshine and low-cost solar energy to transform the Northern Territory's economy. Developed in a partnership between Beyond Zero Emissions and the Environment Centre NT, the report shows that, by 2030, the Northern Territory Government could drive investment in 10 gigawatts of renewable energy, creating more than 8,000 jobs and \$2 billion in new annual revenue. The report also showed how home electricity bills could fall by one-third by 2030, and electric vehicles could save households as much as 80% off transport fuel bills.

The Northern Territory Government has incorporated large parts of the plan in its climate and energy policies, and the report won the 2020 Environmental Philanthropy Award sponsored by Philanthropy Australia. This vision for the Northern Territory is demonstrated by Australia's most ambitious renewable energy project: Sun Cable's Australia-ASEAN Power Link, which, if built, will be one of the world's largest dispatchable renewable electricity systems, supported by the world's largest battery and solar farm in the Barkly region near Tennant Creek.

The vision depends upon meaningful engagement and negotiation with, and informed consent of, Traditional Owners across the Northern Territory. It could support Indigenous people's aspirations for economic development through opportunities such as community ownership of renewable infrastructure.



Figure 19 Solar panel array, Northern Territory

current pressures on the marine environment associated with offshore renewable energy are localised and sparse. However, the pressures are expected to increase, given the need to transition to renewable energy systems.

Invasive species and range shifts

Thousands of species have been introduced, either deliberately or inadvertently, to Australia and become established in all parts of the country, along our coasts and in the marine environment. Introduced species include agricultural species and domestic animals that benefit our economy, as well as species that are detrimental to the environment. Climate change is increasing the incidence of range shifts, where species change or expand their ranges to cope with changed environmental conditions. These species can act as invasive species in their new ranges.

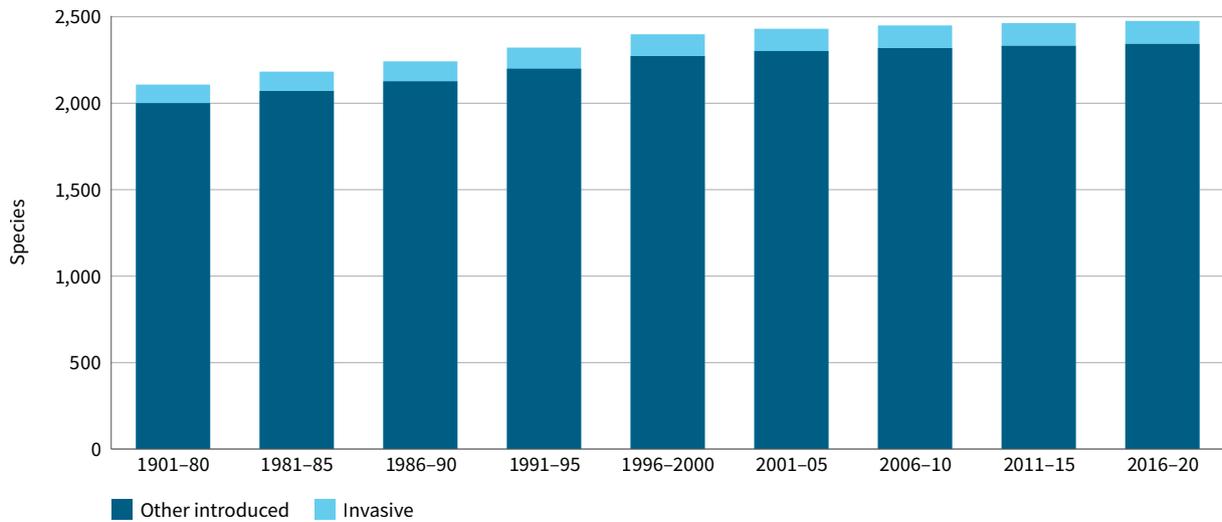
Introduced species now make up a significant proportion of all species recorded in Australia's terrestrial bioregions. The largest numbers are recorded in the intensive agricultural regions surrounding the major cities, such as the Sydney Basin, south-east Queensland, the Flinders Lofty Block and the Victorian midlands. We now have more introduced terrestrial plant species in Australia than native ones (Groves et al. 2005). Approximately 2,800 introduced terrestrial plant species have naturalised, and approximately 10% of these are considered invasive plants.

Invasive species are consistently identified as one of the most prevalent threats to Australian wildlife, and their management is a significant economic burden in Australia (Hoffmann & Broadhurst 2016). It is estimated that, since the 1960s, Australia has spent or incurred losses totalling at least \$389.59 billion (2017 value) as a result of terrestrial invasive species

(Bradshaw et al. 2021). In marine and coastal waters, the vast majority of invasive species are not actively managed.

Invasive species are also having a significant impact on natural heritage, including in a number of Australia's World Heritage properties (e.g. Macquarie island, Lord Howe Island Group, Wet Tropics of Queensland), although this is an issue that is being addressed, particularly in World Heritage Areas, with some success.

The International Union for Conservation of Nature launched a global register of introduced and invasive species (GRIIS) in 2018 to support national government responses to biological invasions (Pagad et al. 2018). Species verified as non-native to a country are assessed for evidence of impact and may be further designated as 'invasive'. This information, combined with Australian occurrence records from the Atlas of Living Australia, provides a national framework for reporting on status and trend of introduced species. Using 1980 as a baseline for the total number of species recorded at least once since 1901, anywhere on the Australian continent and remote territories, the aggregated public data record shows that the number of introduced terrestrial species by 2020 had increased by more than 17% since 1980 (i.e. 368 additional species; Figure 20). Over the same period, the number of invasive non-native species increased by 24% (i.e. 26 additional species). Of the naturalised species, around 10% are likely to become impactful invasive species over time (Williamson & Fitter 1996).



Source: Based on data aggregated by the Atlas of Living Australia from multiple sources, including Terrestrial Ecosystem Research Network survey and monitoring data, as of September 2021 (EcoAssets 2021)

Figure 20 Cumulative number of the first detections of introduced terrestrial species anywhere in Australia or remote territories

Assessment Invasive species and range shifts



Invasive species are one of the most prevalent threats to Australia’s ecosystems and biodiversity. The number of invasive species continues to climb. Some species benefit from background trends pressures such as climate and habitat change. These pressures are also driving changes in the distribution of native species, many of which are moving southwards, resulting in changes to community composition.

Assessments of impact range from low to high
Assessments of trend are deteriorating
Related to United Nations Sustainable Development Goal targets 13.1, 15.8

Biosecurity and sources of invasive species

Biosecurity is Australia's first line of defence against species and disease introductions. Overall, the rate of new weed detections is in decline, and the introduction rates for some groups, most notably invertebrates, are also declining in our region compared with other parts of the world, providing indirect evidence of the effectiveness of Australia's biosecurity system. However, new threats continue to emerge. From 2012 to 2017, biosecurity incursions into Australia increased by almost 50% to 37,014 (CSIRO Futures 2020).

This cumulative burden of new and existing incursions is likely to continue to escalate in future years. A recent study has predicted that the number of established non-native species in Australia is likely to increase by 36% between 2005 and 2050 (Seebens et al. 2021).

More than 250 marine species have been introduced into Australia; however, this is likely to be an underestimate due to a lack of taxonomic clarity and monitoring (see 'Invasive species management'). Only 4 jurisdictions (the Northern Territory, Queensland, Victoria and Western Australia) use active surveillance approaches for marine pests, and hence our capacity to assess the state or trajectory of this pressure is very low.

Eastern Australia is among 5 global regions considered most vulnerable to the establishment of new invasive species, originating mainly from Asia and America via people, trade and tourism (Bellard et al. 2016). South-eastern Australia is an invasion hotspot, and the rate of biosecurity incursions into Australia has been increasing in recent years. Annually, as at 2018, more than 18,000 vessels, 1.8 million sea cargo consignments, 41 million air cargo consignments, 152 million international mail items and 21 million passengers arrive in Australia, and numbers

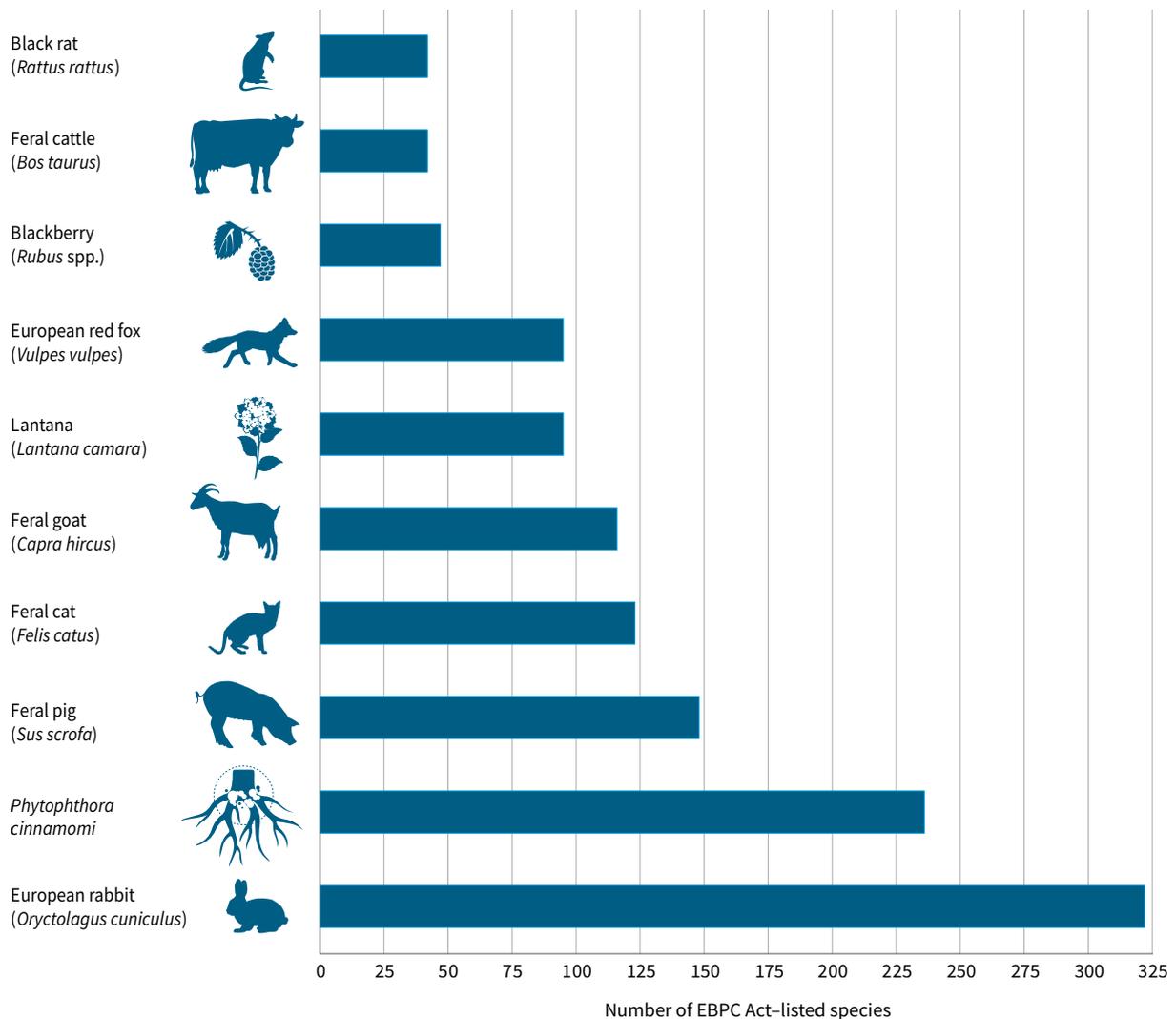
are growing every year (Inspector-General of Biosecurity 2019).

Using data collated by the Atlas of Living Australia, it is clear that the numbers of introduced terrestrial species are higher in regions where more land is intensively used. By 2020, the total number of introduced species recorded since 1980 had increased at a greater rate in the extensive use zone (63% increase) than in the intensive use zone (18% increase). Non-native species may benefit from changing climatic regimes, changes in nutrient or water availability, and establishment opportunities following bushfires and other disturbances – for example, widening of transport routes and clearings for powerlines and fire breaks (Abbott et al. 2020, Seebens et al. 2021).

Impacts of invasive species

Invasive species affected the largest numbers of native species at risk of extinction, as listed under the EPBC Act, compared with other threatening processes, affecting 82% (1,257 of 1,533) of threatened taxa in Australia in 2018 (Figure 21). In total, 267 invasive species (207 plants, 57 animals and 3 pathogens) are listed as affecting Australian threatened taxa (Kearney et al. 2018). This includes 230 non-native species (187 plants, 41 animals and 2 pathogens) and 37 problematic native species (20 animals, 16 plants and 1 pathogen). The top 10 threatening terrestrial species are 7 vertebrate animals, 2 plants (blackberry and lantana) and 1 fungus (*Phytophthora*) that causes disease in plants.

The presence of invasive species can impact Indigenous people's connection to Country through direct effects on native plants and animals, and all aspects of cultural landscapes, threatening the continuation of cultural knowledge and practices (Ens et al. 2015).



EPBC Act = Environment Protection and Biodiversity Conservation Act 1999
 Source: Kearney et al. (2018)

Figure 21 Impacts of major invasive species on terrestrial threatened species

Terrestrial invasive animals

Threat abatement plans under the EPBC Act are in place for key threatening processes arising from feral cats, the European red fox, unmanaged goats, feral rabbits, feral pigs, cane toads, and exotic rodents on offshore islands (see ‘Invasive species management’).

The most commonly cited invasive species affecting Australia’s threatened species is the European rabbit (*Oryctolagus cuniculus*), which threatens 21% (322) of EPBC Act-listed species (Kearney et al. 2018). The feral cat

(*Felis catus*), feral pig (*Sus scrofa*) and feral goat (*Capra hircus*) are cited as threatening more than 100 threatened species each. Feral cats are believed to have been a major factor in the extinction of the 30 Australian native mammal species lost since European settlement. There is no effective broadscale control method for feral cats, so they remain a major cause of decline of many Australian mammals (Legge et al. 2017). The feral pig is widely considered as one of the worst invasive species throughout its introduced range, particularly in the tropical north.

Feral vertebrate herbivores and livestock are an important threat to many species and ecological communities, as well as native vegetation broadly. Feral herbivore management is complex because many species have social and cultural value, and some are considered a resource by landowners, recreational and commercial hunters, and Indigenous communities.

Terrestrial invasive plants

Weeds are the most damaging category of pest in agriculture, and can displace native species and contribute to land degradation. Weed control is estimated to impose an overall average annual cost of nearly \$5 billion across Australia; control in agricultural areas accounts for the majority of costs. About \$300 million is spent each year on public weed control across national parks and Indigenous lands, and on weed research (McLeod 2018). The total annual cost of weeds (revenue loss plus expenditure) to Australian grain growers has been estimated at \$3.3 billion (Llewellyn et al. 2016), and across all grain, beef and wool industries is nearly \$5 billion (McLeod 2018).

Invasive grasses have been intentionally introduced to Australia since colonisation, mostly to support agricultural enterprises (Cook & Dias 2006, Setterfield et al. 2018). Some species have caused profound ecosystem impacts and conservation challenges (van Klinken & Friedel 2018). The environmental impacts of non-native invasive grasses are expected to continue to increase, with most still having relatively restricted distributions compared with their potential distribution. Invasive weed species impact how Traditional Owners use and manage their land. For example, the invasion of buffel grass (*Cenchrus ciliaris*) across arid Australia has impacted bush food collection and hunting, access to traditional lands, and ability to conduct traditional fire management. Further,

it has had cascading negative effects on cultural transmission to younger generations and maintaining cultural practice.

Five particularly high-impact weed species primarily occur across northern Australia: gamba grass (*Andropogon gayanus*), para grass (*Urochloa mutica*), olive hymenachne (*Hymenachne amplexicaulis*), mission grass (*Cenchrus polystachios* syn. *Pennisetum polystachion*) and annual mission grass (*Cenchrus pedicellatus* syn. *Pennisetum pedicellatum*) (Figure 22). Together, these grasses have been listed as a key threatening process under the EPBC Act because of their ability to alter nutrient cycling and water availability, and subsequently cause ecosystem degradation, habitat loss and biodiversity decline. Of particular importance is their capacity to increase fuel loads, resulting in intense fires.

Terrestrial invasive insects

Of particular concern are invasive insects, which can enter Australia through multiple pathways. Their association with a wide range of traded products and ability to endure adverse conditions during travel contribute to their invasiveness (McGeoch et al. 2020). Cut flower and foliage imports, along with plant nursery material and timber trade, are high-risk pathways for the introduction of invasive insects. Over the decade to 2017, for example, imports of cut flowers and foliage increased more than 3-fold, and detections of live insects at the Australian border increased from 13% to 58% of consignments (McGeoch et al. 2020).

Border interception records show that the vast majority of interceptions are of invasive invertebrates, such as tramp ants, which are highly invasive, and cause devastating environmental, economic and social impacts. Between 2001 and 2017, 20 serious tramp ant incursions occurred in Australia, including



Source: © Colin C Wilson, Australian Government Department of Agriculture, Water and the Environment

Figure 22 Invasive buffel grass impacting native ecosystems near Alice Springs, Northern Territory

16 incursions of red imported fire ants (*Solenopsis invicta*) (Inspector-General of Biosecurity 2019).

Australia has the highest success rate globally in invasive ant eradications. For example, 5 out of 6 tropical fire ant infestations have been eradicated from Indigenous land in northern Australia, with eradication of the last likely to succeed in the next 12 months. Yellow crazy ants affecting remote Northern Territory communities have been removed from more than 1,000 hectares, with the risk for further spread eliminated (Hoffmann 2019). Some incursions, such as the red imported fire ant (Figure 23), pose such a high risk to people, industry and the environment that costly eradication measures are justified (Jansse 2017).

Diseases

Diseases, fungi and parasites can affect the health of native species, reducing their ability to reproduce or survive. New diseases caused by introduced pathogens are a particular concern for the agricultural and ornamental industries.

Disease can contribute to the decline and extinction of threatened species. For example, chlamydial disease is one of the main factors threatening the long-term survival of the Vulnerable koala (*Phascolarctos cinereus*). The population of the Endangered Tasmanian devil (*Sarcophilus harrisii*) has declined by up to 80% since the mid-1990s when the infectious and usually fatal cancer devil facial tumour was first detected. Devil facial tumour has now spread over 80% of Tasmania (Lazenby et al. 2020). One of



Photo: Shutterstock

Figure 23 Red imported fire ants

the most devastating diseases affecting fauna over recent decades is amphibian chytridiomycosis, caused by the fungal skin pathogen *Batrachochytrium dendrobatidis*; at least 36 species of Australia's 238 amphibians have declined, and 7 have become extinct due to the disease.

A large number of plant pathogens also occur in Australia. Myrtle rust (*Austropuccinia psidii*) is an invasive species of rust fungus that affects growing tissues of a wide range of species in the Myrtaceae family, including iconic Australian genera such as *Eucalyptus*, *Corymbia*, *Melaleuca* and *Leptospermum*. Although the national-scale impacts of myrtle rust are not fully understood, it has been shown to cause dramatic declines in 2 once-common Australian species (native guava – *Rhodomyrtus psidioides*, and scrub stringybark – *Rhodamnia rubescens*). These

have subsequently been listed as Critically Endangered under the EPBC Act; the native guava is at very high risk of extinction, with only 1 surviving population that does not produce viable seed (Fensham et al. 2020).

Introduced species, diseases, outbreaks of pests and blooms of harmful algae can have substantial impacts on Australia's marine species and habitats (Hallegraeff et al. 2021, Nowak & Hood 2021), as well as having direct and indirect impacts on human health and wellbeing. Although several major disease outbreaks, such as white spot disease (Queensland) and Pacific oyster mortality syndrome (New South Wales, South Australia and Tasmania), have occurred since 2016, the state of algal blooms, viral diseases, parasitic infections and mass die-offs is generally good and stable (Hallegraeff et al. 2021, Nowak & Hood 2021). Between 2016 and

2021, the overall pressures from diseases and infestations were low, although significant marine fish and other marine animal mortalities due to disease were regularly reported from most jurisdictions (Roberts et al. 2019, Readfern 2020, Young et al. 2020).

Range shifts and extensions

All living organisms have a range of temperatures and other environmental conditions in which they can live. Climate change, particularly in the form of local warming, stimulates and sometimes forces species to move, generally away from the equator towards cooler regions. Movement of native species and the occurrence of vagrants from nearby countries is a regular occurrence in Australia but may be increasing because of climate change (Davis & Watson 2018). As species extend their range poleward, they encounter new ecosystems that may not be used to their presence, changing the composition of communities, which can negatively impact the local ecosystem and cause loss of native species.

In coastal regions of northern Australia, crocodiles, with no natural predators, continue to both expand in numbers and increase their range, moving southwards. At least 198 Australian marine species have undergone long-term shifts in their geographic distributions since 2003, most of which (87.3%) have moved towards cooler waters (Gervais et al. 2021). Australian species such as the long-spine urchin (*Centrostephanus rodgersii*) can move into new areas and act like invasive or pest species, altering native ecosystems and processes, with economic and social impacts. Significant geographic shifts have occurred in the distribution of marine algae, including pathogenic and harmful algal bloom species. Some species may end up as far away as Antarctica. Rafts of non-Antarctic kelp, for example, carry a vast array of organisms and

can drift very long distances into Antarctic waters. Invasive species pose a major risk of establishment in Antarctica and the subantarctic as climate change provides more favourable conditions.

Globally, 25–85% of marine species have been documented to be shifting, but little is known about the cumulative ecosystem-level impacts of multiple shifts. In addition to latitudinal shifts in species distributions, some species are thought to also be retreating to cooler, deeper waters; with increasing tidal height, intertidal species and ecosystems may also be shifting. However, these trends are largely unknown for Australian waters.

Climate change is also affecting the range of many plant species. For example, climate change is predicted to shrink the ranges of the majority of Australia's eucalypt species over the next 60 years, and approximately 90% of the current areas with concentrations of highly restricted eucalypts is predicted to disappear (or shift location) (González-Orozco et al. 2016). The shrinking and shifting of the geographic ranges of eucalypts are likely to have significant flow-on effects for ecosystem structure and function, including for the many species that depend on eucalypts for food and shelter.

Much of Australia has limited water resources, and thus there is limited scope for freshwater species to move to more favourable conditions. Species losses under future climates are likely to be high, particularly in inland regions of Australia. In south-western Australia, a marked decline in winter rainfall since the 1970s, coupled with extensive habitat loss and fragmentation, threatens species that depend on wetlands and cannot migrate.

Some species might only persist if they can be introduced to wetter areas. 'Assisted colonisation' translocates species beyond their native range to mitigate a major threat, but this approach requires detailed risk analysis

and should be considered an action of last resort because we cannot accurately predict the consequences of species introductions.

Indigenous governance, rights and access

Ongoing colonisation continues to impact the rights of Indigenous people to access and manage Country. The colonial legal system and the established practices of environmental management have ignored Indigenous people, their knowledge systems and their millennia-long practices of caring for Country. Although there is evidence that governments are developing governance models that include Indigenous people on advisory boards or as part of consultation, Indigenous people need to be included in key decisions about the environment. There must be more willingness by government to embrace Indigenous knowledge and caring for Country principles. Most importantly, Indigenous people need to be empowered to share their knowledge on their terms.

Country encompasses landscapes and seascapes, as well as knowledge and caring for Country practices, including care of plants and animals (see 'Connection to Country'). This holistic approach is not often translated into land management strategies or policies. The inflexibility of government environmental management practices disempowers Indigenous people in managing their Country. The mismanagement of Country has been the result.

A key area that illustrates this is cultural fire management. Australia's environment has been nurtured by Indigenous fire management practices, which were well used across the country. For Indigenous people, cultural burning and fire management are proactive measures taken to create healthy Country.

Since the beginning of colonisation, there has been no consistent cultural fire management nationally. These traditional land management practices have largely stopped or have been significantly curbed by regulations in states and territories.

Many states and territories are developing programs to bring back cultural burning practices, particularly in the context of the current climate change emergency. However, the adoption of such practices is usually within rigid, non-Indigenous management frameworks and should take into account the rapidly changing climate as well as historical legacies of impact. There have been many calls for greater collaboration and joint management of fire management using both Indigenous knowledge and western science. Indigenous people must develop, lead and implement environmental management techniques that are guided by cultural practices and traditional knowledge systems (Maclean et al. 2018, Fisher & Altman 2020, McKemey et al. 2020, Steffensen 2020). The 2020 Samuel Review of the EPBC Act called for greater recognition and inclusion of Indigenous environmental management practices.

Although Indigenous cultural rights, including self-determination rights and protection from racial discrimination, are enshrined in human rights instruments, the laws in Australia are limited in giving meaningful effect to these rights.

The United Nations Declaration on the Rights of Indigenous Peoples 2007 (UNDRIP) provides an international foundation to recognise Indigenous cultural and knowledge rights. It was endorsed by Australia in 2009, but is a nonbinding agreement. It describes 'the rights of Indigenous peoples to live in dignity, to maintain and strengthen their own institutions, cultures and traditions and to pursue their self-determined development,

in keeping with their own needs and aspirations’ (UNPFII 2007). Importantly, it also sets standards of free, prior and informed consent, and advocates for the right of Indigenous people to conserve and protect the environment. Although during the past 5 years we have seen more recognition of these rights by governments and industry in guiding management of our land and sea, too

often they remain ignored in decision-making. There is a lack of understanding of Indigenous cultural governance and rights by corporations, and a lack of effective engagement and collaboration. However, there is some evidence that Indigenous cultural governance is being strengthened, sitting alongside the national and state governance (Talbot 2017).

 **Assessment** Governance, rights, and access to Country for Indigenous people



Changes in native title, land rights, Indigenous Protected Areas and co-management are positive; however, overall environmental management and governance arrangements do not adequately incorporate Indigenous knowledge, practices, culture and rights, and do not ensure equitable access to natural resources. Indigenous people continue to be impacted by poor access to water, constraints on cultural food collection and burning practices, and inadequate protection of Indigenous cultural and intellectual property.

Assessments of impact are very high
Assessments of trend are deteriorating
Related to United Nations Sustainable Development Goal targets 11.4, 15.6

Access and rights to Indigenous estate

The Indigenous estate includes land owned and accessible to Indigenous people. Native title, land rights, Indigenous Protected Areas, and fully and co-managed national parks are mechanisms by which Indigenous people are able to connect with and care for Country. However, there are barriers caused by difficulties in accessing privately owned land, weak land title, and a complicated jurisdictional system of land tenure. The legal rights framework of native title, land rights and access rights is complex, and entities such as governments, industry and private owners are better resourced to use the legal system in their favour for access and use rights. There is a lack of transparency in negotiations.

Indigenous ranger programs offer Indigenous people a source of employment, capacity building and, most importantly, unfettered opportunity to link back with and protect Country. However, limited resources and underfunding are barriers for Indigenous people to effectively perform these duties. The movement of Indigenous people off Country to urban centres changes how Indigenous people can care for Country. Urban areas are also part of Country, and access to green spaces, waterways and sites is important for Indigenous people, but Indigenous people are not often included in urban planning.

Indigenous access and rights to natural resources

The historical and present mismanagement of Australia's environment denies Indigenous people equitable access to natural resources. Mismanagement refers to the poor protection and inequitable allocation of environmental resources and assets, and also the inflexibility

to recognise Indigenous knowledge in management approaches. Areas of concern include water resources, cultural burning practices and fishing rights.

Access to water is a primary and ongoing concern for Indigenous people. The mismanagement and loss of water is a particular issue for Indigenous freshwater communities. The 2019 Murray–Darling Basin Royal Commission highlighted the long-term and irreversible impacts of this poor management (see 'Integrated water management') (Walker 2019).

Limited rights to water have far-reaching health and economic impacts for Indigenous communities. For example, in the Northern Territory, communities rely on low-quality water for domestic uses, which can cause detrimental health outcomes such as lowered life expectancy. The limited commercial usability of native title rights also means that any water rights cannot be used to generate economic outcomes.

Water management laws do not fully recognise Indigenous people's rights to access, use, manage and care for water resources. Australia's recognition of Indigenous people's right to water is one of the weakest of any colonial countries (Moggridge & Thompson 2021). It is estimated that Indigenous water rights in the Murray–Darling Basin are less than 0.01% of diversions (Jackson et al. 2021). Indigenous people and communities have been left out of key conversations about future water-use planning and management.

The rights of Indigenous Australians to participate in the cultural practice of fishing is an ongoing issue. Some states have recognised Indigenous fishing rights; however, they do not extend to the full realisation of rights in UNDRIP.

Indigenous cultural and intellectual property

Indigenous people have a right to use and protect their Indigenous knowledge and knowledge systems. This is at the heart of Indigenous identity (Terri Janke and Company 2018). Cultural and intellectual property encompasses traditional cultural expression such as songs, dance and languages, as well as traditional knowledge such as medicinal and ecological knowledge. Indigenous knowledge of place, time and being informs how Indigenous people connect with community and care for Country. However, Indigenous knowledge has been, and continues to be, subject to widespread appropriation and exploitation, nationally and internationally. The mass and sustained appropriation of Indigenous knowledge dismantles the intricate and nuanced knowledge systems that have been cultivated by Indigenous peoples for thousands of years (Terri Janke and Company 2018).

The appropriation and misuse of Indigenous knowledge and Indigenous cultural and intellectual property (ICIP) continues to be a problem for Indigenous people. The more demand for Indigenous knowledge in commercial activities grows, particularly regarding plants, the more Indigenous people fear misappropriation and exploitation by non-Indigenous entities. Biopiracy of Indigenous knowledge denies Indigenous people the benefit-sharing and economic advantages flowing from the use of their Indigenous knowledge and genetic resources on their lands and waters.

International legal instruments such as the Convention on Biological Diversity and its Nagoya Protocol recognise this issue and seek to compel benefit-sharing arrangements. However, there is an absence of

a comprehensive legal framework in Australia for free, prior informed consent to the use of Indigenous knowledge (see ‘Indigenous cultural and intellectual property and data’).

Only within the past 40 years has the issue of Indigenous knowledge and ICIP been discussed by government and organisations. Significantly, Article 31 of UNDRIP mandates that Indigenous people have a right to ‘maintain, control, protect and develop their cultural heritage, traditional knowledge and traditional cultural expression ... and their intellectual property over this knowledge and expression’. The right of Indigenous people to freely use and develop their Indigenous knowledge and ICIP is interconnected with their right to self-determination.

There are laws for access and benefit sharing in the Commonwealth, the Northern Territory and Queensland. However, the lack of protection nationally allows biopiracy to continue. In 2020, Queensland amended its *Biodiscovery Act 2004* to comply with the Nagoya Protocol. This Act now requires anyone engaging in biodiscovery to take all reasonable measures to reach an agreement with Indigenous knowledge custodians. Indigenous people continue to ask for implementation of the Nagoya Protocol – this includes proper attribution; benefit sharing; and free, informed and prior consent.

Data and lack of access to data have also been identified as key limitations to Indigenous self-determination. Much knowledge and other Indigenous data have been collected by government, universities and research agencies, and Indigenous people call for greater access to, and control over, their data (see ‘Indigenous cultural and intellectual property and data’).

Cumulative pressures

Cumulative pressures are pressures that are acting in combination with other past, present and future pressures. Multiple pressures interact with each other to produce additive, synergistic or antagonistic effects. Cumulative impacts may arise even if the pressures occurred at different times but in the same space (due to the long-term effects of past pressures). A key challenge for the sustainable management of Australia's marine and terrestrial environments is cumulative impacts from the interactions and feedbacks among multiple pressures.

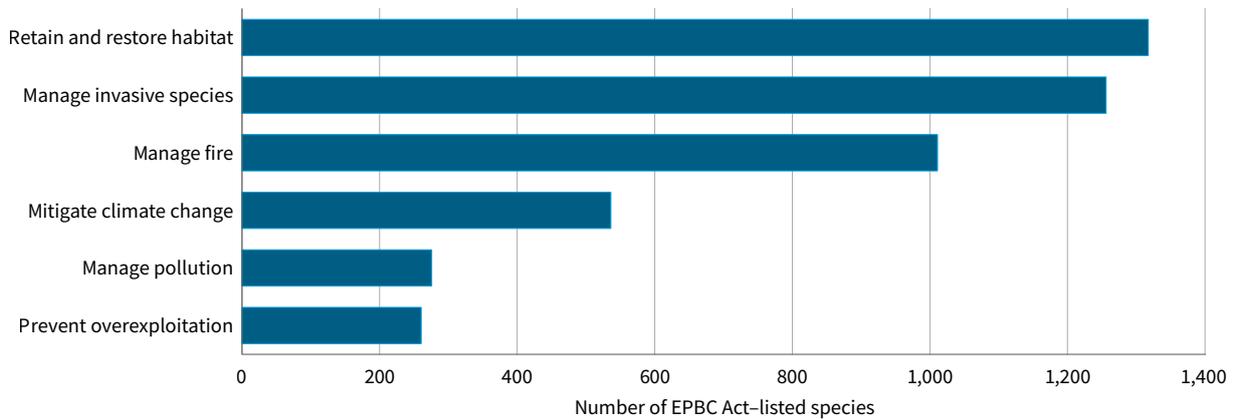
Ecosystems and species seldom respond to pressures in isolation, and the most abrupt changes in ecological systems frequently arise from interactions among multiple pressures rather than changes to a single pressure. Compounding effects erode ecosystem resilience, leaving a system more susceptible to future change. The cumulative effect of multiple pressures over many decades across whole regions and landscapes and seascapes, especially within and around intensive land-use and marine-use zones, exacerbates fragmentation and further degrades the quality of remnant native habitats, which support many threatened plants and animals. Extreme events can also provide a tipping point that overwhelms systems under multiple pressures.

Research has shown that the combination of pressures leads to most of the declines in our threatened species (see 'Threatened species'). Impacts are compounded by the current and forecast impacts of climate change – for example, on land, more heat extremes; more time in drought; more intense, short-duration storms; continued decreases in cool-season rainfall; and a longer fire season for southern and eastern Australia. Rainfall declines result in a decrease in river flows, with implications

for water availability for all purposes. Reduced availability of surface water can increase demand for groundwater, with negative impacts on groundwater-dependent ecosystems. In the ocean, the cumulative impacts of climate change affect the condition of Australia's rocky reefs and algal beds – for example, rising temperatures and heatwaves; increasing flows of warm, nutrient-poor tropical waters into temperate regions; and overgrazing by sea urchins and tropical fish herbivores. These impacts are facilitated and compounded by the removal of urchin and fish predators by commercial and recreational fishing.

More and more we are discovering that most threatened species and ecosystems cannot be recovered by managing a single threat; 86% of Australia's threatened species are subject to multiple threats that result in habitat destruction and degradation, such as logging, mining, urbanisation and agriculture. To deal with these cumulative pressures, the key conservation response is habitat retention and restoration (Kearney et al. 2020). Increasingly, species require multiple integrated management responses to address their threats (Figure 24). However, there remains much uncertainty about how to define and predict the ecological impacts from cumulative pressures.

Cumulative losses of habitat are critical for understanding the overall impact, yet actions referred under the EPBC Act are currently individually assessed. Of the 7.7 million hectares of land habitat cleared between 2000 and 2017, 7.1 million hectares (93%) was not referred to the Australian Government for assessment. Between 2000 and 2017, only 4 of 3,058 referred actions to remove land habitat have been deemed 'clearly unacceptable' (0.1%), 2,252 have been deemed 'not a controlled action' (i.e. not requiring approval to proceed; 74%), and 806



Source: Kearney et al. (2020)

Figure 24 Number of Australian threatened species that would benefit from different management responses

have been deemed a ‘controlled action’ (26%). Since the commencement of the EPBC Act, a significant amount of habitat destruction has either not been assessed or has been approved, albeit sometimes with conditions, resulting in considerable cumulative habitat loss.

The interaction between weed and feral animal invasion and fire is of increasing concern as climate change continues to alter fire regimes. Invasive grasses such as gamba grass (*Andropogon gayanus*) and buffel grass (*Cenchrus ciliaris*) increase fuel loads and fire intensities, sometimes dramatically altering ecosystem structure and function, and forming dense infestations that increase fire connectivity. Intense fires can also exacerbate other pressures – for example, feral cats are more abundant and hunt more successfully in areas that have experienced recent or severe fires (Davies et al. 2020, Legge et al. 2020).

Many pressures, historical and current, impact our inland waters and coasts – including habitat fragmentation and degradation; clearing of catchments; the volume and timing of extractions for use; dams and weirs altering flow patterns and blocking movement of fish; rivers disconnected from their floodplains; changes in nutrients and temperature;

contaminant pollution; introduced weeds and pests; and the disruption of overland flows and aquifers. In the remote and northern parts of the country, these impacts are less significant or more localised, but aquatic ecosystems in the south are highly affected. Understanding these cumulative impacts requires long-term detailed studies, combined with integrated monitoring methods (Sparrow et al. 2020, Taylor & Lindenmayer 2020).

Run-off is affected not only by total rainfall, but also by changes in seasonal patterns and catchment condition. It has been demonstrated that run-off following rain is significantly reduced during droughts. In the northern Murray–Darling Basin, run-off appears to have been more severely reduced during recent droughts than in previous droughts, compounding the impacts on downstream long-term water availability (Vertessy et al. 2019). Low water inflows throughout the system may persist long after the end of the dry weather patterns.

The drying out of wetlands and areas of acid sulfate soils can affect the quality of water and soil. More frequent and severe bushfires also severely impact water catchments and cause water quality impacts if there are subsequent

large rainfall events – from ash, sediment, nutrients and debris. Although storage inflows from deforested catchments may increase in the short term, regrowth of catchment vegetation will result in changes to water yields for many years. Some of these impacts may be the consequence of failures of knowledge,

management or regulation, demonstrating that the challenges of water management are complex, interconnected, and increasingly amplified by climate change.

✓ **Assessment** Cumulative pressures



The great majority of Australia’s ecosystems and threatened species are impacted by multiple pressures, which often accumulate and amplify each other. Despite awareness of the importance of cumulative pressures, management actions often target a single pressure, resulting in declines in threatened species populations and loss of important habitats.

Assessments of impact are high
Assessments of trend are deteriorating
Related to United Nations Sustainable Development Goal targets 11.3, 11.b, 12.2

Pressure on our environment

Human pressures combine to threaten our environment.

Population, climate change and industry each put pressure on our environment. When combined, the threat increases and our environment is damaged – sometimes destroyed.



Land clearing

Our environment can handle some pressure, and often bounces back when the pressure is eased.



More pressure has a bigger impact, and our environment may take longer to recover.

Land clearing + drought



Multiple and more severe pressures can destroy our environment, affecting everything that relies on it – including us.

Land clearing + drought + invasive species



But we can help. Reducing or removing pressures can help our environment heal and withstand other pressures.



Management

Environment management framework

The management of Australia's environment involves many components and many organisations. Most land management is undertaken by landholders, Indigenous communities, nongovernment organisations, industry and volunteers, but only a very small proportion of this management is undertaken with the direct purpose of maintaining or improving environmental values. Conversely, most marine management is undertaken by government (both national and state and territory), with significant efforts directed towards environmental management.

Governments at local, regional, state, territory and national levels – in collaboration with partners – implement a broad range of policies and programs designed to tackle major threats to both the terrestrial and marine environments. These include management of protected areas, protection of heritage, and measures to protect threatened species and ecological communities, and to promote their longer-term recovery.

Australia's Indigenous people have cared for the lands and seas over countless generations and continue to do so today. Their role in caring for Country is far more than environmental management – it is responsibility and stewardship of the land and seas, caring for Country as if land and seas, and plants and animals are kin. There

is a complex web of government laws and agreements that relate to Indigenous people and the environment, but – overall – they are not adequate to deliver the rights that Indigenous people seek. Indigenous people are severely impacted in their ability to continue to manage Country and ensure its continued health. The mismanagement of Country that has occurred since colonisation began drives many Indigenous communities to demand management options that recognise and include Indigenous knowledge and Indigenous participation. Indigenous people continue to call for legislative recognition of their right to care for Country

Legislation, policy and international obligations

Environmental management in Australia is guided by policy and legislation administered at local, state and territory, and national levels, ranging from broad programs to sector-specific regulation (e.g. mining, commercial fishing, offshore oil and gas industries, urban development). Legislation often reflects commitments made under international conventions (e.g. Convention Concerning the Protection of the World Cultural and Natural Heritage, United Nations [UN] Convention on the Law of the Sea), as well as more specific regulations tailored for Australia's unique environment.

✓ **Assessment** Legislation, policy and international obligations



Australia is signatory to many international agreements, which are reflected in legislation and programs. Implementation of our obligations can be effective, although in some areas the rate of progress is inadequate. A recent review of the *Environment Protection and Biodiversity Conservation Act 1999* found that the Act and its implementation were insufficient to protect our environmental values. The legal framework in Australia for Indigenous rights and heritage is regarded as inadequate to fulfil our obligations to care for Country.

Assessments of management effectiveness range from partially effective to effective

Assessments of trend range from deteriorating to improving

Related to United Nations Sustainable Development Goal targets 2.3, 6.4, 6.5, 8.4, 8.9, 11.4, 11.6, 12.2, 12.4, 13.1, 14.2, 14.5, 14.b, 15.1, 15.7

Assessment ratings

For assessments in the 'Management' section

-  **Very effective:** Management measures maintain or improve the state of environment and secure it against known pressures.
-  **Effective:** Management measures maintain or improve the state of the environment, but pressures remain as significant factors that degrade environment values.
-  **Partially effective:** Management measures have limited impact on maintaining or improving the state of the environment.
-  **Ineffective:** Management measures are failing to stop substantial declines in the state of the environment.

Trend

-  **Improving:** The situation has improved since the previous assessment (2016 state of the environment report).
-  **Stable:** The situation has been stable since the previous assessment.
-  **Deteriorating:** The situation has deteriorated since the previous assessment.
-  **Unclear:** It is unclear how the situation has changed since the previous assessment.

International obligations and treaties

Australia is a signatory to many international agreements and conventions related to environmental protection and conservation. These international agreements impose obligations on Australia, which drive actions to deal with the specific matters of concern of the agreement. Our obligations and actions are often reflected in national, and state and territory legislation or in government programs.

International environmental and heritage agreements that Australia has committed to are:

- Conservation and protection
 - Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services 2012
 - Convention on Biological Diversity and the Nagoya Protocol 2010
 - Forum on Forests 2000
 - Montreal Process for the Conservation and Sustainable Management of Temperate and Boreal Forests 1994
 - Convention to Combat Desertification 1994
 - Convention on Biological Diversity 1993
 - Convention on the Conservation of Antarctic Marine Living Resources 1980
 - Convention on the Conservation of Migratory Species of Wild Animals 1979
 - Convention Concerning the Protection of the World Cultural and Natural Heritage 1972
 - Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat 1971
 - International Council on Monuments and Sites 1965
 - Antarctic Treaty System 1959
 - International Plant Protection Convention 1951
- International Union for Conservation of Nature 1948 (nonbinding)
- Development and industry
 - 2030 Agenda for Sustainable Development
 - Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing 2016
 - International Tropical Timber Agreement 2006
 - International Treaty on Plant Genetic Resources for Food and Agriculture 2001
 - Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal 1992
 - Extractive Industries Transparency Initiative 2003
 - Convention on the Law of the Sea Agreement on Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks 2001
 - Convention on International Trade in Endangered Species of Wild Fauna and Flora 1963
 - International Convention for the Regulation of Whaling 1946
- Climate change
 - Paris Agreement under the United Nations Framework Convention on Climate Change 2016
 - Kyoto Protocol to the United Nations Framework Convention on Climate Change 1997
 - United Nations Framework Convention on Climate Change 1992
- Rights and management
 - Declaration on the Rights of Indigenous Peoples 2007 (see ‘Indigenous governance, rights and access’)

- Sendai Framework for Disaster Risk Reduction 2015–2030
- World Trade Organization Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) 1995
- International Seabed Authority 1994
- Convention on the Law of the Sea 1982
- Pollution and contamination
 - Minamata Convention on Mercury 2013
 - International Civil Aviation Organization Assembly Resolution 2010
 - Stockholm Convention on Persistent Organic Pollutants 2001
 - Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000
 - Montreal Protocol on Substances that Deplete the Ozone Layer 1987
 - International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978
 - Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972.

Climate change

The Australian Government has recently committed to net zero greenhouse gas emissions by 2050, and committed to a 26–28% reduction on 2005 levels of emissions by 2030 under the 2015 Paris Agreement. This represents Australia’s ‘nationally determined contribution’ (NDC) to global greenhouse gas emissions reductions. An earlier 2010 United Nations Framework Convention on Climate Change (UNFCCC) agreement (Cancun) commits Australia to a 5% decrease in emissions on 2000 levels by 2020.

NDCs vary from country to country, depending on their circumstances. It is currently not known whether Australia will achieve its target annual value in 2030.

Current and projected levels of success of national, and state and territory emissions abatement programs suggest that Australia’s national 2020 target (5% reduction below 2000 levels) has been achieved, although this will not be formally assessed and reported to the UNFCCC until April 2022. Emissions for the year to December 2020 were 20.1% below the 2005 baseline, following a dip in emissions due to the reduction in human activity during the COVID-19 pandemic lockdowns. This means that a further reduction of 6–8% on 2020 levels is required by 2030 to reach the target of 26–28% below 2005 levels. This will require a slightly faster annual rate of emissions reduction than that achieved between 2013 and 2019 (before the pandemic). A substantially increased rate of emissions reduction overall will be required to achieve net zero emissions by 2050 or earlier.

Sustainable development

The UN Sustainable Development Goals (SDGs) are a key component of a major international agreement that came into force in 2015 (the 2030 Agenda for Sustainable Development) and have become more important in the past 5 years, creating a more holistic view of how we manage our environment. There has been a substantial increase in reporting by government, industry and not-for-profit agencies against the SDGs. The Australian Government has committed to the SDGs (HLPF 2018):

Australia has long recognised the role of sustainable development in ensuring the wellbeing of the country and its people. Government legislation, regulation and policy already drives us towards many of the environmental, social and economic outcomes enshrined in the SDGs. As approaches and circumstances evolve, the SDGs provide a framework through which governments, businesses, organisations and individuals can conceive of a problem

or objective and devise collective action through partnership to drive progress.

The 17 SDGs are not legally binding, but all national governments are expected to take ownership of, and establish national frameworks for, achieving them. The Australian Government has the primary responsibility for follow-up and review of the progress made in implementing the goals. In 2018, it produced Australia's first voluntary national review on implementation of the SDGs, and has established a national reporting platform to provide a single point of access for Australian Government data on the SDG indicators (DFAT 2021).

In this report, we have attempted to communicate how the state of environment assessments align with SDG targets. This will help stakeholders to understand links between the state, pressures and management of Australia's environment and internationally accepted SDGs.

Environmental protection

The Convention on Biological Diversity is a broad agreement covering the sustainable use and conservation of biodiversity, which obliges all parties to develop and implement national biodiversity strategies and action plans, and report on national implementation of the convention. Australia submitted its 6th National Report to the Convention on Biological Diversity (2014–20) in March 2020 (DAWE 2020i). The report detailed measures, activities and investments contributing to Australia's national targets and the global 2020 Aichi targets (see 'Protected areas'). Good progress was reported across targets related to increased engagement with Indigenous people in the management of land and sea Country, increased transboundary control of terrestrial feral animals, better alignment of national and subnational measures for addressing key threats to Australia's

biodiversity, and protection in the terrestrial and marine National Reserve System.

However, this protection is mainly partial, in International Union for Conservation of Nature (IUCN) categories III to VI, and may not meet ecological or social goals. In addition, progress against most other measures was, at best, limited.

The Australian Government has entered into several regional international agreements associated with the Convention on the Conservation of Migratory Species of Wild Animals (often referred to as the Bonn Convention), including bilateral migratory bird agreements with China (CAMBA), Japan (JAMBA) and the Republic of Korea (ROKAMBA); the Agreement on the Conservation of Albatrosses and Petrels; and the East Asian – Australasian Flyway Partnership (see 'Migratory species'). CAMBA, JAMBA and ROKAMBA provide an important mechanism for pursuing conservation outcomes for migratory birds. The Australian Government's Wildlife Conservation Plan for Migratory Shorebirds identifies research and management actions to protect migratory shorebirds in Australia. All 35 species covered by the plan are listed migratory species under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

As a member of the 14-nation High-Level Panel for a Sustainable Ocean Economy, the Australian Prime Minister has committed to sustainably managing 100% of the ocean area under national jurisdiction, guided by a sustainable ocean plan, by 2025. This sustainable plan is to 'be in line with the 2030 Agenda for Sustainable Development, build on integrated ocean management and ecosystem knowledge, address pressures from all land and sea-based sources, and take account of the predicted impacts of climate change' (HLPSOC 2020).

Australia has been an active voice for World Heritage conservation during its terms as a member of the World Heritage Committee (2007–11 and 2017–21), during which Australia led the development of the Convention's Strategic Action Plan. Australia's 2 key nongovernment heritage organisations – the Australian Committee of the International Union for Conservation of Nature, and the Australia International Council on Monuments and Sites (ICOMOS) – are active at the international level. In relation to cultural heritage, there are 2 important international instruments – to both of which Australia is not yet a signatory: the United Nations Educational, Scientific and Cultural Organization (UNESCO) Convention on the Protection of the Underwater Cultural Heritage 2001 and the Convention for the Safeguarding of the Intangible Cultural Heritage 2003. There are also various international declarations, charters and guidance documents related to heritage that form important guidance for cultural heritage practice (e.g. the Sendai Framework for Disaster Risk Reduction 2015–2030, UNESCO's Recommendation on the Historic Urban Landscape 2011 (UNESCO 2011), and the ICOMOS Nara Document on Authenticity 1994 and Xi'an Declaration on the Conservation of the Setting of Heritage Structures, Sites and Areas 2005). Their formal endorsement by the Australian and state and territory governments would be a useful action towards establishing national standards for cultural heritage practice in Australia.

Australia plays a key role in the management of Antarctica and the Southern Ocean through the international Antarctic Treaty system established in 1959. The treaty, originally signed by 12 countries whose scientists were in Antarctica at the time, is now supported by 54 nations that conduct substantial scientific research activity in the region. Seven nations, including Australia, have territorial claims over Antarctica and administer these areas through

the provisions of the treaty and its suite of international agreements. These establish Antarctica as a natural reserve devoted to peace and science, and environmental protection. In 1981, the Convention on the Conservation of Antarctic Marine Living Resources was added. All of Antarctica has a high level of environmental protection; however, certain terrestrial and marine areas of outstanding environmental, scientific, historic, aesthetic or wilderness value are specially protected areas, with even higher levels of protection. The recent challenges of climate change, increasing human activities and the competing geopolitical interests of treaty member nations may need new regulatory instruments to ensure the continued protection of Antarctica (Hemmings 2017).

National, state and territory legislation and policy

Australia's federal system of government places the vast majority of land and coastal sea management responsibilities with our 8 states and territories. These management responsibilities include the implementation of most forms of environmental protections such as protected areas, heritage, managing vegetation clearance and threatened species management. The states also govern separate legislation that establishes and controls local government.

The Australian Government has legislation and policies relating to overarching Australian environment concerns and sectors. Australia's territorial sea (from 3 out to 12 nautical miles) and the much larger 200 nautical mile exclusive economic zone and extended continental shelf (in some areas well beyond 200 nautical miles) are governed by the Australian Government. The main environment legislation in Australia is the EPBC Act, although other legislation covers specific

resources and sectors (e.g. *Water Act 2007*; see 'Water resources').

Environment Protection and Biodiversity Conservation Act 1999

The EPBC Act is Australia's primary national environmental legislation. It has several functions, including:

- providing for the protection of Australia's environment, including identification and management of the listing of heritage places, World Heritage, threatened species and communities
- protecting matters of national environmental significance, which are
 - nationally threatened species and ecological communities
 - migratory species
 - World Heritage properties
 - national heritage places
 - wetlands of international importance (often called 'Ramsar' wetlands after the international treaty under which such wetlands are listed)
 - Commonwealth marine areas
 - the Great Barrier Reef Marine Park
 - nuclear actions (including uranium mining)
 - a water resource, in relation to coal-seam gas development and large coalmining development
- giving effect to Australia's international environmental obligations (see 'International obligations and treaties').

Review of the EPBC Act

The EPBC Act has undergone considerable scrutiny in the past 5 years:

- A 10-year statutory independent review commenced in 2019, and the final report was delivered in October 2020 (Samuel 2020).
- An independent review of interactions between the EPBC Act and the agriculture sector was delivered in 2018 (Craik 2018).
- The Australian National Audit Office audit found that the government's administration of referrals, assessments and approvals of controlled actions under the EPBC Act is not effective, with an absence of effective monitoring, reporting and evaluation arrangements that limits the ability of the department to measure its contribution to the objectives of the EPBC Act (ANAO 2020).
- Several inquiries were conducted by Parliament into aspects of environmental regulation under the EPBC Act, including an inquiry into Australia's faunal extinction crisis, the effect of red tape on environmental assessment and approvals, the construction of the Perth Freight Link with significant environmental breaches, and the destruction of Indigenous heritage sites at Juukan Gorge (see 'Indigenous heritage').

The 2020 Samuel Review concluded that the Australian Government is not able to effectively protect significant and important environmental matters. Key findings of the review include the following:

- Good outcomes for the environment cannot be achieved under the current laws.
- Significant efforts are made to assess and list threatened species; however, once listed, not enough is done to deliver improved outcomes for them.
- Cumulative impacts on the environment are not systematically considered. Decisions

are made on a project-by-project basis, and only when impacts exceed a certain size; this results in net environmental decline.

- The EPBC Act does not facilitate the restoration of the environment, and needs to shift from permitting gradual decline to halting decline and restoring the environment.
- Key threats are not effectively addressed. There is very limited use of comprehensive plans to adaptively manage the environment on a landscape or regional scale.
- Addressing the challenge of adapting to climate change is an implied, rather than a central, consideration.
- The EPBC Act is not fulfilling its objectives as they relate to the roles of Indigenous Australians in protecting and conserving biodiversity, and promoting the respectful inclusion of their knowledge, and does not meet the aspirations of Traditional Owners for managing their land. Indigenous knowledge and views are diluted in the formal provision of advice to decision-makers. This reflects an overall culture of tokenism and symbolism, rather than one of genuine inclusion of Indigenous Australians.

The review made 38 recommendations, including accreditation of state and territory environmental approvals processes; improvements to Indigenous heritage protection laws; actions to support environmental restoration; and integrated data, monitoring and evaluation systems. A major recommendation of the review is the establishment of legally enforceable national environmental standards, which would set clear requirements for those who interact with the EPBC Act and clear bounds for decision-makers (see 'National framework for environmental standards').

In response, the government has committed to a staged program of reforms. It released a

pathway for reforming national environmental law in June 2021.

EPBC Act administration

In 2020, the Australian National Audit Office completed an assessment of the effectiveness of the administration and governance of EPBC Act referrals, assessments and approval of controlled actions. The assessment found many shortcomings.

Before 1 July 2019, 6,253 proposed actions had been referred to the Minister for the Environment: 5,088 of these actions were approved (including 1,034 approved with conditions), and 21 actions were not approved. The report found that the current regulatory approach was not proportionate to environmental risk; the administration of referrals, assessments and approvals under the Act was not effective; and governance arrangements were not sound (ANAO 2020). Regulation is not supported by appropriate systems and processes, and there are no arrangements in place to measure or improve efficiency. The assessment also found that, for the approvals examined, 79% contained conditions that did not comply with procedural guidance, or contained clerical or administrative errors.

It also found that the government is not well positioned to evaluate its contribution to the objectives of the EPBC Act. Based on these findings, recommendations were made to strengthen governance arrangements and support the effective administration of referrals, assessments and approvals. All the recommendations were agreed to by the government, including internal and external performance measures on the effectiveness and efficiency of its regulation of referrals, assessments and approvals.

EPBC Act and state and territory jurisdictions

Each state and territory is responsible for the management of the living and nonliving resources found in that jurisdiction, but how these responsibilities are given effect varies markedly between the jurisdictions. The EPBC Act also has effect where resource management becomes a matter of national environmental significance. The Samuel Review noted that there is duplication between the EPBC Act and state and territory regulatory processes, and recommended that the EPBC Act should enable the Australian Government to recognise and accredit the regulatory processes and environmental policies, plans and programs of other parties, including states and territories.

The EPBC Act currently allows for the accreditation of state and territory laws

and management systems for development assessments and approvals. Bilateral agreements between the Australian Government and the states and territories contain provisions to support information sharing and commitments to cooperate in monitoring compliance with conditions of approval, including through establishing complementary arrangements. To date, however, no complementary arrangements have been established.

Management approaches

Several broad approaches are used in Australian environmental management; some are well established, and some are still in their infancy. Indigenous management and stewardship are increasing.

✓ Assessment Management approaches



Several environmental management approaches are in place or under development in Australia, including integrated management, Indigenous management and co-management. Progress on these approaches varies, and is made more effective by engagement with local and Indigenous communities and stewardship groups.

Assessments of management effectiveness range from partially effective to effective

Assessments of trend range from deteriorating to improving

Related to United Nations Sustainable Development Goal targets 2.3, 6.1, 6.4, 6.5, 6.b, 7.2, 11.3, 11.4, 11.6, 11.a, 11.b, 12.2, 12.4, 12.8, 13.1, 13.2, 14.1, 14.2, 14.4, 14.5, 14.6, 15.1, 15.5, 15.6

Integrated management

Integration in management can be across multiple dimensions, including spatial, hydrological, sectoral, jurisdictional, community, Indigenous and non-Indigenous values. The Australian Committee of the International Union for Conservation of Nature (Zischka et al. 2013) calls for all sectors ‘to break down jurisdictional silos and boundaries and create new models and partnerships for innovative conservation management and financing’ as one of the priorities for conservation.

Key to achieving an effective, national, integrated management framework are as follows:

- Recognition of the different capacities of the different levels of government for management, and development of effective mechanisms to achieve objectives. Broadening and strengthening the role of national councils and committees is vital, as is reviewing the Intergovernmental Agreement on the Environment and other major national agreements.
- Greater standardisation or uniformity of approaches to management. Areas that would benefit from standardisation include national environmental standards, environmental impact assessments, risk management (in particular, in response to climate change), and data capture and management (see Samuel 2020).
- Providing for all key stakeholder groups to be engaged in an active and balanced way that is respectful and promotes environmental protection (see also ‘Stewardship’).
- Greater inclusion of Indigenous people, including in decision-making roles, to ensure that Indigenous rights are respected.

One of the most pressing issues for integrated management is climate change (see ‘Climate

change mitigation and adaptation’). As a pressure affecting all landscapes and seascapes, climate change should be considered and included in all management planning of sufficient scale, as well as adoption of new adaptive management measures. The management of carbon requires greater integration with management of all other natural capital assets. Restoration of vegetation, soil, biodiversity and carbon is an integrated process, which cannot be achieved by considering each of these in isolation. Thus schemes that encourage co-benefits across different types of natural capital are more likely to succeed at landscape scales.

Over the past 2 decades, there has been a slow shift towards more integrated conservation management, from species-centric conservation to greater landscape- and seascape-scale conservation planning that aims to support both social and ecological outcomes. For example, approximately 7.8 million hectares of agricultural land has been set aside for protection or conservation purposes (ABS 2021). The fundamental tenet of this type of conservation is that biodiversity can persist in landscapes and seascapes if the different uses are carefully managed, and if connectivity supports dispersal and other movement by a range of species (Godfree et al. 2017). The incorporation of conservation practices such as ecological restoration, revegetation and agroforestry is gradually transforming Australian agricultural practice, although actions are still fragmented, and many technical, socio-economic and policy challenges limit biodiversity gains in agricultural systems (Campbell et al. 2017).

Integrated land management includes restoration initiatives to mitigate pressures or protect species, including through active planting (revegetation) or by removing pressures so that ecosystems can recover. Within Landcare projects, the most common

management interventions are weed control, feral animal control and habitat improvement or regeneration (Capon et al. 2020). Integration of different management actions can involve a large number and diversity of stakeholders, with conservation activities often delivered by locally based groups.

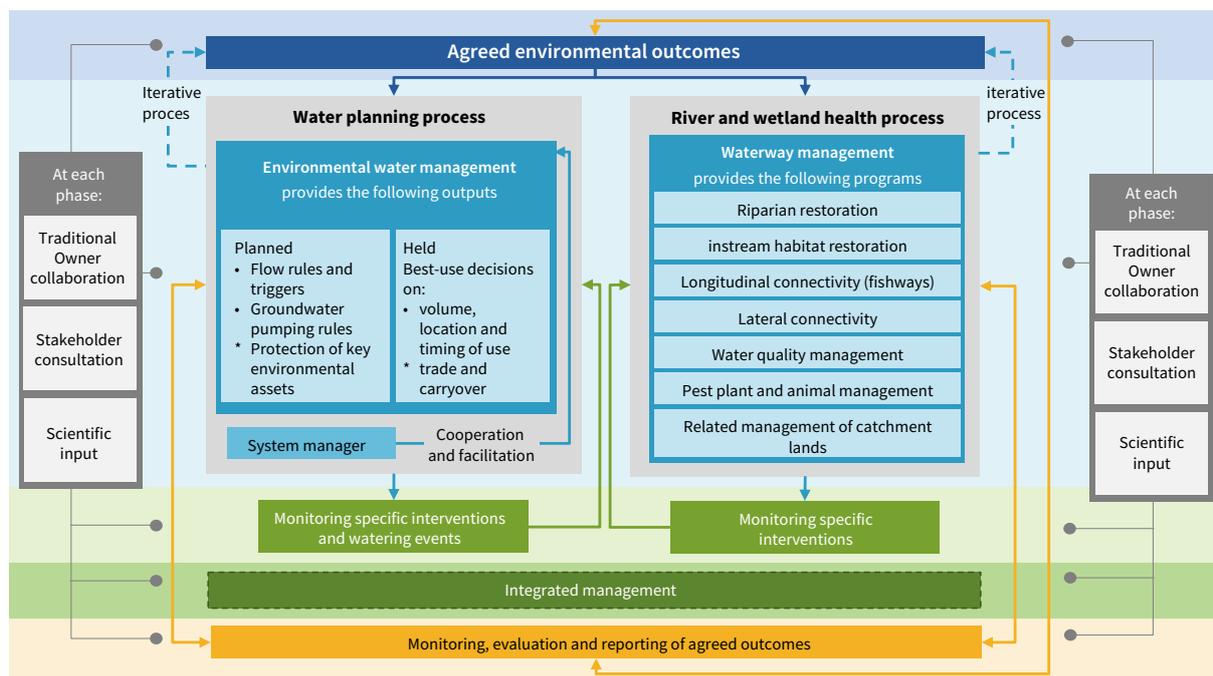
The need for better integration of, and effective adaptation to, climate change in coastal management is widely recognised, but implementation requires a much greater level of collaboration between Australian, state and territory, and local governments. Coastal management in Australia lacks national coordination and integration, largely because of complex governance structures and blocking mechanisms (Harvey 2016). Previous attempts to implement a national approach to integrated coastal 'zone' management in Australia have failed (Clarke & Harvey 2013), but there has been some success in developing a national response to assess coastal management risks associated with climate change. One of the best examples of integrated management in Australia is the ongoing effort to preserve the Great Barrier Reef (see 'Climate change adaptation').

Inland water management in Australia also suffers from lack of integrated management. Flow impacts (e.g. water extraction, changes in catchment hydrology) and nonflow impacts (e.g. grazing, introduced species, loss of instream habitat) are usually subject to different management accountabilities and planning arrangements. The Productivity Commission has identified the need for institutional oversight responsibility for wetland and waterway management, including collaborative planning processes inclusive of Traditional Owners; clear environmental objectives, targets and priorities; oversight of natural resource management actions, and facilitation of on-ground delivery

of environmental water (Productivity Commission 2021b) (Figure 25). An example of a more integrated approach is found in Victoria, where Catchment Management Authorities (CMAs) are responsible for the integrated management of land, water and biodiversity; regional priorities for environmental water management; and facilitation of the delivery of environmental water. Nine (of 10) CMAs, and Melbourne Water for the 10th region, are designated waterway managers with specific responsibilities to develop and deliver regional waterway strategies and associated action plans.

An area of integration that has achieved good progress in recent years is recognition of the connections between groundwater and surface water systems. States and territories have made significant progress in recognising and managing physically connected systems through either integrated or linked planning processes (Productivity Commission 2021b).

In urban areas, integrated water cycle management (IWCM), which integrates water supply, wastewater management and stormwater management, offers opportunities to improve the resilience of water systems by increasing the diversity of water supply – for example, keeping stormwater in the landscape to deliver amenity and environmental benefits. However, shifting to an IWCM approach is complex and can incur substantial costs, which may exceed benefits. Integrated planning that incorporates water supply, wastewater disposal and stormwater management is a first step, noting that stormwater is subject to separate institutional arrangements in many cities. Integrated management also calls for a clear interface and consistent timeframes between land and water planning (Productivity Commission 2020b).



Source: Productivity Commission (2021b)

Figure 25 Integration of environmental and complementary waterway management at the local level, to achieve agreed outcomes

National framework for environmental standards

In April 2012, the Council of Australian Governments agreed to reform the administration of national environmental regulation to reduce duplication and double handling, while maintaining high environmental standards. However, there has been great difficulty in adopting a meaningful system. The 2020 independent review of the EPBC Act (Samuel 2020) recommended a series of reforms, including a set of enforceable national environmental standards. These standards would establish the requirements for the delivery of environmental outcomes, and therefore define the steps for decision-making. The review proposed that the suite of national environmental standards should include requirements relating to:

- ecologically sustainable development
- matters of national environmental significance

- transparent processes and robust decisions, including
 - judicial review
 - community consultation
- adequate assessment of impact, including climate impacts on matters of national environmental significance
- emissions profile disclosure
- Indigenous engagement and involvement in environmental decision-making
- monitoring, compliance and enforcement
- data and information
- environmental monitoring and evaluation of outcomes
- restoration and recovery
- wildlife permits and trade.

In 2021, the Australian Government introduced legislation to establish legally enforceable national environmental standards, and to

create an independent Environment Assurance Commissioner.

Indigenous management

Indigenous people have an obligation to care for Country. This has been the way that the land and seas of Australia have been managed and natural resources have been sustainably used for many tens of thousands of years; 'If you take care of Country, it will take care of you'. Since the beginning of colonisation, caring for Country practices have been interrupted and ignored and there has been a marked lack of opportunity in achieving Indigenous self-determination. Australian Indigenous people hold detailed knowledge on past and current environments and trends, and this knowledge is increasingly informing ecological understanding and conservation management. Indigenous knowledge and partnership can help our nation to manage our greatest environmental pressures, including climate change.

The role of Indigenous-led organisations and rangers is a key part of Indigenous people's ability to care for Country. Indigenous land and sea management (ILSM) is one of the fastest-growing sectors for Indigenous employment in Australia. ILSM involves objectives and activities such as management of fire, water, weeds and feral animals; monitoring and protection of threatened species; revegetation; harvesting of bush foods; pastoralism; and artistic work (Schultz et al. 2019). ILSM activities also support the wellbeing of Indigenous people (Larson et al. 2020), including high life satisfaction, high family wellbeing and general good health (Jones et al. 2018). Popular indicators used by Indigenous people to monitor the effectiveness of ILSM activities involve regular visits to Country for harvesting, resource management, and cultural obligations such

as intergenerational knowledge transfer and ceremony (Austin et al. 2018).

Indigenous knowledge and engagement

In caring for Country, Indigenous Australians draw on laws, knowledge and customs inherited from ancestors to look after the lands and seas of which they are Traditional Custodians. The protection of biodiversity is highly dependent on Indigenous people's knowledge, practices and cultural connections to land (Renwick et al. 2017). There is an urgent need to listen to Indigenous communities and to empower them to lead solutions that incorporate Indigenous knowledge and practices in environmental management, in line with the principles of caring for Country.

Indigenous people express a need for self-determination through greater involvement in all stages of development of caring for Country: policy, planning, performance delivery, and effectiveness and efficiency review. This involves including Indigenous people within the management system as valued partners, recognising traditional knowledge in environmental management, ensuring genuine engagement by government, ensuring Indigenous autonomy to care for Country, using localised community-led approaches in line with community needs, and providing adequate resourcing.

Co-design in Indigenous natural resource management supports the integration of Indigenous knowledge and western science. In recent years, Indigenous knowledge and values have been increasingly recognised in environmental management. For example, local report cards on coastal species have been created by some Traditional Owner groups (TSRA 2016, Nyamba Buru Yawuru 2021).

Other initiatives are bringing Indigenous knowledge systems into environmental

education curriculums and delivery. A review of the National Environmental Science Program (NESP) found that Indigenous engagement in environmental and climate science research has increased access to Indigenous knowledge and cultural practice. These contributions have enhanced scientific knowledge in threatened species, land and water management, fire management and climate change.

Future effective stewardship in Australia will depend on re-establishment of Indigenous connection to Country, and learning from, respecting and sharing Indigenous knowledge and practices. But much more work is required to align key legislation and policies with the aspirations of Traditional Owners for managing their land and sea Country. The continuing legacy of colonial management and disenfranchisement has broken down this connection.

To empower more Indigenous people in environmental management, ensuring cultural safety will be an important consideration. Cultural safety means providing an environment that is safe for people: where there is no assault, challenge or denial of their identity, who they are and what they need. It is about shared respect, shared meaning, shared knowledge and experience; learning, living and working together with dignity; and truly listening (Williams 2008). In 2019, the Victorian Department of Environment, Land, Water and Planning adopted an Indigenous-led Aboriginal Cultural Safety Framework (DELWP 2020).

The revitalisation of Indigenous fire management practices in Australia has been highlighted as an effective way to manage and improve the health of the landscape and improve Indigenous wellbeing outcomes. As well as reducing bushfire risk, promoting regeneration and supporting habitat, cultural burning can reduce smoke pollution and greenhouse gas emissions (Russell-Smith

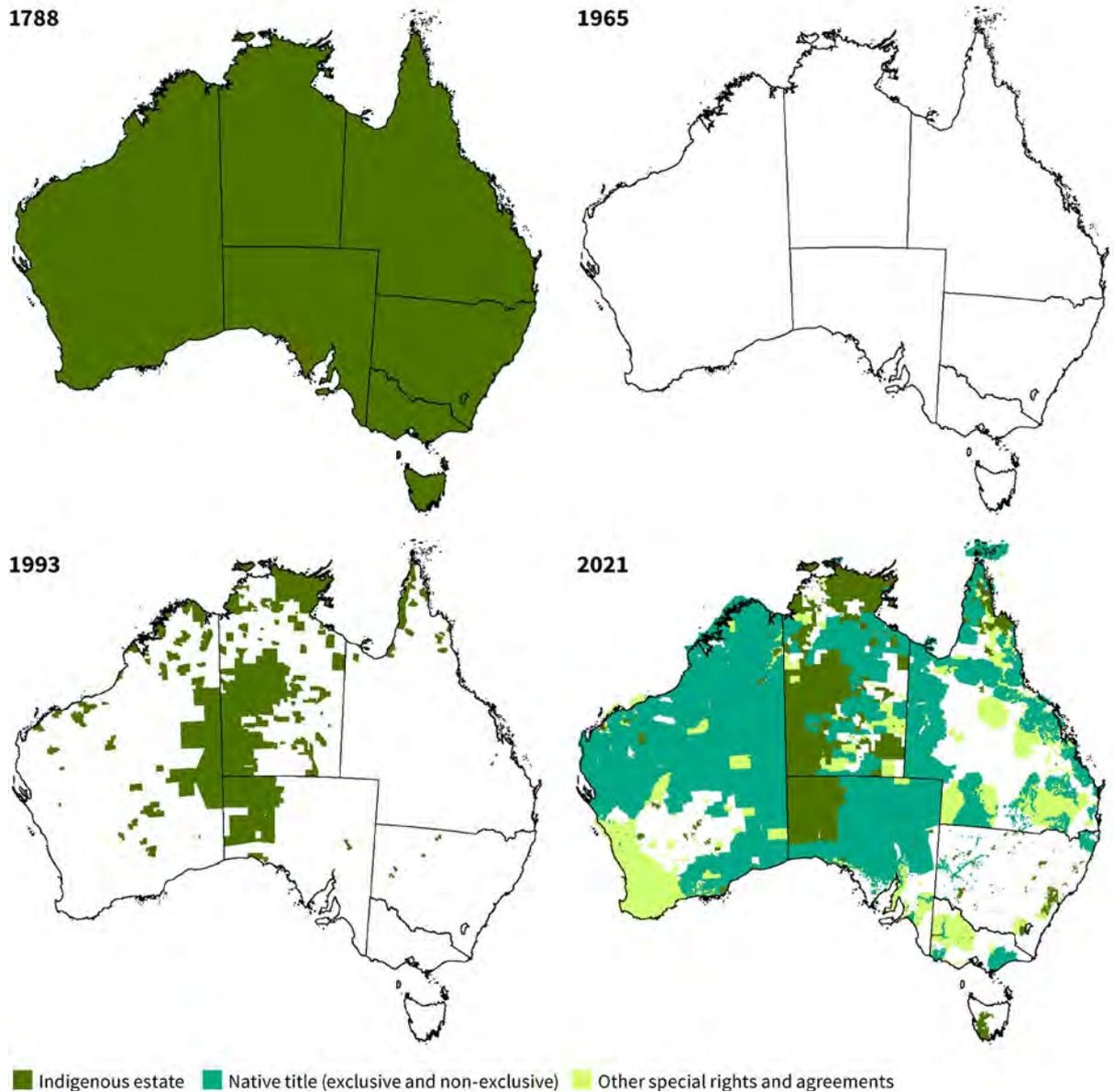
et al. 2013). Indigenous cultural burning and increased public awareness are evident in 70 recent case studies in south-eastern Australia documented in the media and academic literature (McKemey et al. 2020). The experience of the northern Australian savanna burning in the early dry season to reduce late dry-season hot fires has led to the extension of traditional fire practice into management regimes across Australia. Indigenous rangers are now involved in planned burns in the Australian Capital Territory, and traditional fire practices are being applied in some parts of New South Wales and central Victoria. However, with significant funding gaps, tenure impediments and policy barriers, Indigenous cultural burning remains underused – it is currently applied over less than 1% of the land area of Australia’s south-eastern states and territory (McKemey et al. 2020).

Indigenous tenure

The amount of land and sea Country owned and managed by Indigenous people and subject to native title rights is growing, as are the joint and sole management arrangements (Figure 26). The Indigenous estate – the land over which Indigenous people and communities have ownership, management, co-management or rights of use – occurs on all tenures and comprised 438 million hectares (57% of Australia) in 2016 (Jacobsen et al. 2020).

The complex legal system regarding Indigenous rights delivers different outcomes depending on the state or territory, and the nature of the right. For example, the Queensland Government, with the support of Traditional Owners, has converted more than 22 existing national parks to joint management (Cape York Peninsula Aboriginal Land), with Aboriginal freehold as the underlying tenure.

Expanding and intensifying development, and changes to seasons, species and extreme events associated with climate change, are



Source: Recreated using data sourced from National Native Trust Tribunal, Geoscience Australia, and the Australian Bureau of Agricultural and Resource Economics and Sciences

Figure 26 Changes to the Indigenous estate over time

increasingly impacting Indigenous people’s ability to connect to and enjoy land and sea Country. Indigenous people hold obligations to care for parts of Country that are not formally recognised within the Indigenous estate, and increasing urban and peri-urban development limits practices of caring for Country. Lands determined to have non-exclusive native title,

and lands subject to Indigenous Land Use Agreements, may restrict native titleholders’ ability to control access and determine the management of that land.

Indigenous Protected Areas (IPAs) provide a framework for Traditional Owners to govern and manage their customary estate to the benefit of Indigenous people, the environment

and the wider Australian community. In 2020, there were 78 IPAs, which make up 44% of the National Reserve System. ‘Legal’ mechanisms that may support Traditional Owner management of IPAs include legal ownership of lands, Indigenous customary resource use rights enshrined in legislation, protection of sacred sites and other cultural sites and areas through cultural heritage legislation, and protection of significant species and habitats through biodiversity conservation and natural resource management legislation (Gould et al. 2021). Other tools and mechanisms for Traditional Owner management of IPAs include management planning processes based on Indigenous cultural values and governance, Indigenous ranger groups (see ‘Indigenous wellbeing and economy’) and partnerships. But although Indigenous solely and jointly managed protected areas have rapidly grown over 2010–20, several issues remain, including short-term contracts, financial insecurity and tenure insecurity, which constrain the aspirations of Traditional Owners to care for their land over the long term.

Indigenous communities have been developing their own strategies and plans to manage sea Country in IPAs. In recent years, new resourcing models quarantined a significant proportion of the funds within a coastal program for Indigenous-led initiatives and projects. For the Great Barrier Reef, the Reef Trust Partnership is investing \$51.8 million in Traditional Owner reef protection, which equates to 10% of the value of the funds allocated. Also in the Great Barrier Reef, Traditional Use of Marine Resources Agreements provide Indigenous co-management over additional areas of sea Country (GBRMPA 2021b).

Challenges in Indigenous rights extend to water. Indigenous people’s relationships to water involve knowledge, story, law, cultural practices and responsibilities.

As a result of colonial mismanagement, industrialisation, water theft and failure to recognise Indigenous rights to water, the health and quality of waterways in Australia has deteriorated dramatically, as seen with the Barka or Darling River in Barkandji Country. Australian water management has typically resulted from top-down government decision-making because of pressures on water resources. Water resource planning processes have frequently struggled to engage Indigenous people in meaningful conversation or deliberation about future water use and planning options, and rather engaged in ineffective ‘consultations’ and ‘service delivery’ processes (Hemming et al. 2017). Environmental management plans, while containing provisions to engage and to consult with Indigenous communities, have failed to empower Indigenous aspirations; this has resulted in limited access and use of water, no economic self-determination and limited ability to care for Country (Moggridge & Thompson 2021).

Indigenous wellbeing and economy

There is strong evidence that participation in caring for Country activities by Indigenous people in Australia is associated with improved health and wellbeing outcomes, as well as greater participation in cultural activities and language knowledge (Schultz et al. 2019, Larson et al. 2020). The Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services found that recognising the knowledge and values of Indigenous and local people, and including them in environmental governance, often enhances quality of life, along with the conservation, restoration and sustainable use of nature (IPBES 2019).

Indigenous ranger programs are a powerful way to manage land and sea Country to achieve large-scale conservation outcomes, especially in IPAs (Social Ventures Australia

2016). Ranger groups are employed by Indigenous organisations, and national, state and territory land management entities. The IPA program, which is funded until 2028, supports 129 ranger groups and provides employment for more than 1,900 Indigenous Australians in full-time, part-time and casual positions. However, Indigenous people consider that IPA and Working on Country programs are difficult to access, and a common view of Working on Country programs is that there is not enough funding available. This view is also often held by park rangers, who have enough resources for day-to-day management, but not enough to tackle the big issues (see ‘Indigenous funding’).

Indigenous people are increasingly aspiring to grow livelihood and wellbeing benefits from commercial fisheries. Following the 2017 changes to the *Fisheries Management Act 1991*, requiring the Australian Fisheries Management Authority to consider the interests of Indigenous fishers in Commonwealth fisheries management decisions, the Commonwealth fisheries resource sharing framework was released in 2020. This was accompanied by a call for an Indigenous Engagement Strategy for fishing interests. Despite investment from the Fisheries Research and Development Corporation Indigenous Reference Group in several research projects, progress has been slow. There are currently no examples of co-management in Australian commercial fisheries, and traditional knowledge and objectives are constrained by institutional (top-down) governance and policy obligations (Hunter & Fischer 2021).

Indigenous cultural and intellectual property and data

Just as the theft of Indigenous art has been a long-term concern for Indigenous people, the theft of knowledge and resources for medicines, bushfoods and other products is a

cultural and economic burden for Indigenous people. A wide range of Indigenous enterprises involving bushfoods, medicinal and beauty products, and native plant nurseries are emerging from Indigenous knowledge. Such enterprises are largely based on wild harvest from traditionally managed estates, but also involve different models of cultivation, such as enrichment planting and horticulture (Gorman et al. 2020). Wild harvest often occurs in areas under Indigenous land tenure, where Indigenous communities and Indigenous ranger groups are actively involved in land management.

Australian laws on the protection of Indigenous knowledge and access to biological resources are fragmented. In response to the Convention on Biological Diversity, Australian legislation was introduced at a national level with the EPBC Act, and in the Australian Capital Territory, the Northern Territory and Queensland. The EPBC Act and Regulations provide that, where access is for commercial use or potentially for commercial use, the applicant must enter into an access and benefit-sharing agreement with the access provider. For noncommercial purposes, the applicant must obtain written permission and state that it does not intend to use the biological resources for commercial purposes. This can, in principle, assist Traditional Owners of land that is accessed to negotiate agreements for use of resources and associated knowledge. In practice, the law provides limited protection, and the provisions do not take into account Indigenous knowledge (as opposed to access to resources).

The use of Indigenous cultural and intellectual property (ICIP) protocols can help to protect Indigenous knowledge. Some universities have entered into research agreements, and access and benefit-sharing arrangements with Indigenous land and knowledge owners. In

some cases, this has resulted in shared patents and mutual benefit sharing. Protocols can be used along with existing laws and contracts to further protect ICIP.

But generally, Indigenous people consider existing laws to be ineffective. Australia has not yet implemented the Nagoya Protocol, and the result is that there are different approaches and requirements depending on the location of the genetic resources and the nature of the relevant land tenure (Terri Janke and Company 2018). Ratification of the Nagoya Protocol could deliver a nationally consistent system for access and benefit sharing. The *Queensland Biodiscovery Act 2004* was amended in 2020 to include provisions for the protection of Indigenous knowledge that were compliant with the Nagoya Protocol (see ‘Indigenous cultural and intellectual property’).

Indigenous people continue to ask for national implementation of the Nagoya Protocol (see ‘International obligations and treaties’) – this includes benefit sharing; attribution; and free, prior and informed consent.

Intellectual property laws are also limited in the way they recognise ICIP rights. Claims of patents based on Indigenous knowledge by non-Indigenous companies upset cultural production and prevent benefit sharing. A growing number of Indigenous organisations are making use of intellectual property laws, and there are a few Indigenous community organisations that are co-owners of plant patents. However, most Indigenous people are not able to resource such partnerships. Indigenous people continue to call for legal recognition of their Indigenous knowledge systems.

Data management is another area that needs to recognise Indigenous data sovereignty – the right of Indigenous people to control the collection, access, analysis, interpretation, management, dissemination and re-use of Indigenous data (Kukutai & Taylor 2016, Snipp

2016). Adequate recognition would enable Indigenous people and governing bodies to determine how Indigenous people, as well as Indigenous lands, territories, resources, knowledges and geographical indicators, are represented and identified within data. Data infrastructures can be designed to support Indigenous-led initiatives, from cultural heritage and language collection, ranger work, research on and about Country, decision-making, and developing Country-based enterprises and industries, through to intergenerational transfer of knowledge, and the monitoring and evaluation of the effective delivery of services to Indigenous communities.

Stewardship

Local environmental stewardship involves local people in protecting, caring for and sustainably using the environment (Bennett et al. 2018). Stewardship actions include sustainable use of resources; environmental education and advocacy; informal enforcement of policy protection; and restoration, preservation and monitoring – for example, through citizen science projects (Turnbull et al. 2020).

Many Australians have an active interest in maintaining the health and productivity of the landscapes in which they live (Bennett et al. 2018). Those who have a cultural connection have a particular interest; the ongoing degradation of the environment is reducing wellbeing due to burgeoning ‘ecological grief’ in those with emotional attachments to nature, especially Indigenous communities (Gordon et al. 2019, Cunsolo et al. 2020).

Local environmental stewardship can be enhanced in the broad population by experiencing nature; sharing these experiences through social networks; developing concern for sustainability and future generations; and developing a sense of local identity,

respect and responsibility towards nature (Turnbull et al. 2020). These characteristics may be nurtured through outdoor recreational activities, restoration programs, environmental education, citizen science and institutional stewardship, such as threatened species management plans and protected areas (Turnbull et al. 2021b).

Landcare, a grassroots community-led approach to sustainable land management, began in Australia in 1986. The Landcare movement promotes environmental conservation and sustainable land management. It has more than 140,000 volunteers currently included in its networks, and active groups in urban, rural, coastal and marine environments. Landcare participation supports improvements in mental and physical wellbeing, belonging and community resilience, including reduced annual healthcare costs of \$403 for each participant (KPMG 2021). Additional savings of \$191 million per year were estimated to arise from improved productivity and resilience to natural disasters (KPMG 2021).

Land for Wildlife works with landholders to integrate habitat conservation with residential use and agricultural production, and stewardship agreements serve a similar purpose for privately owned land. The reintroduction of cultural burning and land management practices is also a growing movement, with private owners working with Indigenous people. Clean Up Australia Day is the nation's largest community-based environmental event, reporting that more than 38.5 million hours of volunteer time has been donated since it commenced in 1989.

Since 2016, more focus has been placed on the need for integrated stewardship of our oceans by reconciling with Indigenous stewardship in managing sea Country (see also 'Integrated management'). For example, ghost nets have been the focus of considerable attention,

effort and engagement by Indigenous and community groups, and the Australian Government committed \$14.8 million to the Ghost Nets Initiative in 2021 to address ghost nets and plastic litter in the waters and beaches of the Gulf of Carpentaria (Parks Australia 2021a). For example, the Anindilyakwa Land and Sea Rangers, run by the Land Council at Groote Eylandt, manage ghost net and plastic debris along the coastlines of their IPA.

There are also good examples of river catchment communities mobilising for environmental outcomes and sustainable futures. The Cooks River Alliance was established to restore, rehabilitate and renew river vitality through partnerships, advocacy and community action. Importantly, the alliance partners with Indigenous people and organisations in the catchment for projects involving Indigenous history and ecological knowledge. The alliance has coordinated 3 major events with the community; more than 300 school students have been introduced to water-sensitive urban design; almost 1,500 community members have been introduced to stormwater management challenges; and more than 10,000 bags of rubbish and weeds have been collected.

The scale of volunteer work in management of protected areas and heritage places is significant. Invasive species control and environmental rehabilitation in World Heritage properties and National Heritage places often rely on volunteers and grant funding. Private owners make a very large contribution to heritage conservation in Australia, by conserving and maintaining heritage through owning listed heritage places or entering into arrangements to protect natural heritage areas. However, heritage protection and management of natural heritage across Australia are struggling to meet basic requirements for heritage protection and management, even with volunteer support.

We are all stewards of our environment

We all play an important role in protecting and restoring our environment, from our local area to the wider lands, seas and skies.

From individuals to large industries – all of us can make a difference.

Together, we can protect and restore our environment for a sustainable future.



Indigenous people

Indigenous people are sharing knowledge and managing land to help protect our environment.

Community groups

Many different types of groups are leading local actions, protecting nature, and coordinating environmental programs.



Individuals

Australians are caring for their local environments, investing in sustainable alternatives and getting involved in environmental citizen science programs.

Scientists

Scientists are partnering with communities and organisations to include local knowledge in environmental management.



Investors, industries and businesses

Investor groups, industries and businesses are increasingly funding conservation, restoration and sustainable projects and practices.

Governments

Governments are embracing environmental stewardship and supporting local actions through policies.



Natural capital accounting and environmental–economic accounting

‘Natural capital’ is the stock of renewable and nonrenewable natural resources available in the environment. Natural capital is fundamental to our lives, communities and economy – it encompasses all types of assets and resources that people and communities use to live and thrive. Australian farmers, fishers, foresters, miners and the community rely on the productivity of the environment, which depends on the state and trend of natural capital.

How we use and manage the land and oceans can affect natural capital and its condition, defined as its quality or health. Declines in the condition of natural capital affect the economy as a whole and the economic wellbeing of individuals. For example, intensive agricultural practices can directly impact soil health. Improving soil health can increase production and flows of other ecosystem services, which benefit farmers and society more broadly. Diversifying sustainable land uses across a whole region may make the landscape – and the economy and communities that rely on the land – more resilient to climate change. Likewise, diversifying sustainable uses of the ocean can increase resilience.

The System of National Accounts is the standard on how to measure the national economy and is used to provide economic information for decision-makers. The UN System of Environmental–Economic Accounting extends the System of National Accounts to integrate environmental and economic information, and provide a more comprehensive view for decision-making.

Environmental–economic accounting offers an innovative approach to track environmental assets and potentially cumulative impacts

on the environment. In 2018, Australia’s environment ministers agreed to a strategy and action plan for a common national approach to environmental–economic accounting (IEEASC 2018). The Samuel Review of the EPBC Act confirmed the importance of linking environmental–economic accounts to state of the environment reporting, and recommended accelerating the development of accounts (Samuel 2020). The Australian Government has further committed to transformative actions, including the following:

- Release of the first experimental National Land Account, which provides statistics to measure changes in land attributes over time, from both an economic and an environmental perspective. These attributes focus on land cover, land use, land tenure and unimproved land value. The National Land Account will be incrementally enhanced over time through improved data and methods.
- Release of 2 National Waste Accounts, which provide data on how waste and recycled materials are managed and re-used in Australia. Methods and accounts are incrementally being improved to better understand the flow and value of waste material nationally.
- Development of ocean accounting, to achieve the sustainable management of the oceans, joining 14 heads of state who form the High-Level Panel for a Sustainable Ocean Economy (Ocean Panel 2021). After the release of a case study for Geopraphe Marine Park, Western Australia, Australia has committed to the rollout of ocean accounts at a national scale (Prime Minister of Australia 2021), while also sharing expertise and lessons learned from ocean accounting activities within the Asia–Pacific region (Payne 2021).

- A pilot of ecosystem accounting is considering ecosystem extent and condition, biodiversity, the flow of ecosystem services and the benefits or value (monetary and nonmonetary) these services provide. After the release of a case study for the Gunbower–Koondrook–Perricoota Forest Icon Site, the Australian Government is examining the feasibility and utility of establishing a set of national ecosystem accounts.

Currently, environmental–economic accounts value nature in terms of its contributions to direct human benefit through ecosystem services. However, this is not the only way to assess our environment. Many in society also value nature for broader reasons:

- nature for nature’s sake – nonhuman (intrinsic) values (e.g. animal welfare and rights, ecological processes, species diversity)
- nature for human quality of life – anthropogenic relational values (e.g. wellbeing, cultural identity, sense of place) (Pascual et al. 2017).

There is a growing demand for more holistic understanding of all impacts of development, taking into account the full range of natural capital that we rely on and affect, as well as impacts on social and human capital. This requires more nuanced perspectives of both conserving natural values and supporting technology transitions in the production of food, fibre, energy and minerals, while also supporting the wellbeing of society.

These plural values will also need to be considered to ensure that decisions support wellbeing.

Management of specific sectors and resources

Much of environmental management in Australia is focused on specific sectors or resources. While this can enable a focus on specific pressures and needs, lack of coordination and duplication of effort can reduce management effectiveness and waste resources.



Assessment Management of specific sectors and resources



Overall grade: **Partially effective**
Overall trend: **Stable**

Management of sectors and resources varies widely. Restoration programs, species protection and protected areas are all contributing to effective management, although targets in many areas are not being met. Management actions are taking place but have not been able to change the negative trajectories of many threatened species. The protected area estate is growing in size, although recent years have seen more focus on lower protection levels.

Assessments of management effectiveness range from ineffective to effective

Assessments of trend range from deteriorating to improving

Related to United Nations Sustainable Development Goal targets 2.3, 6.1, 6.4, 6.5, 7.2, 8.4, 8.9, 11.4, 11.a, 12.2, 14.5, 14.6, 14.b, 15.1, 15.5, 15.6

Protected areas

Australia has one of the world's largest networks of terrestrial and marine protected areas, covering almost 20% of the land area and just over 36% of the ocean area. This includes a variety of types of areas and approaches, including national parks and nature reserves, IPAs, private protected areas and shared management areas.

Between 2016 and 2020, the overall area of land and ocean managed for conservation has expanded, including through increases in IPAs, and the community and private sectors. Approximately 1.7 million hectares of terrestrial protected area has been added in the past 5 years, equating to an additional 1.5% of terrestrial protected area. Approximately 2.3 million hectares of marine protected area (MPA) has been added in the past 5 years, equating to an additional 0.7% of MPA. The MPA estate for all Australian waters has increased from 9.4% in 2010 to 36.1% in 2020; however, much of this area offers only partial protection (IUCN categories III–VI).

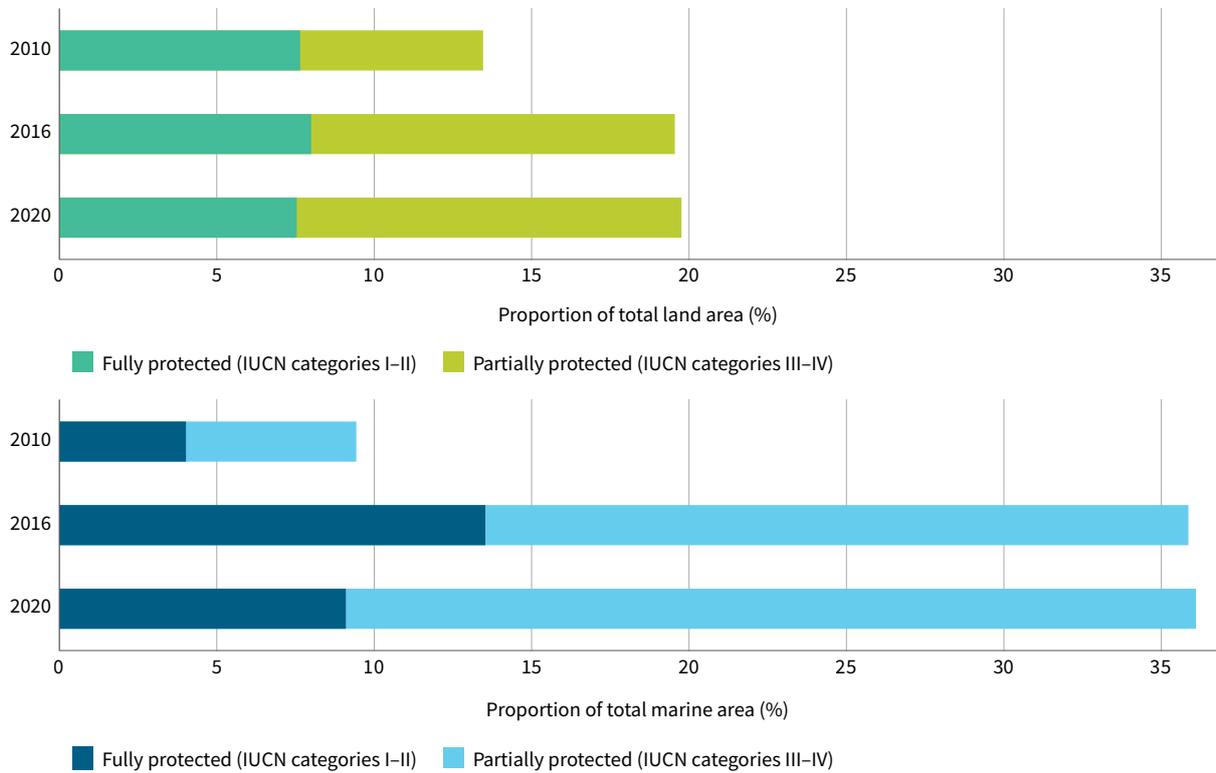
The overall level of protection of these areas (as defined by the IUCN) has decreased with the proportion of Australian lands under the highest level of protection (IUCN categories I and II), falling from 8% to 7.5%, and in the oceans from 13.5% to 9.1%. When considering the highest levels of protection (IUCN categories I–III), most of Australia's ecoregions fall short of the 2020 Aichi target under the Convention on Biological Diversity. The growth in terrestrial protected areas since 2010 has been almost exclusively in multi-use, partially protected areas.

Protected areas are widely considered to be the best way to protect biodiversity, maintain the diversity and quality of ecosystems, and improve their capacity to adapt to change and provide for the needs of future generations. In addition to achieving environmental

outcomes, protected lands and seas improve human health and wellbeing through contact with nature – benefiting and diversifying local communities, building understanding of natural systems, and strengthening resilience to climate change.

The goal of the National Reserve System is to develop and effectively manage a comprehensive, adequate and representative national system of protected areas. Although the overall land and marine area protected in Australia exceeded Aichi targets (Figure 27) (i.e. at least 17% of terrestrial and inland water areas, and 10% of coastal and marine areas), they did not meet the 2020 Aichi target 11 'ecologically representative' criterion of 'including at least 10% of each ecoregion within the country'. Of 88 land bioregions (excluding the Coral Sea Marine Region), 27 (31%) are still below 10% protected, mostly in inland areas, particularly of eastern Australia (Taylor 2020). Of 43 marine bioregions, 6 (14%) are still below 10%, mostly in south-eastern waters.

The 2020 Aichi target also called for protected areas to be equitable, with full participation of local and Indigenous communities. In recent years, we have seen an increase in IPAs and co-management of protected areas in Australia. Ongoing challenges remain, however, in terms of sustainable, long-term funding and rate of investment per hectare. Consultation and planning for additional IPAs have been supported by \$15 million that was committed by the Australian Government in 2017, and a further \$11.6 million that followed in 2021 to expand IPAs into sea Country (DAWE 2021e, NIAA 2021). The security of this tenure is not recognised under most state legislation, and IPAs are not yet an enduring form of protection because they are a voluntary agreement that exists for 20 years. At the end of the voluntary agreement, the owners have the right to change the land use.



IUCN = International Union for Conservation of Nature
 Source: Recreated from Taylor et al. (2020), using data from CAPAD 2010, 2016 and 2020

Figure 27 Land and marine protected areas in Australia

In total, our MPA network comprises almost 3.35 million square kilometres and 441 protected areas, 327 of which are in state or territory waters. MPAs aim to conserve biological diversity and ecological processes, and protect the sustainable use of natural resources, cultural values and Indigenous uses. However, protection levels vary. IUCN categories I and II are fully protected ‘no take’ or sanctuary zones, but categories III and IV allow some fishing and other extractive industries. Queensland has the largest total area under full protection, closely followed by Western Australia. In the Northern Territory, no MPAs are fully protected areas, but in Tasmania 87% of MPAs are fully protected.

It is not currently possible to assess the overall effectiveness of management of Australia’s national marine conservation estate, but recent research indicates that,

on average, Australia’s marine reserves provide significant benefits to fished species (e.g. Bosch et al. 2021, Goetze et al. 2021). However, concerns have been raised that the efficacy of Australia’s reserve system may have been degraded by a trend over time for downgrading protection levels (Cockerell et al. 2020), and that Australia’s marine reserve system is not currently functioning as a connected network because of breaks in the connectivity of reef habitat (Roberts et al. 2021). In addition, only around 25% of these protected areas provide the highest level of protection against extractive uses. For example, Cockerell et al. (2020) and Turnbull et al. (2021a) question the system’s potential to reduce threats to biodiversity. Current work being done to develop integrated approaches to monitoring and evaluating the effectiveness

of management of Australia's marine parks is yet to report (Parks Australia 2021b).

Private conservation has been growing in the past decade, currently covering about 6% of all protected areas. Individuals, nongovernment organisations and businesses are increasingly purchasing and managing significant tracts of land for conservation. A few nongovernment organisations own and manage a large number of properties managed for conservation. For example, the Australian Wildlife Conservancy owns, manages or works in partnership on 31 locations covering more than 6.5 million hectares. Bush Heritage Australia owns 36 reserves covering 1.2 million hectares of land. In addition, Bush Heritage Australia works in partnership with several Traditional Owner groups to deliver conservation and

socio-economic outcomes across more than 10 million hectares.

Antarctica has a high level of environmental protection – and terrestrial and marine areas of outstanding environmental, scientific, historical, aesthetic or wilderness value are specially protected areas. However, the management of the Antarctic protected areas and the World Heritage Areas in the subantarctic have been assessed as partially effective, reflecting in part the complexities facing the 54 member nations of the Antarctic Treaty. Since 2016, climate change, increasing human activities and the competing geopolitical interests of treaty members have made it more difficult for Australia to achieve its aspirations within the Antarctic Treaty system.



Case study Conservation through an integrated landscape approach

James Hattam, Tasmanian Land Conservancy

National parks and other public reserves play an important role in protecting landscapes and wildlife. But, under a rapidly changing environment, they alone are not enough.

By increasing the extent and diversity of habitats protected, private land conservation is increasingly playing a very important role in achieving effective and long-term conservation outcomes.

Nowhere is this more evident than on the Freycinet Peninsula on Tasmania's east coast, which contains a network of protected land, conserved through both public and private efforts.

The iconic Freycinet National Park was Tasmania's first national park and contains the jagged granite peaks of The Hazards, which dominate the landscape. Ecologically significant features occur in the national park and throughout the surrounding landscape.

In this landscape, public reserves are surrounded and strengthened by a network of properties protected under private land conservation initiatives. Private land

initiatives have been steadily increasing over the past 3 years, and are critical in creating and maintaining ecological links across the landscape.

Each year, hundreds of thousands of people stop at the popular Cherry Tree Hill lookout (Figure 28) to appreciate this remarkable landscape. From Cherry Tree Hill, you can see the protected landscapes of The Hazards, Freycinet National Park and the Ramsar-listed Moulting Lagoon. Look back over your shoulder, and from there you can see more than 60 privately protected conservation properties scattered through the landscape. These include 2 Tasmanian Land Conservancy reserves, 2 Bush Heritage Australia reserves, 30 covenanted private properties, 8 Revolving Fund properties and 20 Land for Wildlife properties. Collectively, these private land programs conserve more than 5,000 hectares of this ecologically important landscape.



Photo: James Hattam

Figure 28 Cherry Tree Hill lookout, Tasmania

Biodiversity and natural resources

The Samuel Review of the EPBC Act (Samuel 2020) noted that:

The current streams of Australian Government funding allocated towards environmental protection, conservation and restoration, despite being aligned with matters of national

environmental significance (MNES), are not comprehensively coordinated to prioritise investment in a way that achieves the greatest possible biodiversity benefits. Funding is often spread thinly across the nation, and the link between the investment of program funds on a particular project and outcomes for MNES can be difficult to discern.

Following Australia's ratification of the UN Convention on Biological Diversity in 1993, all Australian governments agreed on the need for a collaborative strategy to manage our biological diversity, starting in 1996 with the National Strategy for the Conservation of Australia's Biological Diversity. This was followed in 2010 by Australia's Biodiversity Conservation Strategy 2010–2030 as the guiding framework for conserving the nation's biodiversity. A review of the progress of the Biodiversity Conservation Strategy found that it had not effectively influenced biodiversity conservation activities; it was not possible to report achievement against its targets; it did not engage, guide or communicate its objectives in a useful way; and, going forward, increased coordination of effort on shared priorities for biodiversity management would be needed (Biodiversity Working Group 2016).

In 2019, Australian, state and territory environment ministers endorsed a new Australia's Strategy for Nature 2019–2030 to guide the development of new and innovative approaches to biodiversity conservation. The strategy functions as a policy umbrella over other national, state, territory and local government strategies, policies, programs and regulations. It sets 3 priorities for actions:

- connecting all Australians with nature
- improving conservation management
- sharing and building knowledge to make better decisions.

The strategy strives to incorporate adaptation, resilience and sustainable natural resource management in its scope. A new overarching website is under development in 2021 for the strategy: Australia's Nature Hub (Australian governments 2021) provides links to all relevant national, state and territory strategies and actions towards the 2020 Aichi targets and the SDGs (see 'Sustainable development'), as well as national goals. However, the new

strategy has been met with some criticism, mainly because there is no associated action plan for guiding and prioritising investment, there is no coordinated approach to monitoring outcomes, and progress measures lack detail and specific, measurable targets. A working group comprising officials from environment departments across Australia is responsible for evaluating and reporting on implementation of the strategy to environment ministers every 2 years; progress reports are to be published every 4 years, aligning with Australia's reporting to the Convention on Biological Diversity.

Biodiversity programs

In general, biodiversity conservation has rapidly shifted in recent decades to embrace landscape-scale conservation planning, which aims to support biodiversity alongside agricultural and other human land uses (see 'Integrated management').

This decade has been declared the UN Decade for Ecosystem Restoration (UNEP & FAO 2021). A diverse range of restoration programs are presented in this report, including Lord Howe Island rodent eradication, with resulting restoration of native species; coastal dune ecosystems; seed banks for flora restoration programs; kelp forests and coral reefs; and native forests, with flow-on effects for carbon storage and the economy.

The National Landcare Program Phase 1 commenced in 2014; Phase 2 commenced during 2017–18 and is being delivered through to 2023. This funding provides for many practical, on-ground elements of natural resource management, mostly focused on maintaining and improving agricultural landscapes. It includes funding to address issues such as loss of vegetation, soil degradation, invasive species, water quality and flows, and changing fire regimes, which

has beneficial flow-on effects for biodiversity in the broader landscape (Figure 29).

The Australian Government also funds relevant environmental research programs through the National Collaborative Research Infrastructure Strategy (NCRIS). This strategy supports a national network of projects that foster high-quality collaborative research to address key national and global challenges. The Terrestrial Ecosystem Research Network, the Integrated Marine Observing System, Bioplatforms Australia and the Atlas of Living

Australia are NCRIS facilities supporting biodiversity and environmental programs.

The Bush Blitz program investigates and documents Australian species. Over the past decade, Bush Blitz has discovered more than 1,735 new species, extended the known range of 250 species, and generated more than 500 records of species listed as threatened, along with more than 1,200 records of pest species. The program has also recorded more than 25,000 individual occurrences of plants and animals, which can be accessed by land managers, scientists and the general



Photo: Landcare ACT

Figure 29 Landcare ACT volunteers doing bushfire recovery work in Namadgi National Park, 2021

public using online tools such as the Atlas of Living Australia. Bush Blitz is now Australia’s largest nature discovery program, with \$11 million funded over 5 years until 2023 as a joint partnership between the Australian Government and a major corporate sponsor, BHP. Recent analysis of the Bush Blitz program has shown that it adds records of new, or previously unrecorded, species at a rate much greater than ‘background’ survey efforts, such as those previously undertaken by museums, universities and citizen science (Ware et al. in preparation).

Threatened species and communities

In 2015, the Australian Government adopted a Threatened Species Strategy that established national priority action areas and targets to report against in 2020 (Table 1). The strategy achieved partial success in its aim to improve the trajectories of 71 priority species by 2020 (20 mammals, 21 birds and 30 plants). The results showed that 34% of the priority species had an improved population trajectory from 2015 to 2020, compared with the 10 years before the strategy (2005–15). Fourteen species were in recovery, moving from a

trajectory of decline in 2005–15 to a trajectory of increase in 2015–20; 7 species were found to be declining but at a significantly slower rate; and 3 species were found to be recovering at a significantly faster rate. The remaining 51 priority species did not show significant improvements. Over the past 5 years, the number of threatened species listed under the EPBC Act rose to 1,918 plant and animal species, with some species transferred to a higher threat category. The number of listed entities will increase substantially in 2021 and 2022 as a result of the 2019–20 bushfires.

Targets that reflected recovery action being undertaken were generally met; however, those that reflected actual changes in threatened species trajectories were largely not met. There was no target reflecting improved trajectories for threatened ecological communities, and therefore it is not possible to determine whether the actions taken for these communities have been effective. Where targets have been achieved, some additional conservation programs are already being implemented and conservation benefits realised.

Table 1 Some results against species trajectory targets of the Threatened Species Strategy 2015–20

5-year target	Overall result	Summary
20 priority birds have improved trajectories	Not met	<p>21 bird species were listed as priority species. Over the strategy period:</p> <ul style="list-style-type: none"> • 6 species improved • 6 deteriorated • 4 were reasonably stable • 5 had trajectories that may have changed but not significantly so. <p>Following the 2019–20 bushfires, 3 of the 21 priority bird species – regent honeyeater, eastern bristlebird and western ground parrot – were identified as priorities for urgent management intervention by the Wildlife and Threatened Species Bushfire Recovery Expert Panel. These species are now receiving targeted support for recovery</p>

continues

Table 1 *continued*

5-year target	Overall result	Summary
20 priority mammals have improved trajectories	Not met	<p>20 mammal species were listed as priority species. Over the strategy period:</p> <ul style="list-style-type: none"> • 8 species improved • 5 deteriorated • 1 was reasonably stable • 6 had trajectories that may have changed but not significantly so. <p>On-ground recovery actions to protect Australia's mammals include monitoring, habitat restoration, and reducing the impact of predators such as feral cats and red foxes. Where threats in the wild are too great for threatened mammals to persevere, establishing ex situ populations in predator-free safe havens has been supported through funding for captive breeding and translocation programs</p>
30 priority plant species have improved trajectories	Not met	<p>30 plant species were listed as priority species. Over the strategy period:</p> <ul style="list-style-type: none"> • 10 species improved • 4 deteriorated • 16 were reasonably stable or had a nonsignificant change in trajectory. <p>Increasing monitoring efforts over 2015–20 led to discoveries of new populations for some plants, revealing them to be more common than originally assessed (e.g. Fitzgerald's mulla mulla, which has subsequently been delisted under the EPBC Act, and the purple wattle).</p> <p>For 4 of the 30 priority plant species – <i>Banksia vincentia</i>, blue-top sun-orchid, silver daisy bush and scaly-leaved featherflower – considerable doubts were raised about their taxonomic validity over the course of the strategy</p>
100% of Australia's known threatened plant species are stored in one or more of Australia's conservation seed banks	Not met	<p>Approximately 67% of Australia's listed threatened plant species (930 of 1,373 species) are now stored in conservation seed banks. Recent research suggests that some of the remaining species may not be amenable to traditional seed-banking methods.</p> <p>Although some threatened species are represented by multiple collections of suitable size, many species are represented by collections of fewer than 500 seeds</p>

continues

Table 1 *continued*

5-year target	Overall result	Summary
Recovery actions are underway for at least 50 plants	Met	Recovery actions are underway for all 30 targeted plant species under the strategy. The 5-year report notes that hundreds of other listed plant species also have recovery actions underway through a range of government and nongovernment programs and initiatives
Recovery actions are underway for at least 60 threatened ecological communities	Met	Recovery actions are underway for more than 60 threatened ecological communities via programs such as 20 Million Trees (at least 54 sites), Regional Land Partnerships (32 different communities) and bushfire recovery programs (16 priority threatened ecological communities)

Source: Australian Government (2015)

A new Threatened Species Strategy 2021–2031 was released in May 2021 that continues work on some of the established priorities from the 2015 strategy, but also broadens the scope, and includes new and emerging challenges. The Threatened Species Strategy Action Plan 2021–2026 now includes reptiles, frogs, insects and fish to add to the priority birds, mammals and plants identified in the first strategy. Furthermore, there is a new focus on ‘priority places’, and a greater focus on landscape-scale actions that are fundamental to the recovery of threatened species.

The estimated cost of recovery of threatened species in Australia is much greater than the amount we actually spend (see ‘Threatened species and environmental restoration funding’). Wintle et al. (2019) estimated the required expenditure to be close to \$1.69 billion dollars per year; the targeted threatened species spending for 2018–19 by the Australian Government was estimated to be \$49.6 million. This spending includes support for activities such as captive breeding of a threatened species or targeted threat management (e.g. fox control) to secure a population of a threatened species. The efforts of the private sector, local government,

nongovernment organisations and private citizens make a significant contribution to threatened species recovery and are not included in the estimates in Wintle et al. (2019). There are also many caveats associated with the estimates, in part because clear reporting on expenditure is not available, and the costs of managing pressures are very difficult to estimate. This is borne out in the declining trajectories of many native species, and in the increasing extent and magnitude of threatening processes and pressures.

The protection of terrestrial threatened species within the National Reserve System has improved over the past decade: 92 EPBC Act-listed species attained minimum protection standards (30% of their range) between 2010 and 2020, and 27 species went from being totally unprotected to having some level of protection. However, 129 species still lack any protection, and a further 541 are below halfway to meeting the standard. Critically Endangered species have the lowest levels of attainment of the minimum standard in the National Reserve System, with 42 Critically Endangered species having no protection. Threatened mammals and birds are relatively well protected in the



Photos: Parrot – Graeme Chapman; banksia – Western Australian Department of Biodiversity, Conservation and Attractions; numbat – Alexander Dudley

Figure 30 Three species in the Threatened Species Strategy that are in recovery, moving from a trajectory of decline in 2005–15 to a trajectory of increase in 2015–20; clockwise from top left: orange-bellied parrot; matchstick banksia; numbat

National Reserve System, whereas threatened invertebrates and plants are the least well protected. Overall, marine, migratory and coastal species are better protected in Australia's protected systems than terrestrial or freshwater species.

Indigenous lands in Australia support a high proportion of threatened species. Approximately three-quarters of Australia's terrestrial or freshwater vertebrate species that are listed as threatened under the EPBC Act have ranges that overlap Indigenous lands. Twenty-two threatened species have more than 75% of their range on Indigenous land, including 5 species with more than 99% of their range on Indigenous land.

Only 16% (13 of 84) of Australia's nationally listed threatened ecological communities meet a 30% minimum protection standard in the National Reserve System. Three Critically Endangered communities with small areas of known or likely-to-occur habitat have no protection of their habitat: Hunter Valley Weeping Myall (*Acacia pendula*) Woodland has only 21 hectares of known or likely habitat; the Elderslie Banksia Scrub Forest in the Sydney Basin Bioregion has only 621 hectares; and the Warkworth Sands Woodland, also in the Sydney Basin Bioregion, has only 800 hectares.

At June 2020, 719 recovery plans were in place for species (for 1,891 listed species), and 27 were in place for ecological communities (for 87 listed ecological communities).

An approved conservation advice was in place for 1,431 species and 71 ecological communities (DAWE 2020i), but many of these plans are out of date, have expired or will sunset in the near future. Recovery plans and conservation advices are critical national planning processes to facilitate national action on threatened species and ecological communities, to engage communities, to monitor progress, and to report on outcomes and conservation success. There have been

many reported conservation success stories in Australia where appropriately resourced and implemented recovery programs, supported by dedicated people, have led to improved conservation outcomes (Latch 2018). But there is no requirement to implement or fund a recovery plan or conservation advice, or report on progress and the outcomes achieved.

The lack of requirement to implement recovery plan actions, and the lack of monitoring of recovery actions, are major impediments to understanding the effectiveness of recovery programs. The recent review of the EPBC Act noted that the considerable effort given to the assessment and listing process is not matched by attention and resources dedicated to effective recovery (Samuel 2020). Experts have forecast that another 7 Australian mammals and 10 Australian birds will be extinct within 20 years unless management is greatly improved (Geyle et al. 2018).

There are 13 approved threat abatement plans covering diseases, feral animals, pollution and bycatch (DAWE 2021g). The threat abatement plan for incidental or bycatch of seabirds during oceanic longline fishing operations (2018) stipulates required research and management actions. Australia has formulated a national strategy for the protection of threatened albatross and petrel species. There are some encouraging signs of recovery; however, populations of some species are still decreasing.

Translocations of threatened species are now commonly used to mitigate the impacts of development, and at least 1,000 plant translocations have occurred since 1950. Survival rates are low, however, with only 13% of assessed translocations considered to have sufficient plants surviving to support ongoing recruitment (Silcock et al. 2019). Translocation of threatened animals to islands and fenced areas is increasing, with relatively high success rates: 86% for islands and 70% for fenced areas.

Water resources

Climate change and associated extreme events are revealing deficiencies in areas of environmental management. For example, the driving national framework for water reform has been the National Water Initiative (NWI), which built on previous national reform agreements. The NWI delivered sizeable benefits to the environment, the water sector and water users, including agriculture. However, it is now 17 years since the NWI was negotiated, and severe droughts have exposed vulnerabilities in water resource management and service provision.

Much has been learned about environmental requirements and responses, integrated management, and the importance of regulatory integrity and community confidence. With the challenges of climate change and increasing extreme events, along with growing community expectations for environmental condition and Indigenous inclusion, the current institutional architecture that supported the NWI has been substantially eroded and is no longer fit for the scale of the water challenge facing Australia. The Productivity Commission has called for a renewal of the reform commitment, with greater recognition of climate change in water planning and management, a focus on water service provision, and a framework for major water infrastructure provision (Productivity Commission 2021b). The Productivity Commission highlights the need for renewed action in national water policy that builds confidence in reform effort and supports cooperation between jurisdictions (Productivity Commission 2021b).

Integrated water management

Since 2016, states and territories have made improvements in specifying environmental objectives for inland waters and in linking

broader environmental outcomes to water management through new or revised water planning, although objectives for groundwater-dependent ecosystems remain less well specified (Productivity Commission 2021b). There is also improvement in the integration of the management of groundwater and surface water systems – these are often physically linked, and consumptive demand shifts between them in response to climatic and other conditions.

To deliver agreed environment outcomes, it is essential that environmental water is integrated with nonflow waterway management, which is subject to different management arrangements and accountabilities. Weeds, grazing, introduced species, loss of in-stream habitat and other pressures can work against the long-term aims of environmental watering. Balancing social, economic and environmental outcomes requires further improvements in the delivery of integrated planning that builds on our current system of environmental flows through additional complementary management arrangements.

One of Australia's most productive regions is the Murray–Darling Basin. Surface water diversions and extensive river regulation, combined with climate change, have resulted in major changes to flow and flood regimes for rivers and wetlands in the Basin. The Commonwealth *Water Act 2007* is enacted through the Murray–Darling Basin Plan, which is a tool for returning water to the environment by reducing the amount taken for irrigation and other consumptive uses (MDBA 2012). The environmental objectives of the Basin Plan are to protect and restore flow-, flood- and groundwater-dependent ecosystems, and ensure that they are resilient to climate change and other threats. The Basin-wide Environmental Watering Strategy (MDBA 2019) provides details of how the environmental objectives of the Basin Plan are to be

implemented, including expected outcomes for river flows and connectivity, native vegetation, waterbirds and fishes.

Recent reviews into compliance and enforcement in the Murray–Darling Basin found numerous shortcomings around governance, practice and resourcing, resulting in growing mistrust and a lack of confidence in water system management during the drought (Productivity Commission 2021b). These failures, and consequent significant media attention and public dissatisfaction, led to the Murray–Darling Basin Compliance Compact being signed by Basin governments in 2018. The compact seeks to restore public confidence in water resource management in the Basin. The Australian Government has established the new statutory role of the Inspector-General of Water Compliance (IGWC) – independent of the Murray–Darling Basin Authority and taking on its previous compliance and enforcement activities. The IGWC has oversight of water management in the Basin and inquiry powers to investigate implementation of the Water Act, the Basin Plan and intergovernmental agreements, including the Murray–Darling Basin Agreement. Several states also undertook institutional reform to improve the integrity of water management, including establishment of the Natural Resource Access Regulator in New South Wales.

For Indigenous people, water is at the core of their culture and ways of knowing, being and doing. Because Australia is the driest inhabited continent on Earth, Indigenous knowledge of water is essential to the survival of its people. Indigenous cultural and spiritual values for water may relate to a range of uses and issues, including spiritual relationships, language, songlines, stories, sacred places, customary use, the plants and animals associated with water, drinking water, and recreational or commercial activities (DAWE 2018). Water is

also strong in lore, song, dance and dreaming, and plays a significant role in the health and wellbeing of Indigenous people (Moggridge & Thompson 2021).

Indigenous people call for greater input into management of water, including cultural or Indigenous flows. Cultural or Indigenous flows (Moggridge et al. 2019) are water entitlements owned by Indigenous nations that sufficiently and adequately allow them to improve the spiritual, cultural, environmental, social and economic conditions of Indigenous people (MLDRIN 2007, NCFRP 2021). The Indigenous Environmental Watering Guidance Project, through the Commonwealth Environmental Water Office, involves the Australian Government working with the Murray–Darling Basin Authority, the Murray Lower Darling Rivers Indigenous Nations and the Northern Basin Aboriginal Nations to incorporate Indigenous environmental watering objectives into planning for environmental flows at a Basin scale.

Alternative water resources

The millennium drought prompted increased investment in less climate-dependent water sources, including desalination and recycling. Most major urban centres, including Perth, Melbourne, Sydney, Adelaide and the Gold Coast, now have desalination plants integrated into their water services provision. In 2019–20, desalinated water provided 4% of water supply, a substantial increase on the previous year, as urban water utilities sought to manage pressure on their storages from low inflows. Perth built its first desalination plant in 2006, in response to a major reduction in inflows into its storages over several decades. It now relies on groundwater and desalination for the bulk of its urban supply; desalination contributed 47% in 2019–20 (BOM 2021b). Melbourne Water reports that, without the desalinated water ordered since 2017, its water storages would

have been around 15% lower at 1 January 2021 (Melbourne Water 2021). Desalination also has a role in mitigating the supply impacts of other extreme events, buffering the water quality impacts of flooding and bushfires.

Australia's total desalination capacity is about 880 gigalitres (GL) per year from 270 desalination plants, of which the major urban plants account for 534 GL. The balance is supplied by the many small-scale plants that desalinate both sea water and brackish groundwater for remote, regional and industrial supply. Management of potential impacts of desalination plant effluent has generally been good in Australia; published studies indicate small ecological impacts of brine release in offshore environments (Clark et al. 2018, Kelaher et al. 2019). However, further work is required to consider the impact of desalinated brine in flow-restricted freshwater systems.

Recycled water in Australia is mainly used for nondrinking purposes, such as watering of public spaces, industrial use or irrigation. It is also used for groundwater recharge in some areas. Total recycled water used in major urban centres in Australia was 145 GL in 2019–20, more than double the 70 GL used in 2010–11. Recycled water is equivalent to 8% of the total water sourced in major urban centres, and this proportion is expected to grow.

Coastal and marine

One of the most complex areas of management in Australia is the coastal zone, where most of our population lives. It involves local councils, which maintain many coastal reserves; state and territory governments, which are responsible for waters out to 3 nautical miles from shore; and the Australian Government, which manages waters beyond that, as well as Defence lands and several Commonwealth national parks. Coastal

management generally lacks Indigenous leadership and contributions.

Overall, the management of Australia's marine estate is effective and improving at a sectoral level. However, climate change and cumulative impacts are not dealt with adequately, and there is a need for widespread uptake of integrated management approaches (see 'Integrated management'). Since 2016, controls on the introduction and spread of invasive species have improved, and more effective curbs on the run-off or discharge of nutrient pollution into coastal waterways have been implemented. The flow of potentially harmful nutrients into the waters of the Great Barrier Reef also decreased, although it remains a significant threat. In addition, management of threatened coastal species is ineffective and deteriorating. There are inconsistencies in habitat protection, and poorly coordinated management between local councils, and the Australian, state and territory governments.

Most management is specific to the sector. For example, fisheries, oil and gas, mining and environmental protection are all managed under separate legislation and policy frameworks specific to each jurisdiction.

In some areas, Australia is considered to be advanced in sector-specific policies and guidance for broader species management, such as the Commonwealth Policy on Fisheries Bycatch and the Commonwealth Fisheries Harvest Strategy Policy. Australia's partnership approach to commercial fishing, linking managers, commercial fishers, scientists and other stakeholders, is recognised globally (Marchal et al. 2016) as a best-practice example for fisheries management and natural resource management more broadly. Almost all fisheries management agencies use, or are planning to use, evidence-based processes, such as harvest strategies for commercially important species, to determine sustainable catch levels. However, some jurisdictions are

lagging in the adoption of such practices, and further resourcing is required to increase the speed of implementation.

Since 2016, sustainability has been improved by implementation of more harvest strategies and risk assessments of the broader impacts of commercial fishing on marine ecosystems. Improved coordination of research and development, and national best-practice guidelines led to the benchmarking of more stocks against sustainable reference points (Little & Hill 2021). An increasing range of mechanisms and technical tools have also been used to reduce interactions of fishing vessels and gear with seabirds, marine mammals, reptiles and other vulnerable species. A National Fisheries Plan is due to be released in 2021 to provide a strategic framework for a clear and consistent national approach.

Management of Australia's recreational fisheries is less effective but is also improving. Harvest strategies are increasingly using data collected through recreational fishing surveys, enabling the integration of fisheries management between commercial, recreational and Indigenous fisheries sectors (Ryan et al. 2016). A recent example is a recreational fishing allocation for the Southern Bluefin Tuna Fishery, set at 5% of Australia's total allowable catch, informed by a national recreational fishing survey (Tracey et al. 2020). Although cooperation and coordination have grown across jurisdictions, there is still only limited alignment of commercial, recreational and Indigenous management policies, strategies and planning.

Heritage

The long-term protection of Australian heritage is primarily achieved through dedicated heritage or protected area legislation, but protection in some areas

is also provided by statutory planning, high-level policy and multilateral government agreements. Australia's national framework and legislation are failing to adequately protect heritage – not all heritage is protected, not all protected heritage is being adequately managed, and much of the legislation is outdated. These failings are leading to gaps in protections, and confusion about responsibilities and obligations, especially between levels of government.

Overall, national, state and territory legislation requires strengthening to adequately protect heritage. International and national heritage is covered by the EPBC Act, and there are separate pieces of legislation for Indigenous heritage, underwater cultural heritage and movable cultural heritage. The states and territories have separate, standalone Indigenous and historic heritage legislation that also provides protection through listing. Heritage protection has traditionally focused on the smaller, tangible, 'place-based' heritage for protection of sites, built heritage and other structures. However, much of the significance of cultural heritage exists at the landscape scale, and many heritage values are best recognised at this level. There is a need to broaden the scope of cultural heritage and types of heritage that are protected. Such an approach provides benefits for cultural heritage conservation that cannot be reproduced by the conservation of individual heritage items.

Significant reform of Indigenous heritage legislation is required. The destruction of the Juukan Gorge rock-shelter in 2020 highlighted that the range of legislation that relates to Indigenous heritage is either not working effectively (e.g. the *Aboriginal and Torres Strait Islander Heritage Protection Act 1984*, the EPBC Act in relation to emergency powers), or not working effectively together (e.g. the *Native Title Act 1993* and state-level Indigenous

heritage legislation), resulting in devastating loss of Indigenous heritage. In addition, despite having significant connections to heritage sites, and the knowledge, cultural practices and ecological management that come with this, Indigenous Australians have limited control and decision-making power over the management of Indigenous sites across Australia. This demonstrates a disregard for Indigenous people's right to self-determination over their cultural heritage, as outlined in the United Nations Declaration on the Rights of Indigenous Peoples.

Two other areas require legislative reform: the need nationally for legislation to specifically protect geological heritage, and the need to significantly strengthen planning laws and statutory planning provisions Australia-wide to provide effective heritage protection.

Heritage protection and management in Australia are supported by national guidelines and international obligations, including the Australian Natural Heritage Charter for the conservation of places of natural heritage significance, the Australia ICOMOS Charter for the Conservation of Places of Cultural Significance (known as the Burra Charter), and *Ask first: a guide to respecting Indigenous heritage places and values* (AHC 2002). The general management approach for cultural heritage in Australia is to protect heritage by retaining the heritage values (i.e. retaining heritage significance), which is known as 'values-based management'.

Although Australia has extensive legislative and policy frameworks for heritage protection, governments are proving slow to respond to heritage challenges – in particular, in addressing Indigenous rights issues in relation to heritage and Country, and the need for improved risk avoidance and mitigation in relation to key pressures. Key improvements in future will be to fill gaps in heritage lists and registers, and to implement condition

and impact monitoring, strategic planning, statutory planning and the regulatory framework more generally. Although many tools to undertake the necessary management exist, inadequate resourcing and a lack of leadership are preventing an adequate management response.

Urban

Australia's urban areas are managed across 3 levels of government: local, state and territory, and national. Each of these levels has its own policies, strategies and regulations that are increasingly looking to, and aligning with, international benchmarks and goals, including the UN SDGs. Although management of our urban environment is very complex, sustainability and urban resilience are increasingly being adopted as an overarching objective for urban planning and development. Urban sustainability seeks to improve the livability of our urban areas, including their ecological, social and economic components, without further eroding our environmental assets. To address urban challenges, the concept of regenerative and resilient development is increasingly seen as a better approach than the sustainable development method of simply reducing resources and waste. The regenerative approach aims to dramatically reduce environmental impacts and to improve urban outcomes (Newman 2020).

Indigenous knowledge has been embraced in many major cities and larger regional centres. An improved appreciation and understanding of the traditional culture of the area, informed by Traditional Owners and Custodians or by Indigenous residents, has resulted in design of place, space and built form that is mindful of the needs and 'voice' of Country and its custodians. Indeed, there is a burgeoning cultural shift in thinking, demonstrated

by inclusive planning legislation, policy development and processes.

Antarctica

Australia gives effect to its international obligations arising from the Antarctic Treaty system through domestic law. The 2 primary pieces of Australian legislation are the *Antarctic Treaty (Environment Protection) Act 1980* (which gives effect to the 1991 Protocol on Environmental Protection to the Antarctic Treaty, and includes environmental protection principles, including biosecurity, and requirements for all activities in the Antarctic Treaty area) and the *Antarctic Marine Living Resources Conservation Act 1981* (which implements the requirements arising from the Convention on the Conservation of Antarctic Marine Living Resources).

Heard Island and McDonald Islands are World Heritage Areas and are managed by the Australian Government because they are located outside the Antarctic Treaty area. The surrounding waters are protected under the EPBC Act as the Heard Island and McDonald Islands Marine Reserve, which is Australia’s most remote Commonwealth reserve. Macquarie Island and nearby islets are part of the state of Tasmania and are managed by the Tasmanian Department of Primary Industries, Parks, Water and Environment. Macquarie Island is also a World Heritage-listed site.

Management of pressures

A key aim of environmental management is to prevent or mitigate the impact of pressures on the environment.



Assessment Management of pressures



Overall grade: **Partially effective**
Overall trend: **Deteriorating**

Management of specific pressures varies, resulting in a range of ongoing impacts from low to very high, with trends that are generally deteriorating. Various initiatives, including emissions reduction, climate change adaptation, invasive species control and pollution reduction, are in place to target improvements in coming years; however, in general, more needs to be done to stabilise and improve the state of the environment.

Assessments of management effectiveness range from ineffective to effective

Assessments of trend range from deteriorating to stable

Related to United Nations Sustainable Development Goal targets 11.3, 11.6, 11.b, 12.4, 13.1, 13.2, 14.1, 14.2, 14.3, 14.4, 14.5, 15.3, 15.7

Environmental impacts

Management of environmental impacts aims to balance the interest of development with the minimisation of environmental damage.

Environmental offsets

A major policy initiative over the past decade has been the increasing use of environmental offsets to compensate for impacts on matters that are protected that are not able to be sufficiently mitigated in a proposed action under the EPBC Act and most state and territory legislation. Environmental offsets are used to compensate for the residual significant impacts of an action (such as development) on matters that are protected, by offsetting with enhancement of the same environmental values at another site. More than 70% of development proposals assessed under the EPBC Act now include offsets as a condition of approval.

The growing dependency on offsets to protect matters of national environmental significance from the impacts of development is risky, given the lack of demonstrated successful outcomes, and inadequate monitoring and oversight. The Australian National Audit Office identified significant concerns with the increase in reliance on offsets, including lack of departmental guidance for reviewing offsets, of a quality assurance process for reviewing approved offset plans, of an agreed method for estimating averted risk, and of appropriate systems to map offsets for internal or external use. Many offsets required by approved development actions have not been implemented – that is, the land has not been secured. Where a funding mechanism is used, the funds for delivering offsets have been accumulating, and it is unclear how they will now be spent.

The effectiveness of offsets is often not evaluated after they are implemented, and it

is becoming clear that many types of impacts can be difficult to offset and that achievement of the underlying principle of at least ‘no net loss’ can rarely be demonstrated (Gibbons et al. 2018). Of 74 fully implemented offsets approved in Western Australia between 2004 and 2015, only 39% demonstrated a ‘successful’ outcome (May et al. 2017), although this did not necessarily mean that no net loss was achieved. Land acquisition offsets are often considered to have addressed the necessary mitigation through a change of tenure, but these offsets do not necessarily include management of threats, or ongoing management and monitoring. Some offsets have not been as effective in improving environmental outcomes as put forward in approved developments, and the lack of data to evaluate effectiveness means that outcomes are rarely publicly known. Offsets that exchange increased protection of existing habitat or vegetation for loss of other habitat can result in biodiversity decline over time. Recent research suggests that the ‘gain’ from protection alone is often overestimated, meaning that offsets are inadequate and net losses accumulate (Maseyk et al. 2021).

New approaches for environmental impact assessment

To move from unsustainable to sustainable development, a major transformation in environmental planning, assessment and reporting in Australia is required.

The current approach to environmental impact assessment across Australia is not meeting expectations in protecting the environment, including cultural heritage (ANAO 2020, Samuel 2020). The current process, where each proposal is developed and assessed individually, does not address cumulative impacts and does not adequately present a complete picture of the state of the environment. The process is also

often criticised for lack of repeatability and appropriate transparency. The environmental approval process requires significant improvement to provide confidence that it is protecting the environment according to agreed environmental standards.

In 2020, the Western Australian and Australian governments began work on developing a shared environmental analytics facility that brings together environmental data, information and models to provide efficient, robust, repeatable and transparent environmental information and analysis to underpin regional environmental assessment, planning, assurance and reporting (WABSI & WAMSI 2019). The objective is to reduce timeframes for assessment, increase consistency in objectives and standards, and provide more robust and consistent consideration of cumulative impacts.

Climate change mitigation and adaptation

Climate change mitigation involves strategies and actions to tackle the causes of climate change – for example, reducing greenhouse gas emissions (see ‘Greenhouse gas emissions’). Climate change adaptation involves reducing the impacts of climate change when they do occur – for example, the human and economic costs of higher-intensity storms and floods. Adaptation to climate change is being actively pursued across multiple levels of government, although the challenges in effective adaptation are formidable. There is an increasing awareness of climate risk, and willingness to address it, across the public and private sectors.

Emissions reduction

Emissions reduction programs operate at all levels of government and across the private sector. In 2012, the Council of

Australian Governments defined roles and responsibilities for the management of climate risk and climate change adaptation within the 3 levels of government, as well as the respective roles of governments and the private sector.

Australia has no federal Climate Change Act; however, a range of legislation covers various climate change-related activities at the national level. For example, Australian Carbon Credit Units (ACCUs) are defined and regulated under the *Carbon Credits (Carbon Farming Initiative) Act 2011* and associated Regulations. The Australian Government’s Emissions Reduction Fund (ERF) makes funds available through an auction process to support projects that reduce direct emissions or sequester carbon. In April 2021, \$108 million was provided to 10 projects to achieve 6.8 megatonnes of mitigation. The ERF also requires the largest emitters to keep emissions below a baseline or purchase credits to offset their excess. The ERF achieved 16 megatonnes of emissions mitigation in 2020, about 3% of average annual Australian emissions (CER 2021). The architecture for defining and measuring units of emissions and mitigation under the ERF (ACCUs) also supports voluntary offset schemes. Vegetation-related projects made up 58% of ACCU supply in the fourth quarter of 2020 and waste-related projects 35%.

Since 2001, the Renewable Energy Target (RET) has set targets for renewable energy generation. The 2020 target of 33,000 gigawatt hours was achieved in January 2021. Together with support for small-scale renewable energy (such as rooftop solar), RET targets achieved 37.3 megatonnes in mitigation in 2020. The Australian Renewable Energy Agency provides grants to support renewable energy projects, focusing on pathways to commercialisation for new technologies, with funding rounds for particular technologies and/or projects. It has

provided \$1.67 billion in funding for a total of 579 projects since 2012.

A wide range of state and territory programs support emissions reduction within their jurisdictions, in some cases complementing national programs. They include promoting renewable energy generation developments, identifying renewable energy zones for developing transmission infrastructure, purchasing renewable energy, and promoting local renewable hydrogen industries.

Transport initiatives to promote electric vehicles include the expansion of charging infrastructure, interest-free loans or direct purchase subsidies, and targets for purchasing zero-emission vehicles for government fleets and public transport. Infrastructure initiatives include minimum energy efficiency standards for new buildings, energy audits, and assistance for improving energy assistance for existing buildings.

Australia has committed to net zero emissions by 2050, including all states, with the exception of the Australian Capital Territory, which has committed to the early target of 2045, and Tasmania, which has committed to the early target of 2030. States can also include state-level emissions targets, or a process for setting them, and requirements for decision-makers under other legislation. Some local councils have emissions reduction targets. Tasmania has reduced emissions to date by 109% since 2005, due to its large forested carbon sinks and carbon-neutral hydroelectricity, and South Australia has achieved reductions of 32.9%; however, emissions have increased 20.6% and 46.5%, respectively, in Western Australia and the Northern Territory.

General government approaches at all levels include targets for low-emissions outcomes in government purchasing (e.g. of vehicles), installation of solar panels on government buildings such as schools, and capture

and re-use of gases generated in waste management facilities, in conjunction with local government. More efficient street lighting and bulk purchases of renewable energy are also major emissions reduction initiatives for local governments in urban areas. Land-use programs include regulation of land clearing and support for carbon farming. For example, Indigenous communities are working with local authorities to establish tropical savanna regions as a carbon sink by promoting traditional burning early in the dry season to limit destructive fires later in the season.

Climate change adaptation

Some level of climate change is ‘locked in’ because today’s emissions will continue to influence future climatic conditions. Managing climate change impacts requires a high level of adaptive management to adjust to the actual and anticipated effects of climate change. Because climate change is an extensive, complex and rapidly developing issue, action in this area should be multidisciplinary and multistakeholder, and take a cooperative, open and shared approach. The lack of cooperative engagement in climate change adaptation at the national level is noticeable and has worsened in the past 5 years. For example, Australian Government funding for its National Climate Change Adaptation Research Facility, which started in 2008, was discontinued in 2017, leading to its effective closure in 2019, although some functions (e.g. CoastAdapt) continue under the auspices of Griffith University.

Coastal adaptation is required but is in its infancy in Australia (Ramm et al. 2017). Actions may include moving houses or infrastructure out of an impact zone; retrofitting accommodation, such as raising floor levels and protection; installing hard engineering structures, such as seawalls; and using soft engineering options, such as

beach nourishment or replenishment, beach scraping and dune management. Despite the establishment of a national CoastAdapt program in 2016–17, responsibility has since shifted to the states and territories. State governments are considering how erosion and inundation will affect coastlines, short-term impacts of individual storms, and longer-term trends such as coastal recession in response to sea level rise. Most states have guidelines on how to undertake coastal hazard assessments and consider nature-based options, such as restoring coastal wetlands.

Climate change management needs to consider that some loss will be inevitable, and to manage for the impacts of loss on the community, which have been found to affect people's sense of place and connection to place, and to increase general anxiety about climate change (e.g. Seekamp & Jo 2020).

Climate change is increasingly recognised in threatened species recovery planning as a current and future risk. However, only a relatively small proportion of recovery plans that list climate change as a threat actually identify any specific actions to mitigate the threat, other than monitoring change (Hoeppner & Hughes 2019). Managing and reducing other threats that reduce the resilience of threatened species populations to climate change are often prioritised but rarely linked to the specific threats of climate change.

Australia's current management of climate change impacts on the marine environment is mostly reactive (after an event). Various reactive regulatory measures have also been used in response to extreme events such as marine heatwaves and tropical cyclones, including fishery closures, zoning changes, restocking (Oliver et al. 2017, Caputi et al. 2019), and changes in harvest rules in reef fisheries (Hodgkinson et al. 2014). However, proactive 'climate-ready' management informed by both short-term forecasts and long-term

climate projections (e.g. reports from the Intergovernmental Panel on Climate Change) is emerging. For example, adaptation planning has been initiated in several Commonwealth fisheries (Fulton et al. 2020), based on long-term projections for exploited stocks (Fulton et al. 2018, Pethybridge et al. 2020).

In coral reef management, the Great Barrier Reef Marine Park Authority has an early warning system for coral bleaching, comprising real-time monitoring (e.g. Garde et al. 2014) and seasonal prediction tools (e.g. Smith & Spillman 2019). Long-term management is informed by 2 climate change adaptation plans (2007–12 and 2012–17) and the resilience blueprint for the Great Barrier Reef.

In marine conservation, management has focused mainly on the drivers of biodiversity and habitat loss, and commensurate responses such as managing overfishing and reducing pollution. However, as climate change is a key driver of habitat loss and ecosystem disruption, restoration can be a complex and multifaceted response. Increasingly, 'assisted' restoration, such as the use of populations or stock specially bred for resilience, and ecological-engineering solutions are being used. These include protecting existing biodiversity and corals from cumulative pressures, using strategies to shade reefs (Baird et al. 2019), assisting reefs to adapt to increasing temperatures, and restoring degraded high-value sites. As the biodiverse giant kelp forests of temperate rocky reefs are already in decline, thermally tolerant giant kelp from remnant forest patches is being investigated as potential foundation stock for reforestation (Wood et al. 2019).

Extreme events management

Responsibility for preparing and responding to extreme events ranges from individuals and

communities to local, state and territory, and national levels of government, guided by the UN Sendai Framework (UNDRR 2015). Australia has recently shifted its emphasis from primarily responding to extreme events to additional investment in preparedness, impact mitigation, resilience and recovery. Australia established a new National Recovery and Resilience Agency in 2021. As well, \$209 million has been invested in a new Australian Climate Service to integrate national data, tools and platforms to provide a single authoritative source of information to support policy, management and operational decision-making.

State and territory governments have primary responsibility for protecting life, property and the environment within their borders, and have established plans to respond to, and recover from, extreme events. The operational agencies that respond to extreme events and their impacts are also predominantly resourced by, and responsible to, state and territory governments, as are the agencies that manage land that is not privately owned. The roles, responsibilities and relationships between emergency services, metropolitan and rural fire authorities, volunteers, land management agencies and local government vary in each state and territory. Planning standards and regulations, usually determined at local and state level, are very important in mitigating the impact of extreme events.

Current management approaches to extreme events vary in effectiveness, depending on the risk. Although management of floods and cyclones is generally good, the increasing impact of heatwaves and bushfires is not yet well managed, and some groups remain exposed to serious risks. Likewise, environmental impacts are expected to intensify.

The Royal Commission into National Natural Disaster Arrangements (Binskin et al. 2020) made recommendations about how to better prepare Australia for climate-related extreme

events. The Australian Government broadly accepted all recommendations, and a series of policy proposals is addressing the integration and coordination of national responses. Inquiries into natural disasters by state and territory governments over the past few years are similarly driving policy responses. Industries, communities and nongovernment organisations are also starting to address the question of how to enhance community, business and environmental resilience.

Historically, planning regulations have put the protection of people first, the protection of assets second and the protection of the environment third. This has downplayed the wellbeing implications of connections between people and the environment, which has particular implications for Indigenous people's connections to Country. In terms of domestic structures, the focus has been on the protection of occupants rather than resilience. However, as the climate changes, existing design assumptions that underpin our built environment are changing, including infrastructure design, building standards, land planning and how to address increasingly unviable (or uninsurable) properties. Decisions about land-use planning, zoning, development, infrastructure, construction and environmental management can all affect a community's exposure or vulnerability to hazards, and the magnitude of impacts. Following multiple extreme events since 2016, the Northern Australia Insurance Inquiry (ACCC 2020) recommended that the insurance industry work with Standards Australia to develop voluntary standards for improved resilience to natural hazards, both for new homes and for the retrofitting of existing dwellings.

On land, examples of adaptation to extreme events include the OneHouse project to design a traditional 'Queenslander' home built with readily available materials that would resist flood, bushfire and cyclones (Suncorp

2021), and would require minimal repair after an extreme event. Another example is the University of Adelaide Environment Institute's Unified Natural Hazard Risk Mitigation Exploratory Decision support system (UNHaRMED), which is an interactive modelling platform that enables planners to assess risks from multiple hazards, consider economic and population changes, and model the effects of different risk reduction options.

Invasive species management

Invasive non-native species are considered one of the greatest direct threats to threatened and endangered species in Australia in the short term (see 'Invasive species and range shifts'). Managing invasive non-native species for multiple Australian ecosystems is the most cost-effective management strategy for reducing the extinction risks for threatened and endangered species (Firn et al. 2013, Chadés et al. 2015, Ponce Reyes et al. 2016, Kearney et al. 2018, Woinarski et al. 2019, Geyle et al. 2021). Effective species-led and ecosystem-based invasive species management strategies and implementation plans are a key to effective biodiversity conservation (Carwardine et al. 2019).

The EPBC Act (for impacts on listed species and ecological communities) and the *Biosecurity Act 2015* (for broader human, agricultural and ecosystem impacts) govern the legal obligations to manage impacts of invasive non-native species in Australia and its external territories. All states have complementary biosecurity Acts. The Australian Government is responsible for offshore and international border management, while the states and territories have primary responsibility for incursion and impact management within their borders (see 'Biosecurity and sources of invasive species').

The huge burden of already established invasive species continues to grow in both land and sea environments. Monitoring in marine and coastal ecosystems is managed on an ad hoc basis, and we do not understand the extent or trajectory of introduced species (or whether they will become pests) in these systems. Only 4 jurisdictions (the Northern Territory, Queensland, Victoria and Western Australia) use active surveillance approaches for marine pests. The main vectors for the introduction of marine pests are transport in ships' ballast water, biofouling on hulls and introduction through the aquarium trade. Australia has developed a national strategic plan – *MarinePestPlan 2018–2023* (DAWR 2018) – to build capacity to respond to and manage the threat of marine invasive species. The plan outlines 5 objectives:

- Minimise the risk of marine pest introductions, establishment and spread through the management of ballast water and biofouling.
- Strengthen the national marine pest surveillance system.
- Enhance Australia's preparedness and response capability for marine pest introductions.
- Support marine pest biosecurity research and development.
- Engage stakeholders to better manage marine pest biosecurity.

A new national strategy for managing weeds has been released (Invasive Plants and Animals Committee 2017b), and a revised list of target weed species is being developed through the National Established Weed Priorities Framework (Wild Matters 2020, 2021).

Pest animals are listed on the Exotic Environmental Pest List (ABARES 2020b), and there is a list of threat categories of non-indigenous vertebrates (Environment and Invasives Committee 2018). A new national

strategy for managing pest animals has been released (Invasive Plants and Animals Committee 2017a), and this is supported by several species-specific plans:

- National Wild Dog Action Plan 2020–2030 (AWI 2021)
- National Feral Pig Action Plan 2021–2031 (APL 2021)
- National Invasive Ant Biosecurity Plan 2018–2028 (Environment and Invasives Committee 2019)
- National Feral Deer Action Plan (draft) (NFDAP 2021).

There is also a nationally coordinated but regionally led program tackling the millions of feral cats in Australia under a threat abatement plan (DoE 2015a). Each state and territory conducts feral animal control of a range of species, particularly feral pigs and deer, with differing degrees of success. Several conservation nongovernment agencies also conduct widespread feral animal management on their estates.

Significant work is required to complete and implement action plans for managing all national priority exotic weeds, pests and diseases, including risk mitigation measures, surveillance, diagnostics and the most appropriate management responses.

The Australian Government appointed the first National Feral Deer Management Coordinator in 2020, who will support community-led deer control in all states and territories across Australia and facilitate co-development of a National Feral Deer Action Plan. A similar model is in place for feral pigs: the Australian Government is supporting a National Feral Pig Management Coordinator, appointed in 2020, to facilitate the delivery of feral pig management approaches.

Australia is currently spending more than \$60 million a year on eradication programs for

5 ant species – seeking national eradication of red imported fire ants, electric ants and browsing ants, and partial eradication of yellow crazy ants (wet tropics of Queensland) and Argentine ants (Norfolk Island) because of their potential for devastating harm to wildlife and impacts on people. The Australian Government has committed \$15.2 million towards the development and potential implementation of the National Carp Control Plan to determine the feasibility of using cyprinid herpesvirus 3 (the carp virus) as a biological control agent for carp, as part of an integrated landscape-scale control effort (McCull & Sunarto 2020).

The successful management of invasive species is a huge challenge that is currently beyond the resources available. Even more innovation will be required, such as commercialisation of new technical and digital solutions, and ensuring a social licence for emerging technologies (CSIRO Futures 2020).



Case study Innovative biological control helping red crabs to recolonise and migrate across Christmas Island

Dr Andy Sheppard, CSIRO

Christmas Island in the Indian Ocean is famous for its red land crabs, an ecological keystone species, along with more than 20 other species of endemic land crabs. Invasive yellow crazy ants (*Anoplolepis gracilipes*) have killed tens of millions of red crabs on the island, as well as decimating the island's population of the world's largest robber crab, the biggest terrestrial arthropod on earth.

Since the early 1990s, yellow crazy ants have created supercolonies, sometimes covering hundreds of hectares, with thousands of queens and up to 10,000 ants per hectare (Parks Australia 2015). This has been driven by mutualistic relationships that the ants developed with introduced honeydew-producing scale insects, especially the yellow lac scale (*Tachardina aurantiaca*).

In December 2016, a biocontrol agent was released to indirectly suppress yellow crazy ants. The agent uses a natural enemy of yellow lac scale, the parasitoid wasp *Tachardiaephagus somervillei* from Malaysia. The wasp acts to suppress the population of yellow lac scale, reducing the supply of honeydew.

Following release of the wasp, ant numbers declined sufficiently at 3 of the 8 monitoring sites to allow recolonisation by red crabs. In 4 of the monitoring sites, red crabs were able to safely migrate through the area (Parks Australia 2021). This is a significant success story, as it is both the first biocontrol of invasive ant populations and the first indirect biocontrol program in the world.

Although many sites still support supercolonies of ants, fuelled by honeydew from other scale insects, the success so far gives confidence that targeting these other scale insects could achieve self-sustaining, long-term suppression of yellow crazy ants throughout Christmas Island.



Photos: Crab – Parks Australia (2015); scale insect – Parks Australia (2021c); wasp – Ong et al. (2019)

Figure 31 Clockwise from top left, red crab, scale insect and parasitic wasp

Pollution management

State and territory governments have the main responsibility for managing waste through legislation, policy, regulation, strategy and planning, as well as permitting and licensing waste transport, storage, treatment and disposal operations. Challenges facing the sector include the diversity and inconsistency of approaches across jurisdictions (DoE 2013), and the lack of a requirement for re-use and recyclability of materials to enable economies of scale and identification of new markets for recycled material. To help manage these challenges, the Australian, state and territory governments, together with the Australian Local Government Association, updated the National Waste Policy in 2018. The policy describes a strong ambition to move towards a circular economy that manages materials sustainably.

The 2019 National Waste Policy Action Plan includes reducing the waste generated in Australia by 10% per person by 2030, 80% resource recovery from all waste streams by 2030, and significant increases in the use of recycled content and the phasing out of unnecessary plastics by 2025. Other local, state-based and national activities are designed to reduce waste losses to the environment. These include legislation to implement beverage container deposits, bans and levies on plastic bags, bans on single-use plastic, drink refill stations, and separation of waste at the household level (e.g. Schuyler et al. 2018, Willis et al. 2019).

Over the past 5 years, considerable progress has been made on developing and implementing waste management programs for marine plastics and debris (particularly for waste that originates on land). But these have been insufficient to reverse pressures on the Australian coastal and marine environments. Plastic pollution and marine debris were

identified as a key threatening process to vertebrate marine life under the EPBC Act because of the potential for ‘injury and fatality ... caused by ingestion of, or entanglement in, harmful marine debris’. Successive management plans have identified the sources and types of harmful marine debris and actions required to reduce impacts. The Australian Fisheries Management Authority, the Australian Maritime Safety Authority, the Maritime Border Command and Parks Australia have coordinated efforts for clean-ups of discarded debris (e.g. Parks Australia 2021a).

The management of marine vessel activity in Australian waters identifies most environmental threats and protects environmental values. Use of low-sulfur fuel oils was made mandatory from January 2020. However, only a limited number of noise-producing activities are regulated – shipping, and oil and gas exploration activities are the largest source of human noise that can affect many marine species.

Oil spills from Australia’s offshore oil and gas industry have the potential to cause adverse impacts on the marine environment. The environmental impacts of the oil and gas industry are understood and well managed, with increasing levels of preparedness for unplanned events (Evans et al. 2021a); however, the effects, if an event should occur, can be significant. Most oil and gas exploration, extraction and production activities are conducted in Commonwealth waters, and most mining activities occur in coastal waters under state and territory jurisdictions. The National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) is the sole regulator for the offshore oil and gas industry, and greenhouse gas storage activities in Commonwealth waters. Since 2016, NOPSEMA has reported high levels of compliance by the offshore oil and gas industry, and few

environmental incidents. Although there is no regulatory framework for offshore clean energy infrastructure, a draft discussion document was released in February 2020, and policy is being developed, with NOPSEMA proposed as the regulator for offshore clean energy developments.

Air pollution

Management of air quality in Australia is a cooperative effort by all levels of government. The Australian Government sets emissions and fuel standards, and is responsible for the National Pollutant Inventory and international obligations.

Because air pollution comes from multiple sources, such as the combined impacts from motor vehicles and wood heaters, it requires an integrated management approach. Encouraging the oldest and dirtiest vehicles off the road, as well as improving fuel standards, would rapidly improve air quality, as would the provision of more reliable public transport to encourage people out of their vehicles. Legislation forcing appliance manufacturers to improve burn efficiencies for wood heaters is being developed in New South Wales. As urban areas are well served by gas and electrical infrastructure, such heaters could be banned in cities to improve air quality in winter. In addition, protecting the health of populations, particularly children, living near large industrial plants should be prioritised via targeted emissions reductions.

Natural sources of air pollution are difficult to control, although some actions can be effective (e.g. increasing groundcover to reduce dust, reducing fuel loads in bushfire-prone regions). Anthropogenic (human) sources can be controlled through strategic air quality policy.

The Commonwealth *National Environment Protection Council Act 1994*, combined with

complementary state and territory legislation, enables Australia's National Environment Protection Council to make National Environment Protection Measures (NEPMs), which are designed to protect Australians from air, water, soil and noise pollution. The council also reports annually on the implementation and effectiveness of NEPMs across Australia. This mechanism provides an agreed, nationally consistent framework of goals, standards, guidelines and protocols for protecting and managing particular aspects of the environment, including air, water, noise, site contamination, hazardous waste and recycling.

State and territory governments are responsible for implementing NEPMs, for state-based licensing of industrial facilities, for legislation, and for reporting progress on NEPM goals. Local governments are responsible for managing air pollution through their urban planning processes.

Air quality monitoring is undertaken by the states and territories 365 days a year, and all jurisdictions are required to report annually on compliance with air quality standards. The information generated is uneven as there are only 211 fixed air quality monitoring stations in operation around Australia, not all of which are NEPM-compliant. Air quality monitoring stations in populated areas with air pollution concerns, such as within the industrial regions of the Hunter Valley in New South Wales and Brooklyn in Victoria, can capture ambient air quality measurements representative of a local area. However, monitoring stations are generally not sited in hotspot areas, such as next to a busy road or in the path of a chimney effluent. Likewise, large parts of inland Australia, particularly in the north and west, have little to no monitoring coverage. Recommendations from New South Wales on the design of an air quality monitoring network are to be adopted nationally (OEH 2019). This

includes the need to increase the number of monitoring stations as the population of a region expands beyond 25,000 people, so that the recent NEPM requirement to assess population exposure to air pollutants can be met.

Government policy and regulation could be improved with an exposure minimisation approach (Zosky et al. 2021). This requires new NEPM targets for air pollution, an increase in air quality monitoring infrastructure, the active participation of industry and residents, and supporting legislation to encourage behavioural change. The National Clean Air Agreement, agreed to by all Australian environment ministers in 2015, is a framework to help governments identify and prioritise actions required to maintain and improve air quality. The initial work plan of the agreement (DoE 2015b) was carried out between 2015 and 2017, and was reviewed in 2018.

Although Australia's Air Quality Index system is designed to communicate air pollution levels and associated health hazards to the general public, reported concentrations of air pollutants are often meaningless to the public unless they are accompanied by a description of whether the concentration might be harmful to health. In addition, NEPM standards are different for each pollutant, making comparisons difficult. The Black Summer 2019–20 bushfires revealed that 24-hourly average measurements of fine particulate matter (PM_{2.5}) were not sufficient for members of the public looking for real-time information; the Royal Commission into the bushfires recommended that a standard hourly reporting system be designed and used in Australia (Binskin et al. 2020). Australian jurisdictions are working towards unifying how they report air quality levels for clearer public messaging.



Photo: John Barker and the Australian Government Department of Agriculture, Water and the Environment

Figure 32 Dust monitoring station, Wentworth

Cumulative impact management

Cumulative impact management considers direct, indirect and consequential impacts, and the incremental and compounding effects of impacts over time, including past, present and reasonably foreseeable future pressures (GBRMPA 2019) (see ‘Cumulative pressures’). Long-term monitoring is required to measure and assess interactions between pressures that together form a cumulative pressure, to inform adaptive management that responds to changing conditions.

Generally, pressures on the environment are considered and managed individually, and opportunities for more strategic approaches that can consider landscape-scale management are not commonly used. Although the EPBC Act stipulates that direct, indirect and offsite impacts (specifically upstream, downstream and facilitated impacts) on matters of national environmental significance should be considered when planning activities and undertaking broadscale strategic assessments, it does not explicitly address cumulative effects (Dales 2011, Dunstan et al. 2019). The Act does provide for strategic environmental assessments (SEAs) that can evaluate cumulative effects, and develop management and planning outcomes at a broader scale. Analysis of the 12 SEAs completed up to 2018 showed that cumulative impact assessment was commonly either ‘not present’ or ‘weak,’ even though the SEA guidance document specifically states that cumulative impacts relating to EPBC Act triggers should be considered or described, and analysed.

The 2020 independent review of the EPBC Act found that, under the current settings, cumulative impacts on, and threats to, the environment are often not well managed. Development assessment and

approval decisions are largely made on a project-by-project basis, with the assessment of impacts largely done in isolation of other current or anticipated projects. This approach underestimates the broadscale cumulative impacts that development can have on a species, ecosystem or region; redressing this is a recommendation of the recent EPBC Act review (Samuel 2020).

Moreover, the increasing focus on implementing ecosystem-based management approaches requires understanding of how human activities influence and reshape ecosystems (Levin et al. 2009), which requires taking a systemic and integrated view of all pressures. Plant and animal species are less resilient when the ecological communities of which they are part decline or change, or when populations become isolated. The cumulative effect of multiple pressures over many decades across whole regions and landscapes, especially in intensive land-use zones, exacerbates fragmentation and further contributes to reductions in the quality of remnant native vegetation as habitat for Australia’s unique flora and fauna. Recognising the cumulative and indirect effects of these impacts, and actively maintaining and re-establishing structural and functional connectivity across systems contribute to ecosystem resilience (DAWE 2020a).

There is a greater recognition that more regional integrated planning assessments are required to look across a broad range of issues, options and futures; these need to be adaptive to uncertainty in the face of accelerating climate change. Although several major assessments have been completed since 2016, these have tended to focus on specific assets (e.g. the northern Australia water resource assessments completed in 2018–19).

Climate change is predicted to have an amplifying impact on many existing pressures on the Australian environment and heritage,

including through more extreme drought and floods. For example, recent drought conditions exposed the difficulties of maintaining critical environmental flows in extreme dry conditions in highly developed systems such as the Murray–Darling Basin. In 2018, the Australian Government Disaster and Climate Resilience Reference Group developed a climate risk management framework that can be used to assess vulnerabilities and explore adaptation options to deal with cumulative impacts in planning (CSIRO 2018). There is an immediate need for heritage risk assessments, risk preparedness and adaptation management plans to consider climate change.

The many different pressures on the Australian marine environment are generally (and increasingly) well understood; however, assessing the cumulative impacts of the interactions and feedbacks among these diverse pressures remains a key challenge for sustainable management. Since 2016, pressures have typically still been treated individually by sector. An exception is the Great Barrier Reef, where the Reef 2050 Long-term Sustainability Plan sets out key actions for managing cumulative pressures. The development of the Great Barrier Reef Cumulative Impact Management Policy in 2018 provides a framework to mitigate or reduce cumulative impacts; the policy is supported by scientific guidelines on how to assess cumulative risks and impacts on the Great Barrier Reef.

To improve the scientific evidence base and available decision support tools for managing the impacts of multiple and cumulative drivers and pressures on marine systems, and the integration of social, economic and cultural factors into marine estate assessments, the National Marine Science Committee has established an Integrated Ecosystem Assessment (IEA) Working Group to examine the applicability of the IEA approach in

Australia. The group has reported on potential case studies and recommended a national trial. IEAs offer a process for identifying trade-offs in the management of different marine industries and sectors, identifying cumulative impacts, and dealing explicitly with uncertainty (Smith et al. 2021a).

The cumulative impacts of multiple forms of water extractions – including the interception of overland flows, farm dams, and mining and petroleum activities – need to be appropriately included in water accounts to avoid undermining environmental objectives. Although some progress has been made in ensuring that such activities are considered in water management and planning, they have not yet fully met the objectives of the 2004 National Water Initiative. Future cumulative impacts from improvements in irrigation efficiency, which reduce return flows to rivers or groundwater systems, are largely unaccounted for but can be reasonably foreseen. Effective management of interception activities will become more important as Australia's climate changes, particularly for systems that are expected to have less water (Productivity Commission 2021b).

Over the past 5 years, several bioregional assessments of the potential cumulative impacts of existing and proposed coal and coal-seam gas developments on the environment of central and eastern Australia have been undertaken (Australian Government 2020). In 2021, a geological and bioregional assessment was published on the potential impacts of shale and tight gas development on water and the environment in central and northern Australia (Australian Government 2021a).

Resources

Environmental management cannot be effective without adequate supporting resources. These resources are not just funding, but also data, staff, volunteers and new technology.

✓ **Assessment** Resources



Resources available for environmental management are generally insufficient to arrest ecosystem declines. The level of funding, and the quantity, quality and consistency of data, in particular, need improvement. Accountability, coordination between agencies and levels of government, Indigenous involvement, and skills (e.g. taxonomy) also need to be improved. Citizen science and the development of new technologies are important enablers of environmental management.

Assessments of management effectiveness range from ineffective to partially effective
Assessments of trend range from deteriorating to unclear
Related to United Nations Sustainable Development Goal targets 11.3, 11.4, 15.5, 15.a, 17.16

Funding

Total investment in environmental management and protection across governments, industry and private citizens is difficult to determine; however, the negative trend in indicators across all areas of the 2021 state of the environment report suggests that our current levels of investment have been unable to slow the decline in the state of our environment. Current funding allocated by the Australian, state and territory governments for

environmental protection, including heritage and threatened species, is inadequate for the task and generally lacks accountability.

There is a significant shortfall in the investment required to manage Australia's unique environments. This is borne out in the declining trajectories of many species, and in the increasing extent and magnitude of threatening processes and pressures.



Case study Australians investing in natural capital

Source: Kilter Rural

Every year, trillions of dollars are available in the private market for investment. And there is a growing demand for investment products that deliver environmental benefits as well as financial profit for investors.

Finding ways of mobilising private funds for projects that achieve economic and environmental protection outcomes, while delivering sustained and low-risk returns to investors, is one avenue for significantly increasing the amount of funding available to restore and protect Australia's environment.

In Australia, a growing number of businesses are seeking to tap into this market by mobilising new institutional capital into agricultural, water and ecosystem investment projects. In Victoria, Kilter Rural has been working for decades to achieve sustainable agricultural production while managing its total natural capital assets to include substantial environmental protection and restoration. Balancing agricultural production with environmental protection delivers sustained returns to investors with reduced risk.

Kilter Rural has 2 impact investment funds with around \$500 million in assets:

- The Kilter Australian Farmlands Fund offers investment in natural capital through the purchase and regeneration of Australian farmland and water. Financial returns are delivered through the regeneration of underused irrigation farming operations for high-value specialist crops, balanced with ecosystem protection to deliver long-term returns to investors (70/30 area split). In 2021, Kilter has about 12,000 hectares under management. Within the irrigated cropping area, up to 40% of the farms are designated for organic crop production. Approximately 4,000 hectares of native revegetation delivers biodiversity rehabilitation and protection along with a net carbon sink, with

intended total fund returns of 10–12% per year. The fund has several carbon projects registered with the Australian Government to accumulate Australian Carbon Credit Units.

- The Murray–Darling Basin Balanced Water Fund secures water for agriculture and the environment through investment in Australia’s southern Murray–Darling Basin water market. In dry years, up to 90% of water entitlements are allocated to irrigators through leases and allocation trade; in wet years, up to 40% of the fund’s entitlements are allocated to deliver water to wetlands. This approach ensures that water is available for farming communities when they need it most, with wetland watering occurring primarily in years when water is less constrained. The fund is jointly managed by Kilter Rural and the Nature Conservancy Australia with the Murray–Darling Wetlands Working Group, which collaborate closely with state and national environmental water holders. Since 2015, more than 6,000 megalitres has been delivered for environmental watering over 26 wetlands. In 2021–22, the fund will donate close to 4,000 megalitres of water to the environment. The fund has delivered returns of around 13% annualised since inception.



Photos: © Sarah Ning, Murray–Darling Wetlands Working Group

Figure 33 O’Kanes Swamp, Victoria, before and after watering

Australian Government funding

Since 2013–14, the Australian Government’s overall investment to ‘conserve, protect and sustainably manage Australia’s biodiversity, ecosystems, environment and heritage through research, information management, supporting natural resource management,

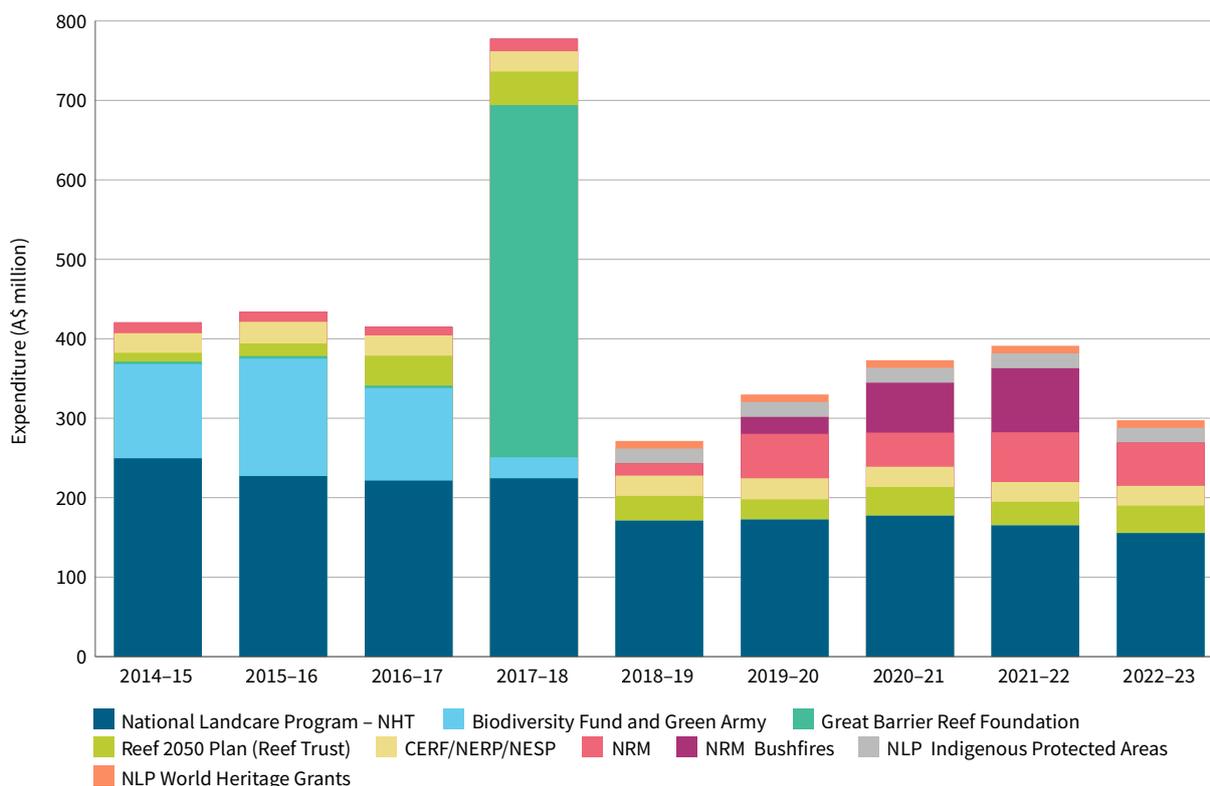
establishing and managing Commonwealth protected areas, and reducing and regulating the use of pollutants and hazardous substances, and coordination of climate change adaptation strategy and climate change science activities’ (DAWE 2021a) has seen reductions in some areas, and increases

in relation to addressing impacts on the Great Barrier Reef and from the 2019–20 bushfires.

Since 2010, biodiversity expenditure remained between \$400 million and \$500 million per year (less than 0.05% of gross domestic product), then dipped below \$300 million in 2018–19, and has been under \$400 million thereafter. National Landcare Program funding has decreased, there is no longer funding for new national reserves, there have been cuts to biodiversity research at CSIRO, and the national Climate Change Adaptation Research Facility was discontinued in 2019. The Great Barrier Reef is one area that received significant new funding, with an estimated investment of more than \$2 billion by the

Australian and Queensland governments for implementation of the Reef 2050 Plan.

The funding of the environmental objectives of the Australian Government Department of Agriculture, Water and the Environment for the past 8 years is shown in Figure 34. A major one-off investment of \$443 million was made to the Great Barrier Reef Foundation Partnership (see ‘Freshwater and marine funding’). The remaining investment across all areas was \$800 million in 2017–18, declining from an average of \$886 million per year over 2013–17. A further investment in bushfire recovery funding between 2019 and 2021 raises the total investment in those years, but the overall investment in the core



CERF = Commonwealth Environmental Research Facilities; NERP = National Environmental Research Program; NESP = National Environmental Science Program; NHT = Natural Heritage Trust; NLP = National Landcare Program; NRM = natural resource management

Note: Excludes funding for Antarctica, which is funded under a different objective; energy funding, which has since been transferred to a different portfolio; and the core funding for meteorology, given that its core function is to support non-environmental objectives of society (noting that it does also support Australia’s research effort in climate).

Figure 34 Australian Government funding for environmental objectives

environmental areas is lower than the pre-2017 funding levels.

State and territory funding

Whereas the Australian Government has responsibility to meet its national and international obligations to protect Australia's environment, the states and territories hold the largest responsibility for environmental management in Australia (see 'National, state and territory legislation and policy').

Although not every jurisdiction produces a state of the environment report, there is significant evidence of inadequate investment to meet jurisdictions' statutory responsibilities. For example, in Victoria, the objectives of the *Flora and Fauna Guarantee Act 1988* include 'to guarantee that all of Victoria's flora and fauna ... can persist and improve in the wild', and 'prevent ... flora and fauna from becoming threatened and to recover threatened' species so that 'their conservation status improves'.

However, a recent audit by the Victorian Auditor-General (VAGO 2021) found:

Funding available to DELWP to protect species falls significantly short of what it predicts is needed. However, DELWP has not provided detailed, evidence-based advice to the government about the cost and benefits of protecting and monitoring threatened species to support further investment. It also lacks performance indicators and reporting to demonstrate the impact of its management interventions on halting the decline of threatened species.

Environmental markets and environment, social and governance investment

Since 2016, conservation on private land has increased (see 'Protected areas'), and the private sector is increasingly investing

in the environment directly, either on its own, with government or with finance. Some approaches have potential for financial return with both private and public benefits, such as environmental markets; environmental offsets; and environmental, social and governance (ESG) investment. Philanthropy from individuals or companies tends to fund direct conservation, where there is often little chance of financial return.

Australia has significant and established experience in environmental carbon markets (i.e. the Carbon Pollution Reduction Scheme, the Clean Energy Act, the Carbon Farming Initiative and the Emissions Reduction Fund), and in water quantity trading. The Reducing Carbon Building Communities fund, backed by the Aboriginal Carbon Foundation, offers a way for buyers to identify projects that offer benefits beyond carbon, including protecting culturally significant natural areas (which can then also increase conservation finance flows into communities).

Environmental markets and certification systems are proposed to reward land managers for protecting and improving biodiversity, as a way to diversify, and potentially boost, farm income. Biodiversity markets are at different stages of development in Australia, and there is an opportunity to extend markets and payments for ecosystem services to landowners who demonstrate improved environmental outcomes in terms of water quality and soil health. Like the carbon market, a voluntary biodiversity credit market could be a game changer for conservation in Australia, allowing businesses to offset their biodiversity impacts.

ESG investment has increased significantly since 2016, allowing both individual and institutional investors to achieve social and environmental outcomes in addition to financial returns. From 2017 to 2019, the responsible investment market rose from

17% to 37% of Australia's total professionally managed assets (Wen 2020). This trend is seen for both institutional and individual investors – for example, 90% of millennials are looking to ESG investment instead of traditional investments (Wen 2020).

Private investment also can be in the form of green bonds and environmental impact bonds that support sustainable land management, as well as the use of private money to leverage philanthropic and government funds. The UN SDGs have encouraged more activity in this area. With Australia's top 4 export markets having net zero climate targets, it is possible that failure to achieve these environmental goals may have economic implications.

This area of investment requires scientifically credible and regularly measured metrics that can quantify and measure conservation, financial and social returns on investment (Ward & Lassen 2018). The UN System of Environmental–Economic Accounting (UNCEEA 2014, 2021) and the Queensland Land Restoration Fund's co-benefits standard (Land Restoration Fund 2020) are examples of frameworks that could be agreed on and applied for consistent and credible verification. A range of philanthropic and commercial entities are working on various aspects of the emerging natural capital marketplace to catalyse private sector and ESG investment at scale. Governments could significantly boost this by creating an enabling environment for finance and investment in private conservation, so that innovative financing can expand private and public investment in nature, such as through the National Reserve System.

Threatened species and environmental restoration funding

Recent reviews have highlighted that existing programs and funding for recovering

threatened species are insufficient to achieve this goal (Samuel 2020, VAGO 2021).

Biodiversity conservation and research are undertaken through a range of efforts, at state and local government levels; through nongovernment organisations, community groups, industry, Indigenous rangers and Traditional Owners; and through other Australian Government initiatives, and so it is difficult to understand the full extent of investment benefiting biodiversity across Australia.

It is possible to examine the amount spent by government on recovery of threatened species. Wintle et al. (2019) estimated that the targeted threatened species spending for 2018–19 by the Australian Government was \$49.6 million, and the total annual spending from all Australian governments is around \$122 million, but that is only about 15% of what is needed to avoid extinctions and recover threatened species (which is estimated at \$1.69 billion dollars per year) (see also 'Threatened species and communities'). The efforts of the private sector, local government, nongovernment organisations and private citizens make a significant contribution to threatened species recovery and are not included in the estimates in Wintle et al. (2019). There are also many caveats associated with the estimates, in part because clear reporting on expenditure is not available, and the costs of managing pressures are very difficult to estimate.

Another measure of financial adequacy is the amount needed for environmental restoration more broadly in Australia, which has been estimated at approximately \$10 billion annually (Ward & Lassen 2018) – this is substantially greater than current levels of investment. The independent review of the EPBC Act noted that, although it is unrealistic to expect government and the taxpayer to fund this level of investment, attracting



Case study The Australian restoration economy

Renee Young, Western Australian Biodiversity Science Institute

Australia, as a large, sparsely populated, politically stable country, is well placed to take advantage of major national and international investment opportunities through the restoration economy (Young et al. in press). The restoration economy is defined as the market consisting of a network of businesses, investors and consumers engaging in economic activity related to ecological restoration (BenDor et al. 2015).

Internationally and across Australia, major private, philanthropic and government investments are driving large-scale restoration efforts by obtaining carbon credits through biodiverse plantings. Carbon credits issued by the Clean Energy Regulator have increased from 100,000 tonnes (t) per month in 2018 to 350,000–400,000 t in 2020 (pre-COVID-19) (Foley 2021). The international market price for carbon is projected to double in the next 15 years (EDF 2018), and carbon projects that deliver co-benefits will return a premium price. Further, it is likely that industry will soon need to report on nature-related risks to support a shift in global financial flows towards nature-positive outcomes (TFND 2021), giving additional value and security to the market.

Australian philanthropists are pledging tens of millions of dollars to fight climate change – for example, Norman Pater and Gita Sonnenberg are aiming to restore 1 million hectares and testing carbon farming models at scale. Queenslanders Julie and Jeff Wicks set up the ACME foundation, which directs funding to 25–30 organisations, including Beyond Zero Emissions (Sommer 2020).

Investment in the restoration economy translates to jobs, predominantly in our regional communities. Government economic stimulus as a result of the COVID-19 pandemic has seen a boost in ‘green’ jobs, with direct funding going towards environmental projects. These include Western Australia’s \$15 million Native Vegetation Rehabilitation Scheme, which has created more than 1,000 jobs.

Coupled with these economic activities is the realisation that well-designed, biodiverse and knowledge-rich restoration has the capacity to deliver environmental, social, economic and cultural co-benefits that:

- support environmental assets such as improved biodiversity and habitat for threatened species, as well as healthier soils, wetlands and water systems
- improve the resilience and strength of regional communities by supporting direct and indirect jobs, and increasing economic opportunities
- provide on-Country business opportunities and new service delivery businesses, as well as supporting cultural and customary connections (Land Restoration Fund 2020).

greater private investment in natural capital and restoration of the environment requires national leadership (Samuel 2020).

A 4-year \$100 million Environment Restoration Fund commenced in 2019–20 and is delivered through a mixture of grants, procurement and specific-purpose payments to the states and territories. It focuses on 3 key areas: protecting threatened and migratory species; protecting coasts, oceans and waterways; and the clean-up and recovery of waste.

Research funding

Funding of the NESP is critical for environment and climate research in Australia, underpinning policy and on-ground management. The first phase invested \$145 million (2014–15 to 2020–21) into 6 research hubs. The second phase will invest \$149 million (2020–21 to 2026–27) into 4 new research hubs. NESP Phase 1 research has generated key content provided throughout this report. An ongoing challenge for NESP has been to appropriately recognise Indigenous knowledge and decision-making. NESP Phase 2 includes increased Indigenous inclusion in research. The NESP principles for Indigenous partnership include recognition of the right to Indigenous cultural and intellectual property, co-created research, and respect and mutual benefit (DAWE 2021h).

Environmental research funding is also made through competitive grant schemes (e.g. Australian Research Council, Cooperative Research Centres) under Australian and New Zealand Standard Research Classification Division 41 (environmental sciences), including groups for climate change, ecological applications, biotechnology, pollution, soil and other environmental science, and environmental management.

Scientific research to understand the status and trends of our environment relies on access to high-quality data, and world-class

research infrastructure plays a fundamental role. The Australian Government funds NCRIS (Table 2), which supports Australian researchers' access to national research infrastructure. NCRIS projects are led by universities, publicly funded research organisations and not-for-profit companies. Of more than 20 NCRIS projects, 5 focus on supporting the assessment and monitoring of our environment relevant to the state of the environment reporting framework, delivering fundamental infrastructure and data that help researchers in academia, government, the community and industry understand environmental state and change. This includes the Atlas of Living Australia, Bioplatforms Australia, the Integrated Marine Observing System, the Marine National Facility and the Terrestrial Ecosystem Research Network.

An area of ongoing concern across Australia is the inadequate level of funding provided to taxonomic research, to keep up with the need for the naming of the huge number of undescribed species in Australia. This limits our ability to truly understand environmental change. Reductions in the number of taxonomists employed in museums and herbariums is a key factor, along with our over-reliance on retired or honorary researchers. The Australian Government, through the Australian Biological Resources Study, manages the National Taxonomy Research Grant Program, which is only able to fund 1 in 6 grant applications. The annual contribution of \$2.03 million has remained unchanged for more than a decade, meaning that its ability to support the sector is declining in real value. This program includes a vital postdoctoral fellowship grant stream, which has an even lower success rate of grants. Following university training, many early-career researchers are unable to find long-term research positions or institutional tenure, and many leave the industry before becoming established taxonomists.

Table 2 Overview of major national environmental assessment, monitoring and data infrastructure investment through NCRIS since 2013

Year	NCRIS project				
	Atlas of Living Australia	Bioplatforms Australia	Integrated Marine Observing System	Marine National Facility	Terrestrial Ecosystem Research Network
2013–14	2,536,556	13,070,473	11,513,351	26,649,000	3,596,340
2014–15	3,228,348	8,258,442	6,859,017	29,107,000	4,577,160
2015–16	4,603,000	25,380,203	13,963,000	30,439,000	5,925,000
2016–17	4,696,000	4,114,200	15,573,697	31,690,000	6,044,000
2017–18	5,293,400	45,930,745	27,512,792	32,760,000	9,895,100
2018–19	4,933,735	19,817,161	17,667,424	40,883,000	6,954,178
2019–20	5,057,078	20,470,066	19,534,172	43,773,000	6,508,727
2020–21	5,696,889	26,849,484	20,622,396	41,495,000	8,326,928
2021–22	6,387,457	16,855,472	21,161,885	42,403,000	8,482,665
2022–23	7,864,437	34,867,085	24,124,615	42,752,224	12,962,691
Total investment	50,296,900	215,613,331	178,532,349	361,951,224	73,272,789

NCRIS = National Collaborative Research Infrastructure Strategy

Note: This does not include Australian Research Data Commons funding, which also includes environmentally focused data initiatives such as the Biodiversity and Climate Change Virtual Laboratory, EcoCommons and many shorter-term initiatives linked to NCRIS.

There is also minimal research funding available for heritage management, specifically for cultural heritage and geoh heritage. This is severely constraining the ability to improve the identification and understanding of this heritage, the ability to respond to the various pressures and the capacity for effective adaptive management.

Freshwater and marine funding

The Australian Government, states and territories, and industry continue to invest in water knowledge and research, but current

investment levels in water research in Australia are close to historical lows. Even at the peak funding levels of the mid- to late 2000s, the funding allocated to research was modest compared with the importance of the public policy issues at stake. In a joint submission to the Productivity Commission, the Australian Academy of Technology and Engineering, and the Australian Academy of Science noted that uncertainty in funding levels and the absence of effective funding mechanisms had degraded the potential efficiency and effectiveness of the water research community. Less

than one-third of the water research and development funding programs involve end users in governance of the research, or in undertaking rigorous performance and cost-benefit assessments.

Water research effort is also not coordinated at a national level. Environmental water management is a relatively new area of activity, which would benefit from increased knowledge to inform adaptive and integrated management. There is no national platform to coordinate generation and sharing of water knowledge, and no national process for identifying water research priorities, including in groundwater, integrated water management and Indigenous water. Given the scale of the challenges, investigation of a more coordinated approach is warranted.

In 2018, the Australian Government announced increased investment in protection for the Great Barrier Reef of more than \$500 million, including a one-off, \$443.3 million, 6-year Reef Trust Partnership with the Great Barrier Reef Foundation (a not-for-profit charity). The objective of the partnership is to ‘achieve significant, measurable improvement’ in the health of the Reef, in accordance with the Reef 2050 Plan, ‘underpinned by innovation, science and community engagement’. The Great Barrier Reef Foundation committed to leveraging a further \$300–400 million from partner co-contributions; \$157 million of the leveraging target is currently pledged from partner co-contributions and other funds, but there is no publicly available information on the breakdown of those contributions. As at 30 June 2021, the partnership has 200 projects underway with more than 300 partners. However, critics of this approach to environmental funding hold that the funds were too concentrated on a small organisation, and that it created potential duplication.

In April 2021, the Australian Government also announced a broader \$100 million Ocean

Leadership package. Of this, over the next 4 years, \$18 million will target practical actions to protect iconic marine species, improve the sustainability of our fisheries through reducing bycatch, commence national ocean accounting and encourage investment in our marine ecosystems.

Indigenous funding

The Australian Government Department of the Prime Minister and Cabinet funds the Indigenous Ranger Program, which has been extended from 2021 to 2028 at \$102 million per year to support activities that protect and manage land and sea Country and culture, including fire management, protection of threatened species and biosecurity compliance. However, further funding opportunities and initiatives are required to support the demand for, and growth in, IPAs, as well as the increasing value placed on traditional knowledge and engagement in biodiversity conservation, land management and research. Resources enable communities to shift from aspirations to developing, designing and monitoring their environment.

In concert with the Australian Government’s investment in ranger programs, state and territory support for Indigenous land and sea management practitioners has continued to grow. The Western Australian Government has invested \$20 million from 2017 to 2021 into its Aboriginal Ranger Program; this has now been increased to \$50 million between 2021 and 2025 to expand the program so that more Indigenous organisations can employ and train rangers to manage Country. In February 2021, the Queensland Government committed to doubling the number of its land and sea rangers to 200 positions, at an additional cost of \$24 million.

Heritage funding

Heritage funding is primarily a government responsibility, but funding to heritage agencies has been progressively cut or has remained the same since the mid-1990s, while the scale of work has increased. This has resulted in inadequate staffing levels, reduced staff expertise and a very limited opportunity to initiate research programs, including for heritage identification and condition monitoring. This is severely constraining the ability to improve the identification and understanding of heritage, to respond to the various pressures and to undertake effective adaptive management.

Government funding models have shifted from agency support to support for particular programs seen as priorities, with a competitive process for accessing these funds (e.g. World Heritage initiatives, National Heritage owners' grants). An updated funding model would allow better strategic planning and resources to protect and manage Australian heritage. Two types of funding are required: increased recurrent funding to agencies for adequate levels of skilled staff and core tasks (including monitoring, strategic planning and restoration); and special project funding for research and conservation, based on identified needs.

There is also room for industry funding for heritage; however, to avoid potential conflicts of interest, these need to be limited to appropriate activities, such as improved conservation on industry-owned or industry-managed land, or the repair of adverse legacies of industry. Private funding is generally focused on purchasing land for nature conservation. Private owners of heritage properties may also provide support through volunteer maintenance activities.

Data

Data and information form the basis of protection, strategic planning and adaptive management. As noted in the recent review of the EPBC Act (Samuel 2020), 'better data and information are needed to set clear outcomes, effectively plan and invest in a way that delivers them, and to efficiently regulate development'.

Many aspects of our environment are under-resourced in terms of routine inventory and condition monitoring. For example, much of Australia's heritage is poorly understood or monitored, although there are significant specific exceptions such as the Great Barrier Reef. There is limited sharing of data and no national data standardisation. Funding is needed for the coordination, sharing and management of heritage data nationally (du Cros 2019). Marine, coastal and freshwater management is complicated by the difficulties in collecting accurate ecosystem information from underwater environments and our inability to effectively manage diffuse sources of impacts in aquatic ecosystems, such as urban and agricultural run-off, marine debris, invasive species, recreational harvesting and climate change.

Data on land and its management have increased substantially since 2016, particularly with the delivery of an experimental National Land Account (DAWE 2021f) and Geoscience Australia's 'Digital Earth Australia', launched in 2018. Although the amount and type of data required for land management are improving, there is a lack of consistent, agreed methods to transform the data into products that support assessment of consistent indicators to drive aggregation and reporting of the information. Leadership is required to foster collaborative agreement on classifications and standards, and engagement of users to validate results and co-develop products

with data custodians, to encourage broad adoption across multiple programs of work. For example, current Australian Bureau of Agricultural and Resource Economics and Sciences datasets on land use and forests are well curated and policy-ready datasets that are accompanied by good-quality metadata and interpretive documentation.

The 2016 state of the environment report stated that ‘during the past few decades, there has been a massive increase in investment [in data collection] from industry as part of development approvals. However, much of the information collected is not available more broadly for decision-making (and no information is available on the size of that investment)’.

This has markedly changed in the past few years, beginning in Western Australia, where government and industry have worked together to begin a digital transformation of environmental impact assessment, driven by demands for increased efficiency, reliability and transparency. The first major steps have been the launch of the Index of Biodiversity Surveys and Assessments in 2018 and its marine counterpart the Index of Marine Surveys of Assessments in 2020. Together, these products capture \$90 million of industry-generated survey data per year to be made available as a resource for the better management of Western Australia. Further investments announced in 2020 by the Western Australian (\$25 million) and Australian (\$30 million) governments have seen the formation of a Biodiversity Information Office, Environment Online, and a Digital Environmental Assessment Program. This program will also feed information into a new Commonwealth Biodiversity Data Repository. These initiatives are a significant step towards creating a sustainable data value chain that incorporates industry, state, national, research and community data. They were highlighted

in the 2020 Samuel Review of the EPBC Act, which specifically referred to these advances made in Western Australia and noted these developments as a model to be followed nationally.

Monitoring

Monitoring is an essential element of environmental management across all the chapters of this report. Monitoring data underpin the evaluation of the effectiveness of management investments and help determine the urgency of management interventions.

Alignment between the national, state and territory governments on monitoring and reporting is lacking, but there has been some movement in gaining a level of concordance under the UN SDG framework. In this report, we have made progress in mapping SDG targets to state of the environment assessments, but there is further to go. National environmental standards could provide a direct mechanism for agreement between all jurisdictions that would significantly simplify and improve state of the environment reporting at all levels (see ‘National framework for environmental standards’).

Monitoring of land cover (see ‘Land clearing’) through surveys and remote sensing provides valuable insights into how land cover changes over time. Different approaches to land-cover monitoring and classifications have been established in different areas of government (Guardian Australia 2021). Nationally, monitoring of vegetation cover has primarily been undertaken for the purpose of greenhouse gas accounting. At state and territory levels, monitoring has been independently undertaken for jurisdictions’ own regulatory purposes. A lack of agreement on key national monitoring datasets is potentially leading to independent development of similar products

(i.e. duplication of effort for very similar purposes).

Poor use is made of the rich sources of data compiled for the purpose of greenhouse gas accounting (woody vegetation and change attribution data) in environmental applications related to native vegetation and soil management.

At the national level, considerable effort is focused on consistent mapping of the extent and type of forest cover across broad areas, including attribution of changes in cover due to human activities such as mechanical clearing, land-use intensification and use of fire (planned or unplanned). The Australian Government Department of Industry, Science, Energy and Resources is responsible for the methodology and data used in the greenhouse gas accounts, consistent with international standards and agreements. The annual woody vegetation cover data series is published regularly, and version 5.0 was recently released (DISER 2021d). However, the spatial attribution data, which are also a valuable resource for environmental management, are not published. Despite this rich source of spatial land-cover data being available publicly for many years, it is not uniformly used in national environmental management applications at the national level (e.g. environmental assessments, grant assessments, environmental status and trend reporting), because it requires further interpretation for these purposes.

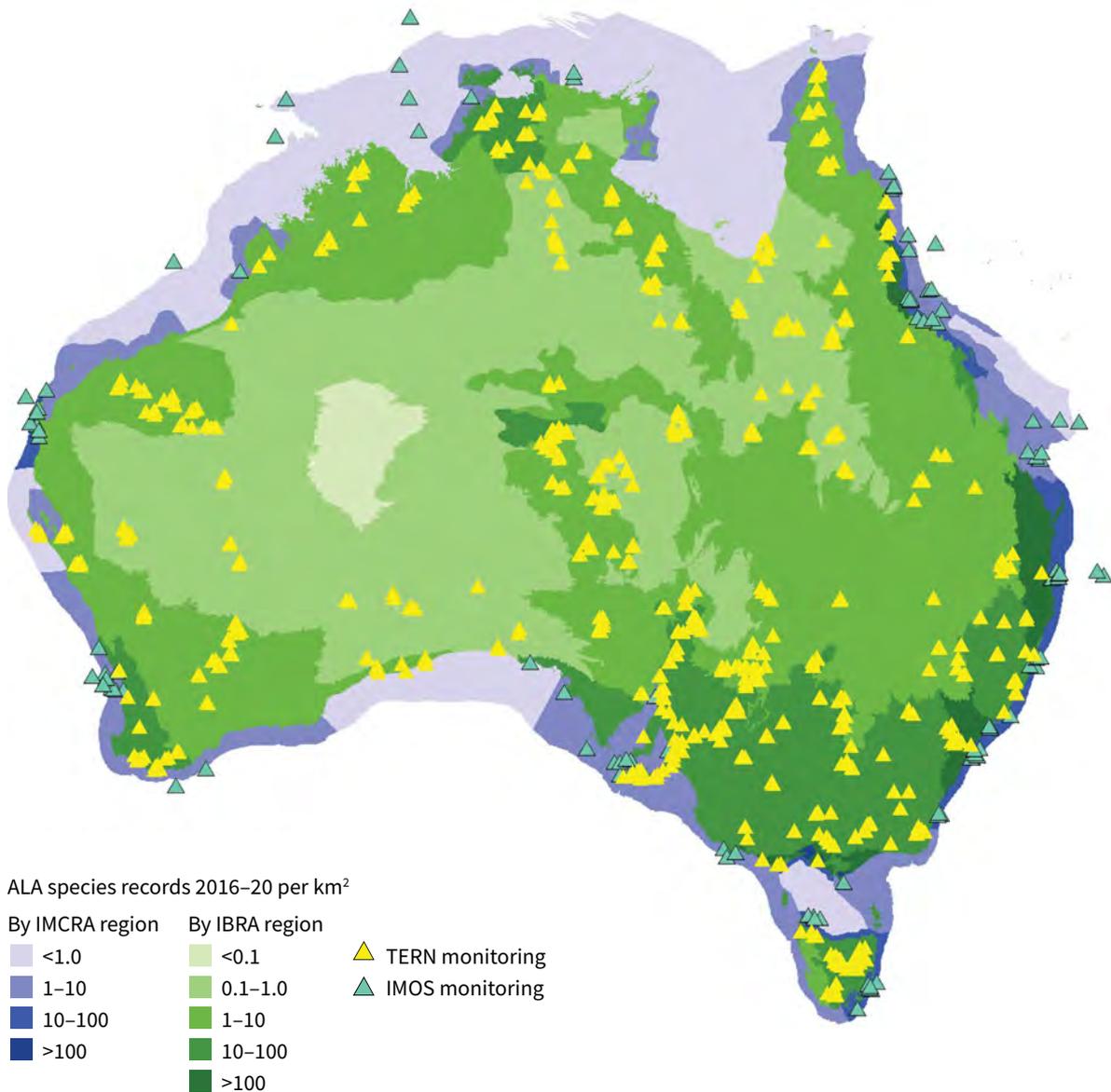
Although the amount and type of data required for land management is improving, the next challenge is to better organise the data in a way that will support assessment of consistent indicators that drive aggregation and reporting of the information. This involves putting governance in place for collaborative agreement on classifications and standards, and engaging users early to validate results and co-develop products with data custodians;

these could be published with the datasets to encourage broad adoption across multiple programs of work.

Over the past 7 years, the work of the NESP has greatly improved knowledge about biodiversity, the state and trend of threatened species and ecosystems, and the actions required to support their recovery (particularly the Threatened Species Recovery Hub, the Marine Biodiversity Hub and the Northern Australia Environmental Resources Hub). However, there are still very large gaps in our understanding of the state and trend of the environment. For example, researchers have recently published a comprehensive assessment of monitoring of the extent and adequacy of threatened vertebrate species (Legge et al. 2018), threatened plant species (Lavery et al. 2021) and threatened ecological communities in Australia (Legge et al. 2018). The assessment demonstrates that monitoring of threatened species and communities is mostly inadequate, and that 21–46% of threatened vertebrates, 69% of threatened plants and 70% of threatened ecological communities are not monitored at all. Where monitoring does occur, its quality in terms of national extent and adequacy is generally poor.

NCRIS supports long-term high-quality environmental monitoring data through the Terrestrial Ecosystem Research Network, the Integrated Marine Observing System (IMOS), and the Atlas of Living Australia for Australia's terrestrial and marine ecosystems and species (Figure 35).

IMOS operates a range of ocean-observing infrastructure and maintains long time-series data on ocean variables that are relevant to environmental management and reporting. IMOS data have supported policy and management decisions in state, national and international processes, including successive state of the climate reports, marine park



ALA = Atlas of Living Australia; IBRA = Interim Biogeographic Regionalisation for Australia; IMCRA = Integrated Marine and Coastal Regionalisation of Australia; IMOS = Integrated Marine Observing System; km² = square kilometre; TERN = Terrestrial Ecosystem Research Network
 Source: Based on an image from the EcoAssets project using data from TERN, the ALA and IMOS

Figure 35 Monitoring locations for TERN and IMOS, overlaid on species record density by region from the ALA, 2016–20

zoning and size, potential climate change effects on fisheries, and World Meteorological Organization statements on the state of the global climate and sea level rise. To increase the capacity of IMOS data streams to inform the state of Australia’s marine environments, IMOS supported a synthesis of numerous long

time-series datasets. This work culminated in the *State and trends of Australia’s oceans* report (Richardson et al. 2020), which was designed to support the 2021 state of the environment report. The report provides a baseline for marine assessments, providing information on the state and trends of

27 ecosystem indicators. There is no ongoing monitoring of the deep sea floor in Australia, so biodiversity or oceanographic trends and the impacts of pressures are unknown in these zones.

In relation to the heritage data required to inform and assess management generally, the most comprehensive, systematic and nationally standard data currently available are for natural heritage and biodiversity values, and underwater cultural heritage. This may be because there are national frameworks for these, although even these are not considered adequate. Historic and Indigenous heritage have significantly less data available. Minimal routine condition monitoring is undertaken for Australian heritage sites, except where there are specific site-based issues (e.g. monitoring of climate change impacts on the Great Barrier Reef). This lack is concerning because of the increasing pressures on heritage places.

Data sources

In the past decade, data collection has rapidly changed from being the domain of 'pure scientists' (predominantly academic researchers and government) to citizen science and industry (see 'Citizen science'). Over recent decades, tools and infrastructure have been established to collate and mobilise the vast amounts of biological data generated by research (e.g. Atlas of Living Australia, Global Biodiversity Information Facility, NatureServe). Big industry is now also engaging in biodiversity information and infrastructures to support access to analytics (e.g. Microsoft and Google). It is clear that industries see a potentially huge market emerging in biodiversity and environmental information.

Indigenous Australians play an important role in environmental monitoring, including for threatened species that occur on their lands and in remote areas, which can

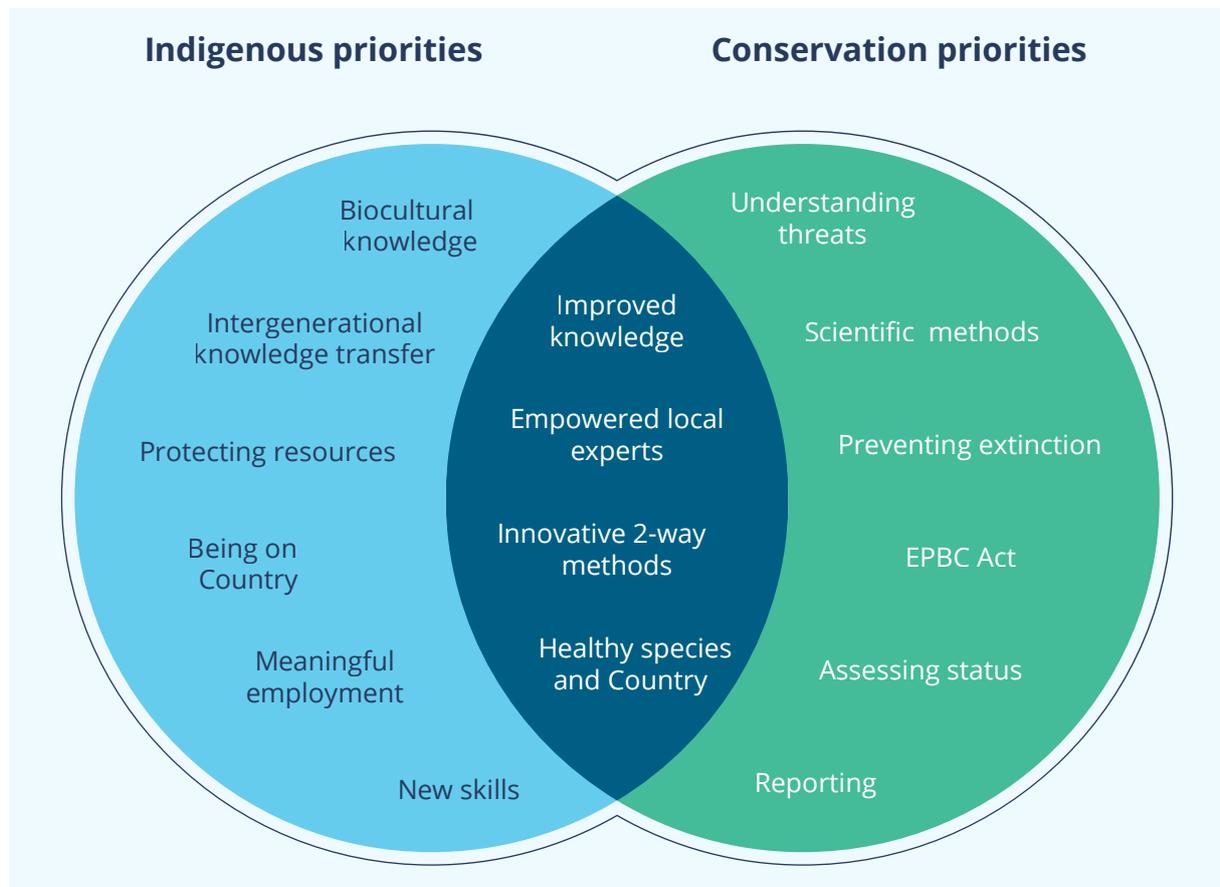
help refine investment supported by the Australian Government. Often, although the data collected to support environmental management processes has included information about native flora and fauna, and landscapes, Indigenous people have had limited or no access to, or control over, these data. Moreover, where Indigenous environmental data are available, the data are often outdated or insufficient to meet community needs (Hill et al. 2013).

A welcome and increasing trend in environmental sciences combines non-Indigenous views and methods with traditional knowledge to support the aspirations of Traditional Owners to manage their Country to lead to long-lasting and successful outcomes (Figure 36). Respectful, bottom-up, collaborative approaches that incorporate local skills and interests are fundamental to the success of monitoring programs (Paltridge & Skroblin 2018).

Big data

Monitoring environmental change is a massive undertaking that can only be achieved with the power of big data and big analytics. Building on existing initiatives, we can improve how we monitor and understand ecosystem dynamics and trajectories to be able to forecast the impact of human activity and to help inform decisions about what to do differently. Environmental data have traditionally come from field research and surveys, but these sources are now dwarfed by improvements in satellite imaging across a variety of wavelengths, LIDAR surveys, GPS tracking, environmental DNA (eDNA), and the thousands of citizen scientists using smartphones.

We can expect an increasing demand for high-resolution, high-precision and close-to-real-time analysis of ecosystem data to support economic shifts towards market instruments driving a restoration economy.



Source: Paltridge & Skroblin (2018)

Figure 36 Outcomes from 2-way monitoring of threatened species on Indigenous land

This includes compliance monitoring required by international markets for investment in our ecosystem goods and services. However, there is a significant shortfall in our current monitoring efforts to inform critical areas of management.

Science, government and industry will need new ways to handle, sort through, and make effective use of, massive volumes of data being generated by remote sensing and other sources to observe multiple facets of biodiversity and ecosystems. Finding new ways of monitoring the environment is necessary to provide 'leading' indicators (those that measure progress towards goals to anticipate a future direction) in addition

to traditional indicators (which give a retrospective measure of status).

The next 5 years will see the evolution of new ways for collaboratively sharing and evaluating big datasets, synthesising into information products that predict and forecast system dynamics, and enable effective decisions in a much more timely manner than in the past.

A good example of how integrated and interactive ecosystem monitoring is developing is the Reef 2050 Integrated Monitoring and Reporting Program for the Great Barrier Reef, jointly managed by the Australian and Queensland governments, and soon to be delivered through an online Reef Knowledge System. The Reef Knowledge System is designed as a 'first-stop

shop' that allows users to easily access a wide range of information about the Reef, including interactive maps, reports, datasets, monitoring and modelling information, and guidance tools for managers (GBRMPA 2021a).

Human resources

Human resources are essential to provide research capacity and expert advice, and to enable on-ground activities in many sectors. Some of these resources are provided by professionals and government experts, whereas others are provided by volunteers or private personnel.

Expert capacity

Key deficits in access to experts is an ongoing concern across many areas of environmental management and research. Two areas of the state of the environment report have consistently reported on inadequate numbers of experts to meet needs: taxonomy and heritage protection. An area of growing concern is a shortfall in Australia's digital analytical capacity, specifically in artificial intelligence and machine learning, to meet the growing need for capability to address big data analytics.

The Australian Biological Resources Study surveys and then analyses the taxonomic community every 10–12 years, providing a useful snapshot of the sector's health and capacity. The last survey was in 2016 (DEE 2017). It found that the number of researchers actively working in taxonomy and systematics has fallen over the years, but that proportionally more women are working in the field. It also found that the field is supported substantially by retired or honorary researchers, with over a quarter of the workforce in unsalaried positions. This enables a sustained level of productivity, but masks the fact that there are fewer paid positions in the field. A consistent concern of researchers in the field is the lack of

funding, job security and career opportunities, highlighted in surveys in 2016, 2003 and 1991.

One of the resourcing issues for heritage protection in Australia is the inadequate number of expert staff in many heritage and protected areas agencies at all levels of government. Australia faces a declining skills base in areas of heritage management, as well as in trades and crafts required for heritage construction, repair and restoration methods, materials and tools. Lack of relevant expertise and skills is a particular issue for small to medium local government bodies with limited resources. In some jurisdictions (e.g. New South Wales, Victoria), a heritage adviser system has been established to bring in expertise on an as-needed basis.

For Indigenous land management, rangers working on Country are the foundation upon which almost all environmental and wellbeing outcomes are based. The value created by an IPA is, therefore, largely proportional to the size of investment in ranger employment opportunities. Indigenous management has various benefits (Social Ventures Australia 2016):

- Indigenous land management is efficient and cost-effective.
- When rangers work on Country, they experience personal benefits, including increased skills and confidence, and better health and wellbeing.
- Community members benefit directly from ranger activities, with the reassurance that Country is being cared for, and opportunities are realised for the transfer and preservation of cultural knowledge.
- The broader community has greater understanding of, and respect for, traditional knowledge.
- Rangers and community members report that there is less violence, resulting in safer communities.

Indigenous ranger programs have also been identified as central to women's employment opportunities. The *Strong women on Country* report (Country Needs People 2018) explores the central role of women in caring for Country and the many reciprocal benefits of employing Indigenous women in this field.

However, although there are growing numbers of Indigenous people working in environmental management, few Indigenous people are working in the coordination of ranger groups and in heritage management. Solutions should be devised through co-design with Indigenous people already participating in these industries to identify gaps in opportunity and potential changes. There is a need to expand Indigenous opportunities, education and training in natural resource management and environmental research, and it is also clear that these systems and structures would benefit greatly from co-design.

Citizen science

In citizen science, members of the general public help to collect and analyse scientific data in collaboration with scientists. A white paper in 2015, *Occasional paper on citizen science* by the then Chief Scientist of Australia (Chief Scientist of Australia 2015), and the subsequent formation of the Australian Citizen Science Association reflect the growing contributions of the public to Australia's research capacity. Australia has fostered an increasing number of citizen science projects, due to increasing funding, infrastructure and government support.

Citizen science has multiple benefits (Steven et al. 2019). The collaboration between scientists and society may produce larger volumes of data than if only professional scientists were employed. Citizen science can provide access to data on private land not normally accessible by researchers or the

public. More broadly, citizen science can fill data gaps and grow support for environmental actions, with positive outcomes for government policy, and land and conservation science. In addition, citizen science projects can potentially persist much longer than conventional research projects by leveraging community support in place of limited research funding cycles (Lloyd et al. 2020). They can also achieve high levels of public education and awareness, and participants benefit from a sense of contribution, wellbeing and learning.

In 2017, 133 citizen science projects in Australia were evaluated, spanning marine and terrestrial realms. Almost half (45%) of these were focused on birds, 34% on mammals, 10% on fishes, and 5% each on frogs and reptiles. Most projects provided training or training resources, and almost half (49%) used structured monitoring methods (Steven et al. 2019). Most data from most projects (65%) were shared with Australia's national biodiversity repository and the Global Biodiversity Information Facility.

The Atlas of Living Australia hosts the Australian Citizen Science Project Finder online database (ACSA 2021), which links to almost 600 projects. Many of these deal with the land environment – for example, 11 on agriculture, 14 on geology and soils, 56 on marine and terrestrial areas, and 107 on natural resource management. Projects include the Atlas of Living Australia's BioCollect platform, Reef Life Survey, Redmap, Tangaroa Blue, Waterwatch, FrogWatch and NatureMap.

Volunteers contribute to heritage management in a wide range of ways, including through surveys and recording, archaeological excavation, invasive species control, land restoration, animal care and rehabilitation, presentations and guiding, and running promotion and celebration events. Volunteers have also made a critical contribution to

identification and protection of underwater cultural heritage.

Community volunteers have been instrumental in climate observations in Australia since the earliest days of formalised weather recording. A large proportion of the Bureau of Meteorology's rainfall observations have been made by volunteers, many of them on rural properties. Many of these observation sites have operated for 100 years or more, spanning multiple generations. Although these observations are not often considered under the term 'citizen science', they are critical to our understanding of rainfall change and variability in Australia. A specific application of citizen science in the climate area has been in the recovery of historical data. Significant quantities of historical

data exist only on paper and are effectively inaccessible for further analysis. The first major Australian citizen science project of this type was completed in 2020, drawing both on volunteers working under the auspices of the Bureau of Meteorology and on the broader community. In this project, daily observations from Adelaide from 1839 onwards were digitised, combining with existing Bureau of Meteorology data (starting in 1887) to produce the longest single dataset in Australia and one of the longest in the Southern Hemisphere (Gergis et al. 2020).



Case study Armchair citizen scientists double their efforts to address Australia's big challenges

Sources: Atlas of Living Australia and the Australian Museum

A growing band of citizen scientists across Australia are helping to protect our environment by contributing to science through the crowdsourcing platform DigiVol.

Identifying animals to help support bushfire recovery efforts is one of the many areas where citizen scientists are making a significant contribution.

DigiVol was first developed in 2011 by the Australian Museum in collaboration with the Atlas of Living Australia. Since then, more than 10,000 citizen scientists have used the DigiVol volunteer portal (Australian Museum 2021) to transcribe specimen labels, field notes and Wildlife Spotter images.

DigiVol provides a way to harness the power and passion of volunteers to help in the digitisation effort to make more information available to science. The DigiVol platform is an inclusive solution to addressing challenging problems, enabling a range of organisations to process images, specimens and field notes. It produces data to assist scientists in transcribing their images much more quickly than was previously possible.

Along with its success in attracting citizen scientists, DigiVol is an excellent example of infrastructure designed to meet many objectives.

In recent years, DigiVol has added capture of camera trap data by citizen scientists to its portfolio through Wildlife Spotter. Wildlife Spotter allows organisations to upload images captured on cameras mounted in the environment, and volunteers then identify and tag animals in the photographs. This process produces large volumes of high-quality data to assist in monitoring Australia's fauna species, including helping to understand the impact of fire and recovery of fauna in fire-affected areas.

Following the Black Summer bushfires and national lockdowns in 2020, the number of volunteers using DigiVol doubled to more than 9,000 individuals. Since then, DigiVol volunteers have contributed more than 6 million transcriptions to expeditions across the platform.

In the future, DigiVol is looking to integrate artificial intelligence into its software to complement the workflow and support the public's effort in species identification.

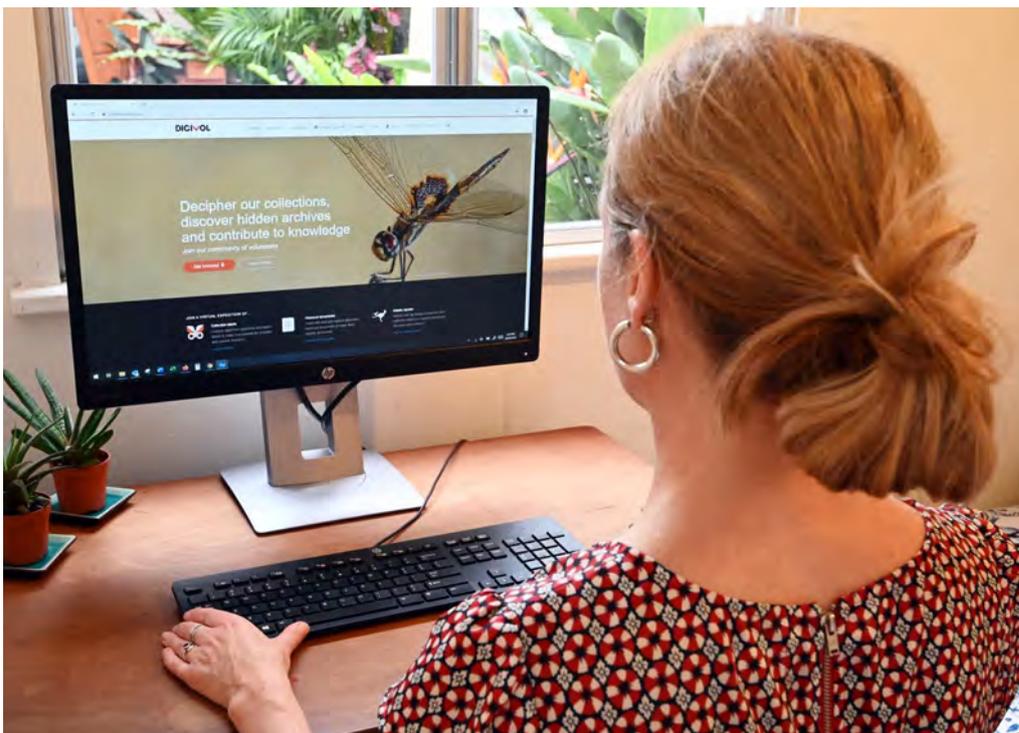


Photo: Australian Museum

Figure 37 The DigiVol platform allows anyone with access to a computer and the internet to contribute to science

New research technologies

The digital revolution continues to change how we monitor and manage the environment. To date, field observation and monitoring have required significant investment of time, money and human resources; however, in the future, remotely sensed data and increasing diversity of satellite-based sensors and modelling systems will reduce these costs when coupled with accessible data infrastructure. Big data offer significant opportunities for conservation and sustainability in terrestrial (Runting et al. 2020) and aquatic (Dafforn et al. 2015) ecosystems (see ‘Big data’).

Australia is already gaining the benefits from programs that support land management using new satellites, such as Digital Earth Australia (GA 2020). A new Australian civil space strategy (Australian Space Agency 2019) and the SmartSat Cooperative Research Centre will progress research that aims to improve technology and data that can potentially inform land management.

The current knowledge of Australia’s biodiversity – including species that are important for economic and ecosystem services functions – is very incomplete. New technologies, including high-throughput DNA sequencing and machine learning, promise a substantial increase in the discovery, naming and documentation of Australia’s wildlife. The Australian Academy of Science has proposed an ambitious mission to discover and document all remaining Australian species in a generation. A cost–benefit analysis has shown that the returns to society of achieving this goal could be as much as 35 times greater than the investment, with benefits for biodiversity conservation, biosecurity, biodiscovery, and agricultural research and development (Deloitte Access Economics 2020).

Metabarcoding of eDNA is increasingly proving to be an effective and efficient method to survey important groups such as soil bacteria and fungi. Older methods of identification are notoriously problematic for these groups, which are the most genetically and ecologically diverse communities on Earth, but poorly understood. eDNA techniques have been used to demonstrate the return of the native soil bacterial community in areas that have been revegetated (Gellie et al. 2017, Yan et al. 2020). Molecular techniques are also increasingly used to monitor the health of marine and coastal ecosystems that have previously suffered from a lack of taxonomic clarity (e.g. Birrer et al. 2017). Such techniques can detect changes not only in marine biodiversity but also in ecosystem functioning, which underpins ecosystem services such as climate regulation (Birrer et al. 2019).

The continuing increase in computing power and the growth of well-designed datasets provide novel opportunities to use artificial intelligence and machine learning (AIML) tools to better understand the state and trend of the environment. AIML can automate repetitive and time-consuming tasks involved in monitoring and evaluation, guide the collection of information where it matters the most by optimising the design of experiments, and help to make cost-efficient decisions by predicting future management outcomes.

Authors and acknowledgements

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Ian Cresswell

Dr Ian Cresswell has extensive experience working in environment and sustainable development in several different areas,

including biodiversity, reserve planning, fisheries, wildlife regulation and protected areas. He has a long history of success in managing large-scale, science-based government programs in natural resource management, with a strong focus on management to balance environmental, economic and social outcomes. He provides high-level advice to government and industry on environmental and sustainability issues. Dr Cresswell has led major research programs in CSIRO in both terrestrial and marine domains, as well as holding senior roles in marine planning, sustainable fisheries and wildlife management, including as the Director of the Australian Biological Resources Study.



Terri Janke

Dr Terri Janke is a Meriam/Wuthathi woman and an international authority on Indigenous cultural and intellectual property (ICIP),

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Emma L Johnston

Professor Emma Johnston AO FTSE FRSN is Dean of Science and Professor of Marine Ecology and Ecotoxicology at

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Dr Graeme Clark is a Senior Research Associate in the Centre for Marine Science and Innovation at the University of New

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Sonia Cooper

Ms Sonia Cooper is a Yorta Yorta woman raised by her Nan on Cummeragunja. She is a community member. She has a strong interest

in culture, the environment, science, policy, law, contracts and geopolitics. She is currently completing her Bachelor of Science degree at the Australian National University. She works as the Living Murray Indigenous Facilitator for Barmah National Park for Yorta Yorta Nation and is a great advocate for the progression of Indigenous rights. Ms Cooper has been engaged to sit on various boards around the country, including CSIRO's Indigenous Reference Group in 2019 and science panels during the past 10 years. She has been living in the bush next to the Murray River for the past year, and can see and feel Country.



Oliver Costello

Mr Oliver Costello is a Bundjalung man from the Northern Rivers of New South Wales and has been actively engaged

in cultural land management projects. He believes strongly in the role of Aboriginal culture as a keystone to maintaining livelihoods, supporting identity, connecting to Country, and enabling healthy and regenerative communities to care for Country. He co-founded the Firesticks Initiative and is a founding Director of both the Firesticks Alliance Indigenous Corporation and the Jagun Alliance Aboriginal Corporation. He holds a Bachelor of Arts in Adult Education and Community Management from the University of Technology Sydney. He has a broad range of experience in natural cultural resource management, cultural fire practices, Aboriginal joint management partnerships, culturally significant species and threatened species management. Mr Costello works to support a range of research, policy, advocacy and on-ground projects. He is passionate about Aboriginal leadership, empowerment, partnerships, and recognition of cultural knowledge and practice.



Zena Cumpston

Zena Cumpston is a Barkandji woman with family connections to Broken Hill and Menindee in western New South Wales.

She currently lives in Melbourne on the lands of the Wurundjeri people with her partner and 2 young boys. Zena works as a writer, curator, consultant and researcher, and is passionate about truth-telling and undertaking projects that directly benefit her community and Country. In 2021, she curated the show *Emu*

Sky for Science Gallery Melbourne, bringing together more than 30 Aboriginal community members from across south-eastern Australia. Running until July 2022, *Emu Sky* explores Aboriginal knowledge through artworks, research and storytelling, and is accompanied by an extensive education program. In 2022, her book *Plants*, co-authored with Professor Lesley Head and Associate Professor Michael-Shawn Fletcher, will be released as part of the First Knowledges series.



Kathryn M Emmerson

Dr Kathryn Emmerson is a Principal Research Scientist at CSIRO, interested in how emissions of gases

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Dr Karen Evans is a Team Leader and Principal Research Scientist with CSIRO Oceans and Atmosphere based in

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international fisheries, and threatened, endangered and protected species. Her recent research has employed multiple disciplinary approaches to investigate the connectivity of shared resources and provide baseline information on the spatial dynamics of top predators in relation to human use and activities in the marine environment. Her projects deliver strategic research to national agencies; regional organisations, including regional fisheries management organisations; and international agencies, including the United Nations.



Mibu Fischer

Ms Mibu Fischer is a descendant of the Noonuccal, Ngugu and Gorenpul clans of Quandamooka. Ms Fischer

is an early career marine ethnoecologist within the multi-use ecosystems tropical coastal group, in CSIRO's Oceans and Atmosphere, having joined CSIRO as an Indigenous Cadet in 2009. She graduated from Southern Cross University with a Bachelor of Marine Science and Management before completing a Graduate Diploma in Natural Resource Management from Charles Sturt University in 2016. Ms Fischer is an Aboriginal scientist with engagement skills for strengthening partnerships between First Nations communities and the research sector. Her specific interests are around traditional knowledge (science) and management practices being considered within modern-day fisheries, coastal and conservation management. She joins with other Indigenous and traditional practitioners to strengthen the global Indigenous voice and leadership in areas of marine research and coastal Indigenous livelihoods. Her goal is to bridge a gap that draws attention to the Indigenous communities facing the frontline of impacts

and changes to coastlines, ecosystems and livelihoods from climate change impacts.



Janice Green

Ms Janice Green leads the team at the Bureau of Meteorology responsible for preparing the bureau's national suite of water

information products and services to fulfil its obligations under the Commonwealth *Water Act 2007* as the national water information agency. Her specialist areas are in hydrology, hydrometeorology and water resources assessment, and she has been influential in developing methods and preparing guidelines for undertaking analyses in the Australian hydroclimatic environment. She has worked as a hydrologist in the public sector, at both state and national levels, in academia and in private industry.



Pia Harkness

Dr Pia Harkness is a social scientist with interests in collaborative environmental governance and management,

and sustainable natural resource-based livelihoods. With a background in spatial science, her interest in community development and environmental issues led her towards the social sciences. She currently coordinates a Traditional Owner water quality grant program at the Great Barrier Reef Foundation. She previously worked with a CSIRO team that focuses on transdisciplinary and interdisciplinary research around knowledge co-creation, and bringing together Indigenous and western knowledge systems in environmental management. Dr Harkness completed her PhD in 2020. Her research examined the implications of marine

conservation and rural development policies on local communities in Savu Raijua District, eastern Indonesia.



Rosemary Hill

Dr Rosemary Hill is a Senior Principal Research Scientist with CSIRO Land and Water, and an Adjunct Professor in James Cook

University's Division of Tropical Environments and Societies, based in Cairns. Dr Hill leads research on environmental governance and multiple knowledge systems, and their impacts on biodiversity, ecosystem services and climate change, with a special focus on Indigenous knowledge. She has more than 60 peer-reviewed articles and book chapters, and more than 100 peer-reviewed reports and conference papers, on these topics. Through applying this science and leading others, she works with communities at multiple scales to foster integration of diverse knowledge systems in sustainability. Her science helps others understand social-ecological dimensions of sustainability, particularly in remote and regional areas.



Sarah Hill

Dr Sarah Hill has a passion for creating thriving cities. As Chief Executive Officer (CEO) of the expanded Western Parkland City

Authority, Dr Hill is leading the delivery of Australia's largest and most ambitious city-building project of the past century. This work builds on the vision she co-created as the inaugural CEO of the Greater Sydney Commission. Under Dr Hill's leadership, the commission developed new ways of engaging with citizens, measuring and monitoring key planning outcomes, and aligning growth with

infrastructure. Dr Hill has received numerous professional awards locally and internationally, including the 2012 UDIA Women in Development Award, the 2015 NSW Planner of the Year award and the 2016 PIA Australian Planner of the Year award. She is a Fellow and past-president of the Planning Institute of Australia (NSW Division); is an Adjunct Professor at the University of Technology Sydney's Faculty of Design, Architecture and Building; and continues to be a thought leader with a particular focus on the economics of cities and the feasibility of development.



Alistair Hobday

Dr Alistair Hobday is Research Director for the Coasts and Ocean Research Program at CSIRO. His research focus is on

investigating the impacts of climate change and extreme events on marine biodiversity and fishery resources, and developing, prioritising and testing adaptation options to underpin sustainable use and conservation into the future. He is former co-chair of the international CLIOTOP (Climate Impacts on Top Ocean Predators) program and is a current member of the steering committee for the international Integrated Marine Biosphere Research program.



Barry Hunter

Mr Barry J Hunter is a descendant from the Djabugay-speaking people of the Cairns hinterland. He grew up beside the

Barron River in the rainforest near Kuranda. Mr Hunter's experience includes employment in government conservation agencies, the mining and exploration industry, community and not-for-profit organisations, and recently

as a consultant working around Aboriginal land management, the carbon industry and community economic development. He has more than 30 years experience in Aboriginal affairs, particularly in land, natural and cultural resource management. Mr Hunter has a Bachelor of Applied Science from Charles Sturt University and has a keen interest in the work that community rangers do in looking after land, fire management and cultural heritage. He also has a real passion for building community capacity and planning that deliver sustainable social, cultural and economic outcomes within our communities. Mr Hunter has run a successful consulting business for 7 years, working in areas including Indigenous economic, community and social development; Indigenous land management and cultural heritage; and reviews of government-funded programs.



Cass Hunter

Dr Cass Hunter is a descendant of Kuku Yalanji and Maluilgal nations. She is an Indigenous social ecological research scientist

with CSIRO Oceans and Atmosphere in Cairns. Dr Hunter leads research on collaborative environmental design, usability and uptake of tools, research translation, and development of participatory tools to support sustainable livelihoods and ecosystems. For more than a decade, she has engaged with many inspiring Indigenous young people, rangers, leaders, educators and scholars. Her focus is on building our national and international networks of Indigenous practitioners to share and develop learnings to place Indigenous people at the heart of environmental and economic co-design and advances.



Melita D Keyword

Dr Melita Keyword is a Senior Principal Research Scientist in the Climate Science Centre of the Oceans at CSIRO. Dr

Keyword's research expertise lies in the chemical and microphysical properties of atmospheric aerosol, which she uses in a variety of applications, ranging from tracking long-term changes in aerosol microphysics and chemical composition of the remote marine boundary layer to understanding aerosol growth and secondary organic aerosol in urban airsheds and biomass burning plumes. Dr Keyword was the 2019 recipient of the Werner Strauss Clean Air Achievement Award from the Clean Air Society of Australia and New Zealand, and is the President of the International Commission on Atmospheric Chemistry and Global Pollution.



Andrew Klekociuk

Dr Andrew Klekociuk is a Principal Research Scientist and leader of the Atmosphere and Ice Sheet Section in the

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Anne McConnell

Ms Anne McConnell is a heritage consultant with broad-based interests and expertise in Australian archaeology, cultural

heritage management and Quaternary geoscience. Ms McConnell has more than 40 years of working experience in the government and private sectors. She works on both Indigenous and historic cultural heritage, covering diverse areas of heritage and diverse contexts, such as protected areas; production forestry; and urban, rural and remote areas, including Antarctica and the subantarctic. Ms McConnell's heritage work has included the development of statewide management systems for forest heritage, and collaborative regional heritage assessment projects, including the evolution and Indigenous history of use of freshwater lagoons in south-eastern Australia and the identification of places of National Heritage significance in Australia's arid zone. Ms McConnell has also had a long-term interest in terrestrial protected area management, initially through membership of the Tasmanian Wilderness World Heritage Consultative Committee and the National Parks and Wildlife Advisory Council. Ms McConnell is a long-term member of Australia ICOMOS and is currently the Convenor of the Australian ICOMOS Indigenous Heritage Reference Group.



Dan Metcalfe

Dr Dan Metcalfe is the Director of CSIRO Oceans and Atmosphere. Dr Metcalfe brings a strong record in science leadership

that spans the broad domain of environmental research, deep network across the innovation system and successful stakeholder

management at all levels. Recently, he led the coordination of CSIRO's science response to the 2019–20 summer bushfires, and subsequent initiatives to improve government, community and industry resilience to climate-related natural hazards. He has also led CSIRO efforts to address the environmental and social consequences of the coincidence of drought, water allocations and extreme weather in the Murray–Darling Basin, as well as contributing to the ongoing management of the Great Barrier Reef as member of the Reef 2050 Advisory Committee. He was awarded a PhD from the University of Cambridge for work in the tropics of South-East Asia, and has also worked across southern and eastern Africa and Australasia. He spent more than 2 decades working in landscape ecology and sustainable resource management across the rainforests and savannas of northern and eastern Australia. Dr Metcalfe has contributed to the development of monitoring and assessment protocols, provided advice and conducted assessments and reviews for state and territory governments and the national governments of Australia and New Zealand. He was a member of Minister Ley's Wildlife and Threatened Species Bushfire Recovery Expert Panel and was author of the 'Land' theme in the 2016 state of the environment report.

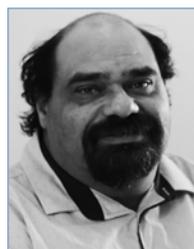


Bradley Moggridge

Associate Professor Moggridge is a proud Murri from the Kamilaroi Nation living on Ngunnawal

Country in Canberra. He is a researcher in Indigenous water science (with qualifications in hydrogeology and environmental science), as well as a part-time PhD scholar at the University of Canberra. Until June 2021, he was the Indigenous Liaison Officer for the Threatened Species Recovery Hub under the

National Environmental Science Program. He is the current Vice-President of the Australian Freshwater Sciences Society and member of the Wentworth Group. Professor Moggridge has won several career awards, has presented widely and is on many committees – from local to international – adding to his 25 years in water and environmental science, cultural science, regulation, water planning and management, including policy development, legislative reviews, applied research and project management. Professor Moggridge hopes to encourage future generations to pursue interests in STEM, promote his ancestors' knowledge of water and mentor emerging Indigenous scientists.



Damian Morgan-Bulled

Mr Damian Morgan-Bulled is a proud Yorta Yorta man based on the Dhungala (Murray) River at Echuca–

Moama on the Victoria – New South Wales border, within Yorta Yorta Country. Mr Morgan-Bulled has worked within the cultural heritage and natural resource management field for more than 25 years, including stints with the Murray–Darling Basin Authority based in Canberra and the Department of Sustainability and Environment, Victoria. He currently works as the Executive Officer for the Yorta Yorta Traditional Owner Land Management Board, which oversees the implementation of the Joint Management Plan for the Barmah National Park in conjunction with Yorta Yorta Nation Aboriginal Corporation and Parks Victoria. Damian has represented the Yorta Yorta Nation on several key negotiating teams and committees at regional, state and national levels. Recently, Mr Morgan-Bulled co-chaired the National First Peoples Gathering on Climate Change Steering Committee that co-designed the

protocols and agenda for the National First Peoples Gathering on Climate Change. He is considered a senior leader within the Aboriginal community of Echuca–Moama and has well-established networks that have seen him recently present First Nations people’s issues in climate change at both the Australian Meteorological and Oceanographic Society and Knowledge Exchange for Climate Adaptation Platforms forums.



Joe Morrison (scoping paper)

Mr Joe Morrison is a Dagoman and Mualgal man with more than 25 years experience working

with Indigenous people. Mr Morrison has a Bachelor of Arts in Land Management from the University of Sydney and an Honorary Doctorate from the University of New South Wales for his contribution to Indigenous land and sea management, policy development, advocacy and related topics nationally. Mr Morrison is currently the Managing Director of Six Season Pty Ltd, which aims to advance Indigenous policy through practical solutions. Mr Morrison’s previous roles have included Chief Executive Officer (CEO) of the Northern Land Council, founding CEO of the North Australian Indigenous Land and Sea Management Alliance (NAILSMA), and an Indigenous Land Management Facilitator. Mr Morrison was unable to continue as lead author of the ‘Indigenous’ chapter due to his appointment as Group Chief Executive Officer of the Indigenous Land and Sea Corporation.



Helen Murphy

Dr Helen Murphy is a Principal Research Scientist at CSIRO Land and Water. She leads research focused on understanding

the scale and magnitude of individual and cumulative threats to Australian biodiversity and the effectiveness of management interventions. She has a background in plant ecology and collaborates across domains spanning conservation, natural resource management, biosecurity and health, and sustainable development. Dr Murphy is based in north Queensland and maintains a strong research interest in tropical ecosystem dynamics. A particular focus is the impacts of invasive species, climate change and extreme climate events on the composition, structure and function of tropical forests.



Gabriela Quintana Vigiola

Dr Gabriela Quintana Vigiola is an academic and consultant in the urban design and

planning sectors. She joined the University of Technology Sydney in 2012, and lectures in urban planning at the School of the Built Environment. Her interests range from urban design to cultural and psychosocial studies. Her current research focuses on social–urban issues, including informal settlements, housing for ‘vulnerable’ populations and place making. Dr Quintana Vigiola’s previous research focused on place making through culture in informal settlements in Caracas, Venezuela. She is currently developing a study about housing for domestic violence survivors, with a focus on place, displacement and violence.



Becky Schmidt

Dr Becky Schmidt is a Principal Environmental Scientist at CSIRO Land and Water, leading interdisciplinary teams

to deliver environmental information that government, community and industry use to make decisions, protect our environment and prosper sustainably. She works with researchers from a range of disciplines, complementing their specialist domain knowledge with her generalist understanding of systems, to address challenges in sustainability, agriculture, coal resource development, and land and water science. Currently, she is collaborating with partners to implement the Australian Government's strategy and action plan for a common national approach to environmental-economic accounting, helping government and businesses make balanced decisions using consistent information on the environment, economy and society.



Linda Thomas

Ms Linda Thomas is a Research Technician in the Coasts and Oceans program at CSIRO Oceans and Atmosphere. She has

a background in marine geoscience and data management. Her work focuses on marine resources and ecosystem adaptation, both nationally and internationally, to a changing climate.



Rowan Trebilco

Dr Rowan Trebilco is a Team Leader in the Marine Resources and Industries program at CSIRO Oceans

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Dr Stephen Van Leeuwen is a Noongar man from Wardandi Country between Busselton

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Dr Dirk Welsford is a Principal Research Chief Scientist in the Australian Antarctic Division, and previously the Acting

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Dr Barbara Wienecke is a Senior Research Scientist at the Australian Antarctic Division. She has studied the foraging ecology of penguins and other seabirds for more than 20 years. Since 1993, she has spent many seasons in Antarctica, the subantarctic and South America, and has published the results of her work in international journals and books. Dr Wienecke is a member of the International Union for Conservation of Nature Penguin Specialist Group and a member of the Agreement on the Conservation of Albatrosses and Petrels working groups.



Kristen Williams

Dr Kristen Williams is a Principal Research Scientist at CSIRO Land and Water, with extensive experience in research management, coordination and delivery. As an ecological geographer, she specialises in the integration of ecosystem and landscape sciences through multidisciplinary team collaborations to generate data and knowledge products informing systems of ecologically sustainable land management, where biodiversity prospers, ecosystems function and adapt, and ecosystem services meet the needs of all people. She has extensive experience co-designing research with end users to ensure that outputs meet their needs, with a focus on biodiversity conservation, vegetation management policies, natural resource management planning and prioritising conservation investment strategies.



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Dr Emma Woodward is a Senior Research Scientist and leader in co-design who brings together different knowledge systems and types to deliver collaborative solutions to land and sea management at regional and national scales. Based with CSIRO Land and Water, her research frequently involves partnering with Indigenous communities to co-develop methods, tools, protocols and guidelines that can facilitate understanding and inclusion of diverse knowledges, values and interests in natural resource planning and management and enterprise development. Dr Woodward has previously worked on Our Knowledge Our Way (OKOW), a transdisciplinary science initiative to produce the first Indigenous-led guidelines for best practices when working with Indigenous knowledge in caring for Country. The outcomes of the OKOW guidelines have made a foundational impact in setting a new standard in how to engage Indigenous people in partnering in science.

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Approach

Background to state of the environment reporting

The state of the environment report is a 5-yearly requirement under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The purpose of the national state of the environment report is to:

- provide a strategic view to shape policy and action
- engage with users to influence behaviour
- assist with assessing our interventions as stewards for the Australian environment.

To ensure that this information is as credible and robust as possible, the report is written by a panel of independent authors, based on the best available evidence, and quality checked through a rigorous consultation, peer-review and fact-checking process.

The ongoing provision of this key information is ensured by a requirement under the EPBC Act for the Minister for the Environment to table a report in Parliament every 5 years on the state of the environment.

The EPBC Act defines the ‘environment’ as:

- ecosystems and their constituent parts, including people and communities
- natural and physical resources
- the qualities and characteristics of locations, places and areas
- heritage values of places
- the social, economic and cultural aspects of the above.

The EPBC Act, among other things, recognises the need:

- to promote a cooperative approach to the protection and management of the environment involving governments, the community, landholders and Indigenous peoples; and
- to recognise the role of Indigenous people in the conservation and ecologically sustainable use of Australia’s biodiversity; and
- to promote the use of Indigenous peoples’ knowledge of biodiversity with the involvement of, and in cooperation with, the owners of the knowledge. (section 3, Objects of the Act)

In preparing a framework for the 2021 state of the environment report, the Australian Government Department of Agriculture, Water and the Environment, led by Jeanette Corbitt, sought to underpin the report by the fundamental understanding that Indigenous participation in management of land and sea is critical to environmental outcomes. With the support of the Department’s Indigenous Advisory Committee, appointed under the EPBC Act, the Hon. Sussan Ley MP, Minister for the Environment, supported a new approach put forward by the department on how to achieve an Indigenous voice in the report.

Based on this advice, the Minister for the Environment chose to engage 3 co-chief authors: 2 senior scientists and an Indigenous chief co-author. Along with the co-chief authors, the department sought to engage Indigenous co-authors for all the report themes.

Indigenous authors have written in almost every chapter of this report – biodiversity,

climate, coasts, extreme events, heritage, Indigenous, inland water, land, marine and urban. For Indigenous people, writing a report of this nature can be difficult, in that the categories of the environment are dissected and discussed in isolation from one another. This runs counter to the Indigenous world view, in which all aspects of the environment and culture are linked. This has necessitated overlap and interconnections across themes given the interconnectedness of culture.

Framework for the 2021 report

The framework adopted for the 2021 state of the environment report (SoE 2021) adopts and adapts that used in 2011 (SoE 2011) and 2016 (SoE 2016). The 'Overview' chapter provides a synthesis and integration of more detailed content and assessments found in 12 thematic chapters and provides the overall outlook for the Australian environment.

The 12 chapters on air quality, Antarctica, biodiversity, climate, coasts, extreme events, heritage, Indigenous, inland water, land, marine and urban contain detailed discussions of outlook and impacts, state and trend of the environment, pressures, and management. Each chapter provides readers with:

- a comprehensive review of the state of the environment, based on available data and information
- information on the pressures on the environment and the drivers of these pressures
- information on the effectiveness of management to address environmental concerns
- information on the human wellbeing impacts of the above
- an overall outlook for the Australian environment.

What is new in SoE 2021?

SoE 2021 builds on SoE 2011 and SoE 2016. Where possible, we have tried to standardise against previous baselines for comparisons over time.

Although SoE 2021 provides updates to the information in SoE 2011 and 2016, its focus is to bring together the extensive information that has emerged over the past 5 years, and to report on the main emerging issues facing Australia. We have included new themes of 'Extreme events' and 'Indigenous', in line with the major focus that has emerged in these areas in the past 5 years. In 2021, we extend the digital delivery of SoE to improve the usefulness of SoE reporting for evidence-based policy and management. This enables decision-makers, researchers and interested members of the public to explore and discover information of interest to them in a variety of ways.

SoE 2021 continues the 2011 and 2016 approach to the assessment of pressures, state (condition) and trend of the environment, and management effectiveness (Figure 38). Consistency of grade scales has also been maintained where possible: pressures are assessed using a 4-item scale ranging from very low to very high impact; state ranges from very poor to very good; management ranges from ineffective to very effective; and trend ranges from deteriorating to improving, with an option for unclear trend. Information has been provided on the methodology and evidence used to make each assessment, and, where possible, we provide information on the comparability of the assessments to previous reports. This aims to strengthen the transparency and repeatability of the assessments.

Before commencement of the 2021 assessment process, assessment standards were prepared and agreed with authors,

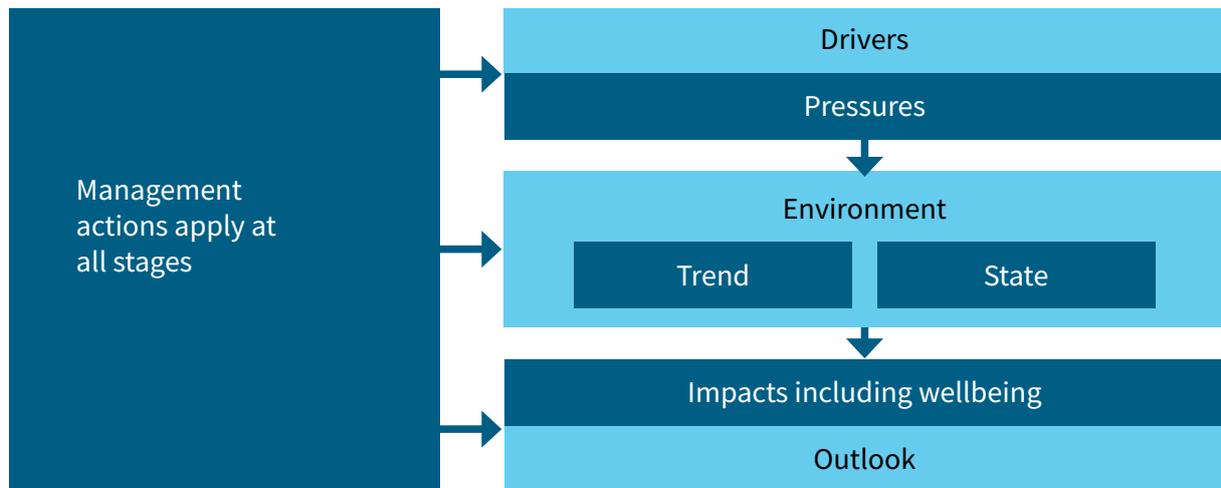


Figure 38 Links between drivers, pressures, the environment, human wellbeing, outlook and management

outlining the approach and meaning of each grade. Integration of Indigenous and non-Indigenous knowledge systems was aided by the preparation of Indigenous collaboration guidelines based on the Indigenous co-authorship strategy developed for the report. Assessments were completed by expert panels of Indigenous and non-Indigenous authors, and in many cases external (non-author) experts. Specifics are provided in the ‘Approach’ section of each chapter.

We have added new assessments in this report for the human wellbeing impacts of environmental state and trends, in keeping with the ‘Impact’ in the Driver–Pressure–State–Impact–Response (DPSIR) model (European Commission 1999). This new category of assessment reflects the important connection between environmental and human health, and the inseparability of people from Country in Indigenous world views. Recent trends in environmental reporting focus on this relationship, including nature’s contribution to people (Díaz et al. 2018), evolution of the DPSIR model into DPSIR and DAPSI(W)R(M) (Scharin et al. 2016), and the combination of environmental and

social dimensions in the global Sustainable Development Goals (SDGs).

SoE 2021 also introduces summary assessments in the ‘Overview’ chapter. These assessments summarise the theme-level assessments across the 12 detailed chapters, based on the range and most frequently reported grade (mode). Assessments were compiled and refined by an expert panel that included chief authors, to ensure appropriate weightings across chapter contexts and realms. Summary assessment text consolidates the narrative across contexts and realms.

Finally, SoE 2021 introduces mapping of assessments to SDG targets, in line with recent state SoE reports (Queensland and Victoria). Each assessment indicates the SDG targets that it may relate to. We use this terminology because the majority of SDGs focus on the latter stages of DPSIR (Impact and Response), so pressure, state and trend assessments, and many of our more specific wellbeing and management assessments can only partly inform these higher-level goals. These mappings have been developed based on input from chapter authors and expert panel evaluation.

Independent nature of the state of the environment report

A team of independent experts led the coordination and drafting of each thematic chapter and contributed to this 'Overview' chapter. The SoE 2021 authors are experts in their fields. They used the available evidence and extensive consultation to produce robust, peer-reviewed thematic chapters, which are rigorous and highly credible.

The authors were supported in their work by the Australian Government Department of Agriculture, Water and the Environment, including a project board of departmental senior executives, members of the cross-jurisdictional SoE Reporting Forum and many other contributors, who are recognised in the 'Acknowledgements' sections of the chapters. The department's Indigenous Advisory Committee was consulted on drafts of all the chapters. The best available information has been used to inform the thematic chapters, select assessment components, and determine grades for status and trends. Information has been used from a wide range of data sources (referenced in the thematic chapters) and extensive consultations with experts in a variety of scientific disciplines across Australia. In many cases, experts contributed directly to the assessments in the thematic chapters. Expert workshops were also held to gather evidence and information, discuss issues and gauge opinion. The authors have indicated the strength of the evidence and consensus for their conclusions within each set of assessments. Content review, fact checking and independent peer review were used to validate and strengthen the content. All draft reports were reviewed by key stakeholders from the Australian Government, state and territory governments, the scientific

research community and industry before undergoing independent peer review by subject matter experts.

SoE 2021 contains data and information up to 30 June 2021, except where otherwise noted. There will always be new developments between this date and the publication of the report, but these cannot be included. By its very nature, this overview is not able to reflect the depth of analysis, data and variation on particular issues that are covered in the detailed thematic chapters. Because it is a national-level summary, some of the information and conclusions reached may also not be representative of the situation in a particular jurisdiction. Readers seeking more detailed information, evidence and further references are encouraged to explore the thematic chapters and information available on the SoE digital platform.

Acronyms and abbreviations

Term	In full
eDNA	environmental DNA (deoxyribonucleic acid)
EPBC Act	<i>Environment Protection and Biodiversity Conservation Act 1999</i>
ICOMOS	International Council on Monuments and Sites
IPA	Indigenous Protected Area
IUCN	International Union for Conservation of Nature
NCRIS	National Collaborative Research Infrastructure Strategy
NESP	National Environmental Research Program
SDG	Sustainable Development Goal
UN	United Nations
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples 2007

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Index

An ‘f’ following a page number indicates a figure, and ‘t’ indicates a table.

A

accounting (national accounts), 148–149, 180, 186
acid sulfate soils, 125
agriculture, 103–104, 154–155
 climate change impacts on, 18, 70–71
 conservation practices incorporation in, 137
 cost of weeds, 18
 environmental impact, 46, 58, 70, 103–104
 food production, 70–71
 land cleared, 97; *see also* land clearing
 pesticides and chemical pollutants, 104
 pressures on, 70–71
 production – environment protection balance, 182–183
Aichi targets *see under* Convention on Biological Diversity
air pollution, 99–100, 177–178
 bushfire smoke, 17, 37, 38f, 72, 91, 99
 effects on human health, 37, 71
 particulate matter, 37, 39, 39f, 71, 91, 106
 smog, 17, 38f, 72, 99
 sources, 99, 177
air quality, 17, 37–40, 71
 assessments of state and trend, 28, 68
 COVID-19 lockdown impact, 37
 heatwaves and, 72
 management and monitoring, 177–178
 pressures on, 37, 99–100
 timeline of major events, 38f
 urban areas, 37, 39–40, 72, 91, 99, 177
airborne pollen, 37, 99
algal blooms, 34–35, 46, 48, 71, 104, 118
alpine ecosystems, 57
amphibian chytridiomycosis, 118
amphibians, threatened, 58, 60–61
Andropogon gayanus (gamba grass), 116, 125
annual mission grass (*Cenchrus pedicellatus* syn. *Pennisetum pedicellatum*), 116

Anoplolepis gracilipes (yellow crazy ant), 117, 173, 174
Antarctic fur seals (*Arctocephalus gazella*), 99
Antarctic research stations, 43, 101, 133
Antarctic toothfish (*Dissostichus mawsoni*), 62
Antarctica, 41–43, 44
 assessments of state and trend, 29
 climate change impacts, 16, 42–43
 commercial fisheries, 106
 debris and pollution, 99, 101
 direct human impacts, 43, 101
 fish populations, 62, 106
 heritage sites, 80–81
 international obligations and treaties, 106, 133, 152, 166
 invasive species risk, 119
 management, 43, 106, 133, 152, 166
 species at risk, 43
ants, invasive non-native, 116–117, 173
aquaculture, 104–105; *see also* commercial fishing
aquatic ecosystems *see* freshwater ecosystems; marine ecosystems
Arctocephalus gazella (Antarctic fur seals), 99
artificial intelligence and machine learning, 201
assisted colonisation (species), 119–120; *see also* range shifts
assisted restoration (marine habitats), 170
asthma events, 17, 37, 38f, 99
Atlas of Living Australia, 112, 114, 155, 156, 188, 189t, 193
Australia International Council on Monuments and Sites (ICOMOS), 133, 165
Australian Academy of Science, 33, 189, 201
Australian Academy of Technology and Engineering, 189
Australian Climate Service, 171
Australian humpback dolphin (*Sousa sahulensis*), 61, 67
Australian National Audit Office
 assessment of EPBC Act referrals administration, 134, 135
 on offsets, 167

- Australian sandalwood (*Santalum spicatum*), 64
 Australian sea lion (*Neophoca cinerea*), 61
 Australian snubfin dolphin (*Orcaella heinsohni*), 61, 67
 Australian Wildlife Conservancy, 152
 Australia's Strategy for Nature 2019–2030, 154
Austropuccinia psidii (myrtle rust), 118
Azorella macquariensis (Macquarie cushion plant), 81
- B**
- Balaenoptera musculus* (blue whale), 67
 Bellinger River snapping turtle (*Myuchelys georgesii*), 48
 BHP, 156
 billabongs, 49; *see also* wetlands
 billfish, 67
 biodiversity, 54–67
 assessments of state and trend, 55–56
 climate change impacts, 18, 48, 57
 current knowledge incomplete, 201
 defined, 54
 fauna, 59–63
 fungi and microorganisms, 65
 local extirpation, 56–57
 loss of *see* biodiversity loss; extinctions
 migratory species, 65–67
 native species (number), 54
 plants, 63–64
 soil biodiversity, 47
 species discovery, 156
 threatened communities *see* threatened ecological communities
 threatened species *see* threatened species
 threats, 56, 58, 95
 UN Convention on, 123, 130, 132, 144, 150, 154
 biodiversity loss
 bushfire impacts, 34
 global risk, 18
 species decline, 56–58
 see also extinctions
 biodiversity management, 153–160
 funding, 182–191
 national strategies, 14, 154
 outlook, 14
 programs, 154–156
 threatened species and communities, 156–160
 biological control programs, 173, 174–175
 biopiracy, 123; *see also* Indigenous cultural and intellectual property
 Bioplatforms Australia, 155, 188, 189t
 biosecurity, 114, 172–173
 birds
 migratory species, 65–66, 132
 at risk of extinction, 160
 seabirds, 66, 132, 160
 shorebirds, 65–66, 132
 threatened species, 58, 59f, 60, 156–160, 156t
 waterbird abundance, 31, 49
 Black Summer fires (2019–20), 72, 80, 90–92, 92f, 178
 blackberry (*Rubus* spp.), 114, 115f
 black-footed tree-rat (*Mesembriomys gouldii gouldii*), 57
 blind cave eel (*Ophisternon candidum*), 63
 blind cave gudgeon (*Milyeringa veritas*), 63
 blue economy, 37
 blue whale (*Balaenoptera musculus*), 67
 blue-tailed skink (*Cryptoblepharus egeriae*), 60
 Budj Bim Cultural Landscape, 77, 80
 buffel grass (*Cenchrus ciliaris*), 104, 116, 117f, 125
 built environment, 19–20, 40–41
 climate change impacts, 73–74
 infrastructure, 95, 102
 resilience, 72, 171–172
 urban heat island effect, 74
 see also urban environments
 burden of disease caused by air pollution, 37, 71; *see also* diseases
Burrumys parvus (mountain pygmy possum), 57
 Burrup *see* Murujuga Cultural Landscape (Burrup)
 Bush Blitz, 155–156
 Bush Heritage Australia, 152, 153
 bush rat (*Rattus fuscipes*), 57
 bushfires, 18, 90–93
 air quality, 17, 37, 38f, 72, 91, 99
 animals lost or displaced, 92
 area burned, 30, 92f
 biodiversity and ecosystems impacts, 34, 36, 62, 80, 92, 125–126
 Black Summer fires (2019–20), 72, 80, 90–92, 92f, 178
 climate change–induced risk, 90–91

- CO₂ released to the atmosphere, 30
 - fire weather days, 87f
 - human lives and homes impact, 91, 92f
 - native vegetation lost, 30, 46–47, 92
 - recovery data, 199–200
 - recovery funding, 184
 - risk reduction, 141
 - seasonal fire periods, 87
 - threatened species impact, 10, 19, 156, 156t
 - timeline, 38f
 - water quality impacts, 34, 62
 - see also fire regimes
- C**
- Calidris tenuirostris* (great knot), 66
 - capital cities
 - air quality, 37, 39, 40
 - population, 40, 94
 - see also urban areas
 - carbon dioxide emissions
 - absorbed by oceans, 86
 - by energy subsector, 110f
 - released by bushfires, 30
 - see also greenhouse gas emissions
 - carbon markets, 185, 187
 - carbon sinks, 30, 53, 169, 182–183
 - Caretta caretta* (loggerhead turtle), 61
 - caring for Country, 14, 16, 19, 74–76, 120–121, 128, 140–144, 198; see also connection to Country; Indigenous land and sea management
 - carp (*Cyprinus carpio*), 173
 - Carpentarian rock-rat (*Zygomys palatalis*), 57
 - case studies
 - Armchair citizen scientists double their efforts to address Australia's big challenges, 199–200
 - The Australian restoration economy, 187
 - Australian sandalwood (*Santalum spicatum*), 64
 - Australians investing in natural capital, 182–183
 - Conservation through an integrated landscape approach, 152–153
 - Innovative biological control helping red crabs to recolonise and migrate across Christmas Island, 174
 - The 10 Gigawatt Vision, 111
 - catchment management, 138, 139f, 146; see also inland waterways; Murray–Darling Basin
 - cats, feral, 60, 115, 125, 157t, 173; see also feral animals
 - cauliflower soft coral (*Dendronephthya australis*), 61
 - Cenchrus ciliaris* (buffel grass), 104, 116, 117f, 125
 - Cenchrus pedicellatus* syn. *Pennisetum pedicellatum* (annual mission grass), 116
 - Cenchrus polystachios* syn. *Pennisetum polystachion* (mission grass), 116
 - central rock-rat (*Zygomys pedunculatus*), 57
 - Centrostephanus rogersii* (long-spine urchin), 119
 - cetaceans see dolphins; whales
 - Champtocephalus gunnari* (mackerel icefish), 62
 - Christmas Island flying fox (*Pteropus natalis*), 57
 - Christmas Island forest skink (*Emoia nativitatis*), 60
 - Christmas Island, yellow crazy ant suppression and red land crab recolonisation, 174–175
 - cities see urban areas
 - citizen science, 99, 195, 198–200
 - Clean Up Australia Day, 146
 - climate, 22–25
 - El Niño / La Niña events, 22, 41, 53
 - variability, 86
 - climate change, 22–25, 86
 - amplifying effect on pressures, 179–180
 - assessments of state and trend, 24–25, 68
 - international obligations and treaties, 130, 131
 - management approaches, 137, 138, 161, 163, 168–170
 - mitigation, 168–170
 - outlook for the environment, 10, 16
 - rainfall, 86; see also drought; rainfall patterns
 - warming, 22, 84f, 86, 88, 89–90; see also drought; heatwaves; temperature
 - Climate Change Adaptation Research Facility, 169, 184
 - climate change impacts, 16, 18, 36, 82–93, 84f, 124
 - adaptation to, 138, 168–170, 180
 - on agriculture, 18, 70–71
 - on Antarctica, 16, 42–43
 - assessments of impacts and trend, 68, 82–83
 - on biodiversity, 18, 48, 57
 - on built environment, 73–74
 - on coasts and coastal ecosystems, 34–36, 50–51, 61, 88, 138
 - fire periods, 87, 87f

- on freshwater ecosystems, 48, 119
 - on heritage, 80–81, 180
 - on human health and wellbeing, 68, 71–72, 76, 86, 88
 - on Indigenous communities, 76, 86, 88, 141–142
 - on marine environment and ecosystems, 36, 50–51, 90, 170
 - on natural heritage, 80–81, 179–180
 - on oceans, 16, 36, 87–88; *see also* ocean
 - acidification; sea level rise
 - on plant species, 119–120
 - pressures amplified, 179–180
 - range shifts, 50–51, 112, 113, 119–120
 - on reefs, 18, 45, 50–52, 124, 170
 - research facility discontinued, 169, 184
 - risk management framework, 180
 - species loss, 119
 - on urban environments, 73–74
 - on water resources, 22
- Closing the Gap initiative, 19
- COAG *see* Council of Australian Governments (COAG)
- coal and coal-seam gas developments, 134, 180
- coastal ecosystems
 - assessments of state and trend, 45
 - bushfire impacts, 34
 - climate change impacts, 35, 50–51, 61
 - condition of, 16, 27, 34–36, 45, 50–51, 53–54
 - industrial pollutants, 107–108
 - monitoring (molecular techniques), 201
 - pressures on, 34, 35, 61, 95, 99, 100, 125
 - threatened species, 61, 160
 - vegetation loss, 46–47
 - see also* marine ecosystems
- coasts
 - artificial marine structures, 95
 - assessments of state and trend, 26, 27
 - climate change adaptation, 169–170
 - climate change impacts, 34–36, 88, 138
 - climate change management, 138
 - coastal urban areas, 61, 82, 95, 100
 - condition of, 16, 34–36
 - debris and pollution, 37, 99
 - flooding, 41
 - management effectiveness, 163–164
 - pressures on, 34, 35, 95, 125
 - see also* coastal ecosystems; marine environment
- colonisation
 - historic heritage, 69, 78–79, 107, 164
 - impact of, 56, 74, 76, 116, 120, 128, 140; *see also* Indigenous governance, rights and access
- commercial fishing, 104–105, 106
 - environmental impact, 71, 104–105
 - Indigenous engagement in, 144
 - management, 163–164
 - sustainability and value, 37, 67, 104–105, 190
 - see also* aquaculture
- Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), 106
- connection to Country, 12, 13–14, 15f, 35, 36, 41, 73, 74–76, 141; *see also* caring for Country; Indigenous land and sea management
- conservation advices, 59, 160
- conservation management *see* management; management approaches; management of pressures; management of specific sectors and resources
- conservation seed banks, 157t
- contaminants *see* pollution
- Convention on Biological Diversity, 123, 130, 144, 150, 154
 - Aichi targets, 132, 150, 154
 - Australian report on progress (2014–20), 132
 - see also* Nagoya Protocol
- Convention on the Conservation of Antarctic Marine Living Resources, 133, 166
- Cooks River Alliance, 146
- coral bleaching, 18, 22, 50, 90, 170
- coral mortality, 51, 88
- coral reefs, 51–52, 53
 - climate change impacts, 18, 51, 170
 - cyclone impact, 93
 - fish abundance and distribution, 50–51
 - threatened coral species, 61
 - see also* Great Barrier Reef
- Council of Australian Governments (COAG), 139, 168
- Country, concept of, 14; *see also* caring for Country; connection to Country
- COVID-19 pandemic impacts
 - on emissions, 131

plastic pollution increase, 99
 on population growth, 94
 on tourism patterns, 100
 on urban environments, 37, 40, 73

crocodiles, 55, 119

Cryptoblepharus egeriae (blue-tailed skink), 60

cultural and intellectual property, 121, 123,
 144–145, 188; *see also* Indigenous knowledge

cultural burning, 120, 141, 146

cultural heritage *see* heritage

cultural safety, 141

cultural water, 34, 48–49, 71

cumulative pressures, 89, 124–126, 127f
 assessments of impacts and trend, 126
 cumulative impact management, 179–180

cyclones *see* tropical cyclones

Cyprinus carpio (carp), 173

D

Daly–Roper water control districts, 33

Dampier Archipelago *see* Murujuga Cultural
 Landscape (Burrup)

Darwin water control districts, 33

data, 11–12, 20, 168, 191–197
 big data, 195–197
 citizen science, 99, 195, 198–200
 climate information, 171
 greenhouse accounts, 96
 Indigenous data sovereignty, 123, 145; *see also*
 Indigenous knowledge
 natural capital accounting, 148–149, 186
 sources, 195
see also monitoring and reporting

deer, feral, 173

Dendronephthya australis (cauliflower soft coral),
 61

Department of Agriculture, Water and the
 Environment
 environmental objectives funding, 184–185, 184f

Department of the Prime Minister and Cabinet, 190

Dermochelys coriacea (leatherback turtle), 61

desalination, 16, 96, 162–163

diatoms, 46

digital access, 73

digital and urban divide, 95

digital technologies, 199–201

diseases
 burden of disease caused by air pollution, 37, 71
 global risk, 18
 impacts of, 56, 117–119

Dissostichus eleginoides (Patagonian toothfish), 62

Dissostichus mawsoni (Antarctic toothfish), 62

dolphins, 61, 66

drought, 31, 34, 45, 49, 90
 environmental flows reduction, 180
 land degradation, 30
 run-off reduced, 125
 severity, 18, 90
 vegetation loss, 97

dryland salinity, 33

dust, 37, 38f, 99

dutjahn (Australian sandalwood – *Santalum
 spicatum*), 64

E

Echuca Declaration 2007, 48–49

ecological engineering, 95, 170

ecosystem services, 14, 30, 36, 103
 accounting, 148–149
 defined, 67
 markets, 185

ecosystem-based management approaches, 172,
 179, 180

ecosystems
 assessments of state and trend, 44
 data on *see* data
 groundwater-dependent, 50
 national accounts, 149
 restoration, 154
 at risk of collapse, 30, 44
 types, 46
see also habitat loss, fragmentation and
 degradation; threatened ecological
 communities; *and specific ecosystems*: alpine
 ecosystems; Antarctica; coastal ecosystems;
 freshwater ecosystems; marine ecosystems;
 terrestrial ecosystems

ecosystems management *see* management
 approaches; management of specific sectors
 and resources

El Niño events, 22, 53

Elderslie Banksia Scrub Forest, 160

- electric vehicles, 99, 111, 169
- electricity generation, 85, 109–112
- emissions *see* greenhouse gas emissions
- Emissions Reduction Fund, 168
- Emoia nativitatis* (Christmas Island forest skink), 60
- energy consumption, 95–96, 109f
- energy production, 109–112; *see also* oil and gas exploration and extraction
- energy sector emissions, 85–86, 109
- energy sources, 109f
- environment, social and governance investment, 182–183, 185–186; *see also* funding
- environment protection, 10–20, 147f
- funding, 143, 144, 153, 158, 182–191
- international obligations *see* international obligations and treaties
- local environmental stewardship, 145–146, 147f
- national, state and territory legislation and policy, 128–129, 133–136, 164–165
- outlook, 13–17
- see also* environmental degradation; management approaches; management of pressures; management of specific sectors and resources; protected areas
- Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), 133–136
- administration of, 135
- Antarctic waters and Southern Ocean protection, 166
- functions, 134
- habitat loss assessment, 124–125
- historic heritage listing, 79
- impact assessments and, 179
- Indigenous heritage protection, 78, 164–165
- Indigenous knowledge protection, 144
- invasive species management, 172
- key threatening processes, 115, 116, 176
- listed species *see* threatened species
- Migratory Species List, 65
- review of, 78, 120, 129, 134–135, 136, 139, 148, 153, 160, 179, 186, 188, 192
- state and territory jurisdictions' role, 136
- threat abatement plans, 115, 160
- environmental degradation, 10–20
- impacts on environment, 18–19
- impacts on human health and wellbeing, 19–20
- threat to humanity, 18
- see also* environment protection; pressures on the environment; *and specific environments and ecosystems*
- environmental impact assessments, 167–168, 179–180; *see also* cumulative pressures
- environmental management *see* caring for Country; Indigenous land and sea management; management; management approaches; management of pressures; management of specific sectors and resources
- environmental offsets, 167–168
- environmental restoration funding, 186–188
- environmental standards, national framework for, 139–140; *see also* *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)
- environmental water, 33–34, 138, 139f, 161–162, 180, 183
- environmental–economic accounting, 148–149, 186
- estuaries
- bushfire impacts, 34, 93
- condition of, 34–35
- fish populations, 62
- pressures on, 62
- see also* wetlands
- Eubalaena australis* (southern right whale), 66–67
- eucalypts, 46, 118, 119
- European rabbit (*Oryctolagus cuniculus*) *see* rabbits
- European red fox (*Vulpes vulpes*) *see* foxes
- evaporation, 22, 31
- experts (human resources), 197–198
- export markets with net zero climate targets, 186
- extinctions
- amphibians, 118
- birds, 160
- climate change factor, 84f
- fish, 62
- functional extinction, 59
- mammals, 14, 56, 59–60, 115, 160
- mammals at most risk of, 57
- risk increase from bushfires, 92
- undercounted, 14
- see also* threatened species
- extreme temperatures, 76, 90; *see also* heatwaves
- extreme weather events, 18, 19–20, 72, 88–93
- adaptation to, 20, 171–172
- assessments of impacts and trend, 25, 68, 82–83

- climate change effects, 24, 68, 71–72
 - impacts on biodiversity, 57–58
 - intensity and frequency, 16, 89
 - management, 170–172
 - pressure on coasts, 34
 - pressure on Indigenous sites and cultural values, 76
 - reactive regulatory measures, 170
 - risk assessment, 172
 - see also bushfires; drought; hailstorms; heatwaves; rainfall; tropical cyclones
- F**
- far eastern curlew (*Numenius madagascariensis*), 66
 - fauna, decline in
 - alpine regions, 57
 - coastal and marine species, 61
 - fishes, 61–62
 - invertebrates, 62–63
 - subterranean fauna, 63
 - terrestrial fauna, 59–61
 - see also threatened species
 - feral animals, 89, 115–116, 115f, 125, 157t, 173
 - financing see funding
 - fire regimes, 16, 63
 - changes in, 58, 63, 64, 80, 125, 154–155
 - cultural burning, 120, 141, 146
 - fire exacerbation of pressures, 125
 - see also bushfires
 - fish
 - coastal species decline, 50–51
 - extinctions, 62
 - fish stocks condition, 37, 71
 - native fish population decline (rivers), 48
 - Southern Ocean, 62, 106
 - threatened species, 61–62
 - fish deaths, 33, 48, 62, 90, 104
 - fish farming see aquaculture
 - fishing
 - commercial see commercial fishing
 - fisheries management, 37, 144, 163–164, 170
 - impacts on ecosystems, 71, 100–101, 104–106, 124
 - Indigenous customary fishing, 105, 122
 - recreational, 71, 100–101, 105–106, 164
 - vulnerable species interaction with fishers, 164
 - Fitzgerald's mulla mulla, 157t
 - Flinders Ranges, 80
 - flooding, 31, 41, 72, 88–89, 93, 171
 - flying fox mass deaths, 90
 - food production, 68, 70–71; see also agriculture
 - food webs, 36, 42, 51, 53, 99
 - forest clearing, 96–97; see also land clearing; native vegetation
 - fossil fuels, 109, 109f; see also oil and gas exploration and extraction
 - foxes, 60, 89, 115, 115f, 157t
 - freshwater see water quality; water resources
 - freshwater ecosystems
 - assessments of state and trend, 45
 - bushfire impacts, 70, 92–93
 - climate change impacts, 119
 - condition of, 47–50
 - pressures on, 31, 47, 104, 125
 - salinity levels, 33
 - water temperature and turbidity, 104
 - see also inland waterways
 - freshwater species
 - climate change impacts, 48, 119
 - fish, 61–62, 63
 - frogs, 58, 60–61
 - protection effectiveness, 160
 - subterranean, 63
 - threatened species, 160
 - turtles, 48, 60
 - Freycinet Peninsula, Tasmania, 152–153
 - frogs, threatened, 58, 60–61
 - functional extinction, 59
 - funding, 143, 144, 153, 158, 182–191
 - grants, 75, 146, 168–169, 184f, 188, 191
 - heritage programs and agencies, 189, 191
 - Indigenous rangers, 190
 - for research, 188–190
 - fungal pathogens, 117–118
 - fungi species, 65, 201
- G**
- Galaxias pedderensis* (Pedder galaxias), 62
 - gamba grass (*Andropogon gayanus*), 116, 125
 - geoheritage, 69, 79–80, 81, 165, 189
 - ghost nets, 146
 - goats, feral, 115; see also feral animals

- Gondwana Rainforests, 80
 grants, 75, 146, 168–169, 184f, 188, 191; *see also*
 funding
 grasses
 native, in saltmarshes, 53
 non-native invasive, 104, 116, 125
 see also seagrasses
- Great Barrier Reef
 climate change adaptation plans, 170
 climate change impacts, 18, 170
 condition related to Indigenous quality of life, 74
 coral bleaching, 18, 22, 90, 170
 cumulative pressures management, 180
 Indigenous management and projects, 143
 marine heatwaves, 90
 ocean acidification, 88
 pollutants, 34, 107–108
 protection funding, 143, 184, 190
 Reef 2050 plan, 74, 180, 184, 184f, 190, 196
 Reef Knowledge System, 196–197
 tipping point, 88
- Great Barrier Reef Foundation, 190
- great knot (*Calidris tenuirostris*), 66
- green cover in urban areas, 41
- greenhouse gas emissions, 30, 85–86, 95–96
 Australia's place among global emitters, 85
 carbon sinks, 30, 53, 169, 182–183
 changes by category (source), 85–86, 85f
 CO₂ emissions by energy subsector, 110f
 from electricity generation, 109
 industrial pollutants, 107–109
 land clearing contribution to, 96
 from mining, 106
 net zero emissions, 82
 reduction targets, 82, 85, 108, 131, 168–169
 from road vehicles, 73
see also carbon dioxide emissions
- groundwater
 condition of, 32–33
 dependent ecosystems, 50
 levels, 32–33
 management, 138, 161
 pressures on, 16, 50
 recharge, 31, 32, 93, 163
- groundwater species, 50
- H**
- habitat loss, fragmentation and degradation, 56,
 58–59, 61, 95, 96, 97, 98f, 106, 119
 cumulative impacts, 179
 cumulative losses, 124–125
see also land degradation; threatened ecological
 communities
- hailstorms, 16, 24, 71, 72
- handfish (*Sympterychthys unipennis*), 62
- health and wellbeing *see* human health and
 wellbeing
- healthy environment, 21f
- Heard Island, 43, 66, 80, 166
- heatwaves, 17, 25, 68, 82, 89–91, 99, 100
 Antarctic continent, 43
 health implications of, 71–72
 management, 170, 171
 marine heatwaves, 16, 18, 28, 35, 50, 51, 53, 82,
 90, 124
- heritage, 77–81
 climate change impact risk, 80–81, 180
 defined, 77
 degradation of, 17
 funding, 189, 191
 geoheritage, 69, 79–80, 81, 165, 189
 historic/cultural, 77, 78–79, 80, 107, 133, 146, 164
 Indigenous, 17, 69, 74, 76–80, 123, 143, 164–165;
 see also Indigenous cultural and intellectual
 property; Indigenous knowledge
 international obligations and treaties, 133
 lists and registers, 79
 natural, 79–81, 146
 outlook, 17
 protection and management, 17, 69, 78, 79–80,
 146, 164–165
 recreation and tourism impacts on, 100–101
 World Heritage, 77, 80–81, 112, 133, 146
- house construction materials, 171–172
- human environmental damage *see* people-related
 pressures
- human health and wellbeing, 18, 67–81
 air quality impacts, 37, 39–40, 71
 assessments of state and trend, 68–70
 climate change impacts, 68, 71–72, 76, 86, 88
 food, water and air quality, 68, 70–71
 healthy environment, 21f

- impacts on, 12, 19–20, 37
 - Indigenous Australians' wellbeing, 19, 39–40, 41, 69, 71, 74–76, 86, 88, 143–144, 197–198
 - from Landcare participation, 146
 - livability of environment, 29, 69, 72–74
 - nature and quality of life, 149
 - soil biodiversity importance, 47
 - top threats to, 18
 - 'wellbeing' defined, 67
 - human population growth, 17, 40, 73, 94, 95; see also people-related pressures
 - human resources, 197–200
 - citizen science, 99, 195, 198–200
 - expert capacity, 197–198
 - human-induced climate change see climate change
 - humpback whale (*Megaptera novaeangliae*), 66, 67
 - Hunter Valley Weeping Myall (*Acacia pendula*) Woodland, 160
 - Hymenachne amplexicaulis* (olive hymenachne), 116
- I**
- IMOS see Integrated Marine Observing System (IMOS)
 - impacts see environmental degradation; pressures on the environment
 - Important Bird Areas, 66
 - Indigenous Australians
 - connection to Country, 12, 13–14, 15f, 35, 36, 41, 73, 74–76, 141
 - customary fishing, 105, 122
 - disempowerment, 18, 89, 141
 - health and wellbeing, 19, 39–40, 41, 69, 71, 74–76, 86, 88, 143–144, 197–198
 - plant foods and materials, 44, 49, 70, 76, 144
 - population, 40
 - women, 75–76, 198
 - Indigenous cultural and intellectual property, 121, 123, 144–145, 188; see also Indigenous governance, rights and access; Indigenous knowledge
 - Indigenous Environmental Watering Guidance Project, 162
 - Indigenous estate, 89, 107, 141–143
 - access and rights, 122
 - changes over time, 142f
 - threatened species on, 160
 - see also Indigenous land and sea management
 - Indigenous governance, rights and access, 120–123
 - assessments of impacts and trend, 121
 - customary fishing, 105, 122
 - legal framework, 120, 129, 141, 143
 - water entitlements, 34, 48–49, 71, 162
 - see also Indigenous cultural and intellectual property
 - Indigenous heritage, 17, 69, 74, 76–80, 123, 143, 164–165
 - Indigenous knowledge, 120–123, 140–141
 - climate change and adaptation responses, 88, 89
 - inclusion in research, 188
 - languages, 76
 - legal protection of, 144–145
 - significance of, 12, 13–14, 15f
 - in urban planning and policy, 17
 - water resources and water management, 34, 49, 146, 162
 - Indigenous land and sea management, 132, 140–145
 - caring for Country, 12, 14, 16, 19, 74–76, 120–121, 128, 140–144, 198
 - climate change mitigation and adaptation, 88, 89
 - commercial fisheries, 144
 - cultural fire management, 120, 141, 146
 - cultural flows (water entitlements), 48–49, 162
 - environmental monitoring, 195, 196f
 - funding, 144, 190
 - invasive species impact on, 114, 116
 - sea Country management, 146
 - see also connection to Country; Indigenous estate; Indigenous Protected Areas (IPAs); Indigenous rangers
 - Indigenous Land Use Agreements, 19, 142
 - Indigenous languages, 76
 - Indigenous people (Australian) see Indigenous Australians
 - Indigenous Protected Areas (IPAs), 16, 75–76, 89, 122, 142–143, 144, 150, 190
 - Indigenous rangers, 16, 122, 140, 141, 143–144, 146, 190, 197–198
 - Indigenous rights (Australian) see Indigenous governance, rights and access

- Indigenous rights (international agreements), 120–121, 122, 123, 130, 143, 165
- Indigenous tenure *see* Indigenous estate
- Indigenous wellbeing *see under* Indigenous Australians
- industrial pollutants, 40, 99, 107–109
- industry, 101–112
 - agriculture *see* agriculture
 - aquaculture and fishing, 104–105
 - assessments of impacts and trend, 101
 - mining, 18, 103, 106–107
 - transportation, 102–103
- infectious diseases *see* diseases
- infrastructure, 95, 102; *see also* built environment
- inland waterways
 - assessments of state and trend, 27
 - condition of, 16, 30–34, 47
 - management, 138, 139f, 146, 161–162
 - pressures on, 104, 125
 - salinity levels, 33
 - streamflow, 31, 34–35, 180
 - see also* freshwater ecosystems; rivers and streams; water quality; water resources; wetlands
- insects
 - biodiversity threats, 63
 - invasive species, 116–117, 173
 - see also* invertebrates
- Inspector-General of Water Compliance, 162
- integrated conservation management, 137–140
- Integrated Ecosystem Assessments of (IEA)
 - approach, 180
- Integrated Marine Observing System (IMOS), 155, 188, 189t, 193–194, 194f
- integrated water management, 138, 138f, 161–162
- intellectual property, 121, 123, 144–145, 188; *see also* Indigenous knowledge
- intergovernmental agreements (national)
 - climate change adaptation, 168
 - on the environment, 137
 - Murray–Darling Basin Plan and Agreement, 161–162
- Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services, 130, 143
- international arrivals, cargo and freight, 102–103
- International Council on Monuments and Sites (ICOMOS), 133, 165
- international obligations and treaties, 128–133
 - Antarctica and Southern Ocean, 106, 133, 152, 166
 - assessments of effectiveness and trend, 129
 - biological diversity, 123, 130, 132, 144, 150, 154
 - climate change, 131
 - environment protection, 132–133
 - greenhouse gases reduction commitments, 82, 85, 96, 108, 131, 168–169
 - heritage protection, 133, 165
 - list of agreements, 130–131
 - sustainable development, 19, 131–132
 - see also* United Nations
- International Union for Conservation of Nature (IUCN)
 - Australian Committee, 133, 137
 - Important Bird Areas, 66
 - Red List, 58, 60, 61, 62, 65
 - register of introduced and invasive species, 112
 - World Heritage outlook, 80
- introduced species, 56, 60, 103, 112, 113f, 114, 118
 - sources of, 102–103, 114
 - see also* feral animals
- invasive species, 18, 36, 56, 58, 89, 112–120
 - animals, 114–116
 - assessments of impacts and trend, 113
 - biosecurity and sources, 102–103, 114
 - diseases, 117–119
 - eradication, 43, 66, 81, 117
 - exotic, 103
 - impacts of, 114–119
 - insects, 116–117, 173
 - on islands, 36, 66, 81
 - management of, 172–174
 - number of, 112, 113f, 114
 - plants, 112, 114, 115f, 116; *see also* weeds
 - range shifts as invasiveness, 112, 119–120
 - subantarctic and Antarctic regions, 36, 43, 66
 - threat to wildlife, 104, 112
 - top 10 threatening species, 114, 115f
- invertebrates, 34, 43, 160
 - climate change impacts, 63
 - invasive species, 116–117, 173
 - number of Australian species, 62

- threatened species, 58, 61, 62–63
 - threats, 63
 - investment (environment, social and governance investment), 182–183, 185–186; *see also* funding; private conservation initiatives
 - IPAs *see* Indigenous Protected Areas (IPAs)
 - islands
 - invasive species, 36, 66, 81
 - low lying, climate change threat to, 86, 88
 - subantarctic, 36, 43, 66, 80
 - threatened species, 36
 - threatened species translocations to, 160
 - IUCN *see* International Union for Conservation of Nature (IUCN)
- J**
- Juukan Gorge rock-shelters, 77–78, 107, 164
- K**
- Kati Thanda–Lake Eyre system, 31, 89, 93
 - kelp, 18, 51, 119, 154, 170
 - key findings, 10–12
 - key threatening processes, 115, 116, 176
 - Kilter Rural impact investment funds, 183
 - knowledge systems
 - Great Barrier Reef, 196–197
 - indigenous *see* Indigenous knowledge
 - see also* data; research programs and facilities
 - koala (*Phascolarctos cinereus*), 117
 - krill, 106
- L**
- La Niña events, 22, 41
 - Lake Eyre Basin, 31, 89, 93
 - land clearing, 18, 46, 47, 96–97, 98f, 103; *see also* native vegetation
 - land degradation, 33, 103, 116; *see also* habitat loss, fragmentation and degradation; soils
 - land environment
 - assessments of state and trend, 26
 - condition of, 14, 16, 30
 - conservation protection, 16
 - monitoring from space, 201
 - national accounts, 148–149
 - pressures on, 17, 63
 - waste (impact of), 19
 - Land for Wildlife, 146, 153
 - land-use changes, 30, 85, 97, 103
 - Landcare
 - community-led program, 19, 137–138, 146, 155f
 - National Landcare Program, 154–155, 184, 184f
 - landfill sites, 19, 107, 108
 - lantana (*Lantana camara*), 114, 115f
 - lead exposure, 40
 - leatherback turtle (*Dermodochelys coriacea*), 61
 - legislation, 128, 133–136, 139–140
 - Antarctica and Southern Ocean protection, 166
 - assessments of effectiveness and trend, 129
 - climate change related, 168
 - heritage protection, 77–78, 143, 164–165
 - Indigenous knowledge protection, 123, 144–145
 - invasive species management, 172
 - see also* Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act); international obligations and treaties
 - Lepidochelys olivacea* (olive ridley turtle), 61
 - Lepidodactylus listeri* (Lister’s gecko), 60
 - letter to the minister, 8–9
 - lichens, 43, 81
 - light pollution, 61, 100
 - Lister’s gecko (*Lepidodactylus listeri*), 60
 - litter, 19, 99, 108, 146
 - livability, 29, 72–74, 165
 - assessments of state and trend, 69
 - see also* human health and wellbeing
 - local environmental stewardship, 145–146, 147f
 - local extirpation, 56–57
 - local governments, 133, 138
 - air pollution and emissions management, 169, 177
 - expertise lack, 197
 - extreme events impact mitigation, 171
 - threatened species recovery contribution, 158, 186
 - waste management, 176
 - weed control, 102
 - loggerhead turtle (*Caretta caretta*), 61
 - long-spine urchin (*Centrostephanus rodgersii*), 119
- M**
- mackerel icefish (*Champsocephalus gunnari*), 62
 - Macquaria australasica* (Macquarie perch), 62
 - Macquarie cushion plant (*Azorella macquariensis*), 81

- Macquarie Island, 43, 66, 80, 166
- Macquarie perch (*Macquaria australasica*), 62
- mammals
- extinctions, 14, 56, 59–60, 115
 - at risk of extinction, 57, 60, 160
 - threatened species, 58, 59f, 60, 156, 157t
- management, 128–136
- framework, 128
 - funding *see* funding
 - Indigenous practices *see* Indigenous knowledge; Indigenous land and sea management
 - international obligations, 130–133
 - national, state and territory legislation and policy, 128–129, 133–136, 164–165
 - resources *see* resources for environmental management
 - see also* *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act); funding; international obligations and treaties; legislation
- management approaches, 20, 136–149
- assessments of effectiveness and trend, 136
 - collaborative and adaptive, 11–12, 23f
 - ecosystem based, 172, 179, 180
 - Indigenous, 140–145
 - inflexibility of government management practices, 120, 122
 - integrated management, 137–140
 - natural capital accounting, 148–149, 186
 - stewardship, 145–146, 147f
 - see also* Indigenous land and sea management; monitoring and reporting
- management of pressures, 166–181
- assessments of effectiveness and trend, 166
 - climate change mitigation and adaptation, 168–170
 - cumulative impacts, 179–180
 - environmental impacts, 167–168
 - extreme events, 170–172
 - invasive species, 172–174
 - pollution, 176–178
- management of specific sectors and resources, 149–166
- Antarctica, 43, 106, 133, 152, 166
 - assessments of effectiveness and trend, 149
 - biodiversity and natural resources, 153–160
 - coastal and marine, 163–164
 - heritage, 69, 164–165
 - protected areas, 150–153
 - urban areas, 165–166
 - water resources, 161–163
- management resources *see* resources for environmental management
- mangroves, 53
- marine ecosystems
- assessments of state and trend, 45
 - assisted restoration, 170
 - climate change impacts, 50–51, 90
 - condition of, 36–37, 50–54
 - fishing impacts on, 71, 104–106, 124
 - invasive species management, 172
 - monitoring, 170, 201
 - pressures on, 51, 180
 - range shifts and, 119
 - threatened species, 61–62
 - see also* Great Barrier Reef; reefs
- marine environment
- area protected, 150–152, 151f
 - assessments of state and trend, 28
 - assisted restoration, 170
 - climate change impacts, 36, 90, 170
 - condition of, 16, 36–37
 - cumulative pressures, 180
 - debris and pollution, 34, 37, 61, 99, 100, 103, 107–108, 146, 176–177
 - diseases, 118–119
 - light pollution, 61, 100
 - management, 163–164, 170, 180
 - noise pollution, 100, 108–109, 176, 177
 - research funding, 190
 - vessel damage to, 100, 102, 103
- marine heatwaves, 16, 18, 28, 35, 50, 51, 53, 82, 90, 124; *see also* ocean warming
- Marine National Facility, 188, 189t
- marine pests, 103, 114, 172
- marine reserves, 150–152
- marine species
- density, 194f
 - protection, 160, 190
 - range shifts, 50–51, 119
 - threatened, 61
 - see also* marine ecosystems

- marine turtles, 61
 matchstick banksia, 159f
 McDonald Islands, 43, 66, 80, 166
Megaptera novaeangliae (humpback whale), 66, 67
Mesembriomys gouldii gouldii (black-footed tree-rat), 57
 microorganisms, 65
 migratory species
 assessments of state and trend, 56
 international obligations and treaties, 132
 protection effectiveness, 160
 threatened, 65–67
Milyeringa veritas (blind cave gudgeon), 63
 mining, 18, 103, 106–107; *see also* oil and gas exploration and extraction
 mission grass (*Cenchrus polystachios* syn. *Pennisetum polystachion*), 116
 molecular technologies, 201
 monitoring and reporting, 192–195
 air quality, 177–178
 collaborative approaches, 195, 196f
 cumulative pressures, 179
 EPBC Act administration shortcomings, 134, 135, 136, 160, 167
 extreme climate events, 57–58
 Great Barrier Reef early warning system, 170
 heritage protection, 165
 introduced species underestimate, 114
 marine reserve effectiveness, 151–152
 Murray–Darling Basin, 48
 needs, 20, 139
 shortcomings, 154, 185
 threatened species, 58, 157t, 195, 196f
 see also data; management approaches
 mosses, 43, 81
 mountain pygmy possum (*Burramys parvus*), 57
 Murray–Darling Basin
 bushfire ash run-off, 62, 92–93
 climate change impacts, 22, 48
 condition of, 48–49
 drought impacts, 30, 33–34, 125
 environmental degradation, 33
 groundwater levels, 32–33
 rainfall, 90
 run-off reduction, 125
 streamflow, 31
 turtle declines, 60
 water allocation, 33, 48–49, 122, 183
 water management, 122, 161–162
 Murray–Darling Basin Balanced Water Fund, 182–183
 Murray–Darling Basin Plan, 161–162
 Murujuga Cultural Landscape (Burrup), 77, 80
 myrtle rust (*Austropuccinia psidii*), 118
Myuchelys georgesii (Bellinger River snapping turtle), 48
- N**
- Nagoya Protocol, 123, 130, 145; *see also* Convention on Biological Diversity
 Narran Lakes wetland system, 31
 National Agreement on Closing the Gap, 19
 National Clean Air Agreement, 178
 National Collaborative Research Infrastructure Strategy (NCRIS), 11, 58, 155, 188, 189t, 193
 National Cultural Flows Research Project, 34
 National Environment Protection Measures (NEPMs), 177–178
 National Environmental Science Program (NESP), 11, 58, 184f, 188, 193
 Indigenous partnership principles, 141, 188
 threatened species indexes, 58, 59f, 60, 63
 national frameworks
 environmental standards, 139–140; *see also* *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)
 environmental–economic accounting, 148–149, 186
 see also legislation
 National Greenhouse Accounts, 96
 National Landcare Program, 154–155, 184, 184f
 National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA), 176–177
 national parks
 co-management, 122, 141
 Freycinet Peninsula, Tasmania, 152–153
 weed control, 116
 see also protected areas
 National Recovery and Resilience Agency, 171
 National Reserve System, 16, 46, 75, 132, 143, 150, 158, 160

- National Water Initiative, 161, 180
- native guava (*Rhodomyrtus psidioides*), 118
- native title, 107, 122, 141, 142, 142f; *see also*
- Indigenous estate
- native vegetation, 30, 41
- alpine regions, 57
 - assessments of state and trend, 44
 - in coastal habitats, 53–54
 - condition of, 46–47
 - conservation and restoration initiatives, 47
 - diseases, 118
 - eucalypts, 46, 118, 119
 - extent of, 46
 - loss of, 30, 46–47, 92, 96–97; *see also* land clearing
 - Macquarie Island, 81
 - threatened plant populations, 58, 81
 - see also* land clearing; plant species
- natural capital accounting, 148–149, 180, 186; *see also* funding
- natural disasters
- resilience to, 146, 171
 - see also* bushfires; extreme weather events; flooding; hailstorms; tropical cyclones
- natural gas *see* oil and gas exploration and extraction
- natural heritage
- conservation, 17, 79–80, 146
 - invasive species threat to, 112
 - pressures on, 100–101
 - see also* environment protection; World Heritage places
- natural resource management *see* management
- nature, value of, 148–149
- nature discovery programs, 156
- NCRIS *see* National Collaborative Research Infrastructure Strategy (NCRIS)
- Neophoca cinerea* (Australian sea lion), 61
- NEPM *see* National Environment Protection Measures (NEPMs)
- NESP *see* National Environmental Science Program (NESP)
- net zero emissions, 82, 85, 169, 186
- El Niño / La Niña events, 22, 41, 53
- noise pollution, 43, 100, 108–109, 176, 177
- nongovernment organisations
- feral animal management, 173
 - Great Barrier Reef partnership, 190
 - properties managed for conservation, 152, 153
 - threatened species recovery initiatives, 158, 186
 - see also* private conservation initiatives
- NOPSEMA *see* National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA)
- northern hopping-mouse (*Notomys aquilo*), 57
- Northern Territory, 10 Gigawatt Vision, 111
- Notomys aquilo* (northern hopping-mouse), 57
- numbats, 159f
- Numenius madagascariensis* (far eastern curlew), 66
- nutrient pollution, 34, 48, 93, 104, 107, 108, 163
- ## O
- ocean acidification, 16, 42, 53, 67, 87–88
- Ocean Leadership package, 190
- ocean warming, 50, 51–52, 67, 90; *see also* marine heatwaves; sea surface temperature
- oceans
- climate change impacts, 16, 36, 87–88
 - national accounts, 148
 - phytoplankton blooms, smoke induced, 24
 - seabed habitats, 52–53, 99
 - sustainable management, 132
 - water column habitats, 52
 - see also* marine ecosystems; marine environment; marine species
- offsets, 167–168
- oil and gas exploration and extraction, 37, 108, 109, 110, 176–177; *see also* mining
- olive hymenachne (*Hymenachne amplexicaulis*), 116
- olive ridley turtle (*Lepidochelys olivacea*), 61
- OneHouse project, 171–172
- Ophisternon candidum* (blind cave eel), 63
- orange-bellied parrot, 159f
- Orcaella heinsohni* (Australian snubfin dolphin), 61, 67
- orchids, 63, 81
- Oryctolagus cuniculus* (European rabbit) *see* rabbits
- outlook for the environment, 10, 13–20
- oysters, 35, 84f, 104, 118
- ozone, 40, 71
- ozone layer hole, 42

P

- para grass (*Urochloa mutica*), 116
- Paris Agreement on climate change (2015), 130, 131;
see also greenhouse gas emissions – reduction targets; international obligations and treaties
- particulate matter, 37, 39, 39f, 71, 91, 106
- Patagonian toothfish (*Dissostichus eleginoides*), 62
- patents, 145; see also intellectual property
- Pedder galaxias (*Galaxias pedderensis*), 62
- people (human resources for environmental management), 197–201
- people-related pressures, 94–101, 127f
assessments of impacts and trend, 94
collaborative and adaptive management, 23f
land clearing, 18, 46, 47, 96–97, 98f, 104
pollution see pollution
population growth, 17, 40, 73, 94, 95
recreation and tourism, 100–101
urbanisation, 94–96; see also urban areas
- pest animals, 172–173
foxes, 60, 89, 115, 115f, 157t
rabbits, 43, 66, 81, 115, 115f
rats, 43, 66, 81, 115f
see also feral animals; invasive species
- PFAS (per- and poly-fluoroalkyl substances), 108
- Phascolarctos cinereus* (koala), 117
- philanthropy, 185, 186, 187; see also private conservation initiatives
- Phytophthora*, 114, 115f
- pigs, feral, 115, 173; see also feral animals
- plant pathogens, 118
- plant species, 157t
Indigenous foods and medicines, 44, 49, 70, 76, 144
invasive species see weeds
pressures on, 63
range shifts, 119–120
taxonomic validity, 157t
threatened, 58–59, 59f, 63–64, 118, 156–160
translocations, 160
see also native vegetation
- plastic waste, 53, 99, 103, 146, 176
- policy, 133–136
assessments of effectiveness and trend, 129
see also legislation; management approaches
- pollen, airborne, 37, 99
- pollution, 63, 97–100
agricultural pollutants, 104
air pollution see air pollution; air quality
Antarctic environment, 43
in estuaries, 62
Great Barrier Reef waters, 34
health effects, 37, 71, 104
industrial pollutants, 40, 99, 107–109
light pollution, 61, 100
marine environment, 34, 37, 61, 99, 100, 103, 107–108, 146, 176–177
noise pollution, 43, 100, 108–109, 176, 177
ozone, 40
plastics, 53, 99, 103, 146, 176
seabed habitats, 53, 99
see also habitat loss, fragmentation and degradation
- pollution management, 176–178
international obligations and treaties, 131
see also waste management
- population growth, human, 17, 40, 73, 94, 95
- predation, 49, 60, 89, 157t; see also feral animals; pest animals
- pressures on the environment, 10, 14, 16–20
climate change see climate change
cumulative pressures, 89, 124–126, 127f, 179–180
global risks, 18
human see people-related pressures
Indigenous governance of see Indigenous governance, rights and access
industry, 101–112
invasive species see invasive species
management see management of pressures
- private conservation initiatives, 146, 152–153, 185–186, 191; see also nongovernment organisations; philanthropy
- protected areas
area protected, 150–152, 151f
Indigenous Protected Areas (IPAs), 16, 75–76, 89, 122, 142–143, 144, 150, 190
management effectiveness, 150–153
national parks, 116, 122, 141, 152–153
National Reserve System, 16, 46, 75, 132, 143, 150, 158, 160
natural heritage conservation, 79–81, 146
rangelands, 103–104

- volunteer work, 146
 - see also Antarctica; Southern Ocean
- Pteropus natalis* (Christmas Island flying fox), 57
- purple wattle, 157t
- R**
- rabbits, 43, 66, 81, 115, 115f
- rainfall, 93
 - decline in, 22, 96, 119, 124
 - evaporation, 22, 31
 - groundwater recharge, 31
 - La Niña events, 41
 - mean rainfall, 31
 - run-off see run-off
 - see also drought; streamflow
- rainfall patterns, 16, 18, 22, 27, 31, 86
- rainforest, 74, 80
- Ramsar wetlands, 31, 48, 49, 130, 134, 153
- range shifts, 50–51, 57, 112–113, 119–120, 160
- rangelands, 103–104
- rats, 43, 66, 81, 115f; see also invasive species
- Rattus fuscipes* (bush rats), 57
- recovery plans, 59, 160, 170
- recreation, 100–101
 - boating, 100
 - recreational fishing, 71, 100–101, 105–106, 164
- recycling
 - waste materials, 148, 176, 177
 - water, 163
- red imported fire ant (*Solenopsis invicta*), 117, 118f, 173
- Reef Trust Partnership, 143, 190; see also Great Barrier Reef
- reefs, 35, 51–52, 53, 95
 - climate change impacts, 18, 45, 50–52, 124, 170
 - condition of, 16, 45, 51–52, 53, 124
 - dark and twilight reefs, 53
 - habitat connectivity, breaks in, 151
 - see also coral reefs; Great Barrier Reef; marine ecosystems
- renewable energy, 109–112, 168–169
- Renewable Energy Target (RET), 168–169
- reporting see monitoring and reporting
- reptiles, threatened, 58, 60, 61
- research programs and facilities
 - Atlas of Living Australia, 112, 114, 155, 156, 188, 189t, 193
 - Bioplatforms Australia, 155, 188, 189t
 - climate change adaptation, discontinued, 169, 184
 - funding, 184f, 188–190, 189t
 - IMOS, 155, 188, 189t, 193–194, 194f
 - Marine National Facility, 188, 189t
 - NCRIS, 11, 58, 155, 188, 189t, 193
 - NESP, 11, 58, 59t, 60, 63, 141, 184f, 188, 193
 - taxonomic research, 188, 197
 - TERN, 58, 155, 188, 189t, 193, 194f
 - see also citizen science; data
- research technologies, 201
 - DigiVol system, 199–200
- resilience
 - to bushfires, 80
 - of Indigenous communities, 89
 - marine conservation approaches, 170
 - to natural disasters, 146, 171
 - planning for, 16, 165, 171
 - of structures, 72, 171–172
- resource extraction see agriculture; aquaculture; commercial fishing; mining; oil and gas exploration and extraction
- resources for environmental management, 181–201
 - assessments of effectiveness and trend, 181
 - data, 191–197
 - funding, 182–191
 - human, 197–201
- restoration see environmental restoration funding
- RET see Renewable Energy Target (RET)
- Revolving Fund properties, 153
- Rhodamnia rubescens* (scrub stringybark), 118
- Rhodomyrtus psidioides* (native guava), 118
- risks, global, 18
- rivers and streams
 - bushfire impacts, 92–93
 - climate change impacts, 22
 - pollutants, 92–93, 108
 - pressures on, 125
 - water quality, 27, 33, 34, 62, 104
 - see also estuaries; freshwater ecosystems; inland waterways; water resources; wetlands
- road network, 102

- rocky reefs, 35, 50–52, 95, 124, 170
- rodents, 43, 66, 81, 115, 115f, 154
- Royal Commissions
- Murray–Darling Basin, 122
 - National Natural Disaster Arrangements, 171, 178
- run-off
- agricultural/industrial pollutants, 104, 107–108
 - bushfire ash and sediment, 34, 48, 62, 71, 92–93, 125–126
 - in coastal regions, 93, 107
 - nutrient-rich, 107, 108
 - per cent of rainfall, 31
 - reduction in, 96, 108, 125
 - urban run-off, 96
 - water quality impact, 34, 46, 93, 125–126
- S**
- salinity, 33
- saltmarshes, 53
- Santalum spicatum* (Australian sandalwood), 64
- Sarcophilus harrisii* (Tasmanian devil), 117
- scientific research *see* research programs and facilities
- scrub stringybark (*Rhodamnia rubescens*), 118
- sea Country, 35, 36, 74, 105, 132, 141, 143
- ghost net and plastic litter management, 146
 - IPAs in, 143, 150
 - see also* Indigenous land and sea management; marine ecosystems; marine environment
- sea ice, 16, 42, 43
- sea level rise, 16, 22, 24, 42, 86, 88
- sea lions, 61
- sea snakes, 61
- sea surface temperature, 22, 42, 50, 61; *see also* ocean warming
- sea urchins, 51, 52, 124
- seabed habitats, 52–53, 99
- seabirds, 66, 132, 160
- seagrasses, 53–54
- seamounts, 45, 52
- seed banks, 157t
- shale and tight gas developments, 180
- shipping and boating impact on environment, 100, 102–103
- shorebirds, 65–66, 132
- smog, 17, 38f, 72, 99
- smoke *see* air pollution; bushfires
- soil bacteria, 201
- soils
- acid sulfate soils, 125
 - assessments of state and trend, 26
 - biodiversity, 47
 - carbon storage, 30
 - ecosystems services value, 30
 - restoration, 47
 - see also* land degradation
- solar energy, 111, 168, 169; *see also* renewable energy
- Solenopsis invicta* (red imported fire ant), 117, 118f, 173
- Sousa sahalensis* (Australian humpback dolphin), 61, 67
- southern bluefin tuna (*Thunnus maccoyii*), 67, 164
- Southern Ocean
- climate change impacts, 16, 42–43
 - fish populations, 62, 106
 - international obligations and treaties, 106, 133, 152, 166
 - management, 106, 133, 152, 166
 - whales, 67
- southern right whales (*Eubalaena australis*), 66–67
- species
- decline and loss *see* biodiversity loss; extinctions; fauna, decline in
 - density, 194f
 - discovery, 156, 201
 - extinction *see* extinctions
 - identification, 199–200
 - translocation of, 119–120, 157t, 160; *see also* range shifts
 - see also specific types of species:* freshwater species; invasive species; marine species; migratory species; plant species; threatened species
- state and territory jurisdictions
- climate change adaptation, 170
 - emissions reduction programs, 169
 - EPBC Act and, 136
 - extreme events protection and response, 171
 - funding for environmental management, 185, 190
 - heritage protection, 164–165

- IPA tenure security, 150
 - legislation and policy, 128, 133, 136, 164–165
 - pollution management, 176, 177
 - water management, 138, 161–162
 - stewardship, 145–146, 147f
 - streamflow, 31, 34–35, 180; *see also* inland waterways; rivers and streams
 - Strong Peoples – Strong Country framework, 74, 75f
 - stygofauna (subterranean aquatic fauna), 50, 63, 108
 - surface water *see* inland waterways; oceans; rivers and streams
 - Sustainable Development Goals (UN), 19, 131–132, 186
 - Sydney Basin Bioregion, 160
 - Sympterychthys unipennis* (handfish), 62
- T**
- Tachardina aurantiaca* (yellow lac scale), 174
 - Tasmanian devil (*Sarcophilus harrisii*), 117
 - Tasmanian Land Conservancy reserves, 153
 - taxonomic research, 54, 188, 197
 - temperature
 - extremes, 76, 90
 - sea surface temperature, 22, 42, 50, 61
 - stress to ecosystems, 22
 - trends, 90
 - warmest years, 22, 84f, 86
 - water temperature (dams and inland waters), 104
 - see also* heatwaves; ocean warming
 - 10 Gigawatt Vision, 111
 - TERN *see* Terrestrial Ecosystem Research Network (TERN)
 - Terrestrial Ecosystem Research Network (TERN), 58, 155, 188, 189t, 193, 194f
 - terrestrial ecosystems, 46–47, 50
 - assessments of state and trend, 44
 - terrestrial fauna, 59–61; *see also* birds; mammals; reptiles
 - threat abatement plans, 115, 160
 - Threatened Bird Index, 58, 59f, 60
 - threatened ecological communities
 - assessments of state and trend, 55
 - bushfires (2019–20), 92
 - habitat land cleared, 96, 98f
 - listed (number), 56, 59, 160
 - listing process, 58
 - management, 156, 160
 - recovery plans / conservation advices, 59, 158t, 160
 - Threatened Plant Index, 58, 59f, 63
 - threatened species, 56–59, 118
 - action plan results, 10, 156–159
 - after bushfires of 2019–20, 92
 - assessments of state and trend, 55
 - birds, 58, 59f, 60, 156–160, 156t
 - climate change as risk to recovery, 170
 - collaborative approaches to monitoring, 195, 196f
 - cumulative pressures, 124
 - diseases, 117–118
 - fauna, 58, 59–63, 156–160
 - fungi and microorganisms, 65
 - habitat loss, 96, 98f; *see also* land clearing indexes, 58, 59f, 60, 63
 - invasive species impact on, 60, 104, 114
 - on islands, 36
 - listed (number), 10, 56, 58, 59–62, 156, 157t, 160
 - listing process, 58
 - mammals, 58, 59f, 60, 156, 157t
 - management, 124, 125f, 156–160
 - Murray–Darling Basin, 48, 60
 - plants, 58–59, 59f, 63–64, 118, 156–160
 - priority species, 10, 156–158
 - recovery funding/spending, 158, 186–188
 - recovery plans, 59, 160, 170
 - threat abatement plans, 115, 160
 - threats, 56, 57f, 58, 104, 124
 - translocation of, 157t, 160
 - trends, 58, 59f
 - in urban areas, 41
 - see also* extinctions
 - Threatened Species Strategy, 10, 156–159
 - thunderstorm asthma events, 37, 38f
 - Thunnus maccoyii* (southern bluefin tuna), 67, 164
 - Torres Strait islands, 24, 86, 88
 - tourism, 100–101, 114
 - traditional knowledge *see* Indigenous knowledge
 - Traditional Owner management *see* Indigenous land and sea management

- translocation of species, 119–120, 157t, 160; see *also* range shifts
- transport
greenhouse gas emissions, 73
pressure on environment, 102–103
- tropical cyclones
economic losses, 71, 93
impacts on habitats, 50–51, 93
impacts on urban and built environments, 41, 72
intensity and frequency, 89, 93
management approaches, 171
number of (2016 to 2020), 93
- tropical fire ants, 117
- tuna, 67
- turtles, 48, 60, 61
- U**
- underwater cultural heritage, 79, 133, 164
- United Nations
Convention on Biological Diversity, 123, 130, 132, 144, 150, 154
Declaration on the Rights of Indigenous Peoples 2007 (UNDRIP), 120–121, 122, 123, 130, 165
Framework Convention on Climate Change, 82, 130, 131
Sustainable Development Goals, 19, 131–132, 186
UNESCO conventions on protection of cultural heritage, 133
see also international obligations and treaties
- urban areas, 94–96
air quality, 37, 39–40, 72, 91, 99, 177
coastal, 95
infrastructure investment, 95
livability, 29, 69, 72–74, 165
management, 165–166
planning, 17, 40–41, 122, 165–166
population growth, 17, 40, 73, 94, 95
regenerative and resilient development, 165
resource consumption, 95–96
urbanisation, 40, 94–95
waste production, 97, 99
water management, 138, 146
water supply, 162–163
- urban environments
assessments of state and trend, 29, 68
climate change impacts, 73–74
condition of, 40–41
green cover, 41
pressures on, 17, 19–20, 94–95
- Urochloa mutica* (para grass), 116
- V**
- vessel impacts on environment, 100, 102, 103
- volunteers *see* citizen science; local environmental stewardship
- Vulpes vulpes* (European red fox) *see* foxes
- W**
- waang (Australian sandalwood – *Santalum spicatum*), 64
- walarda (Australian sandalwood – *Santalum spicatum*), 64
- Warkworth Sands Woodland, 160
- waste *see* industrial pollutants; litter
- waste management, 19, 108, 176, 177
national accounts, 148
waste generated per person, 97, 176
see also pollution management; recycling
- Water Act 2007*, 161–162
- water consumption *see* water resources; water supply
- water lily (yarlbun), 49
- water management, 48–49, 138, 139f, 143, 161–163, 180, 190
- water quality, 19, 70–71
after bushfires, 70, 92–93, 125–126
assessments of state and trend, 68
coastal regions, 34, 46
cumulative impacts, 125–126
estuaries, 34–35
native vegetation sensitivity to, 46
rivers and streams, 27, 33, 34, 62, 104
see also inland waterways; marine environment
- water research, 189–190
- water resources
accounting, 180
allocation for agriculture, 104
alternative, 16, 162–163
assessments of state and trend, 27
climate change impacts, 22

- coal and coal-seam gas development impacts, 134, 180
 - cumulative impacts of extractions, 180
 - cumulative pressures, 125–126, 180
 - household consumption, 96
 - Indigenous people’s access to, 48–49, 122, 143, 162
 - litter in, 19; *see also* water quality
 - management *see* water management
 - outlook, 14, 16
 - recycling, 163
 - research funding, 189–190
 - shale and tight gas development impacts, 180
 - see also* environmental water; freshwater ecosystems; inland waterways; Murray–Darling Basin; rivers and streams
 - water storage, 31–32, 96
 - number of dams, 31
 - percentage of capacity (trends), 32f
 - water temperature, 104
 - water supply, 16, 31–32, 96
 - desalination, 16, 96, 162–163
 - groundwater, 32, 162
 - recycled water, 163
 - water temperature
 - dams and inland waters, 104
 - sea surface temperature, 22, 42, 50, 61
 - see also* ocean warming
 - water use *see* environmental water; water resources; water supply
 - waterbird abundance, 31, 49
 - wave and tidal energy, 110
 - weather *see* extreme weather events
 - weeds, 103, 104, 112, 114, 115f, 116
 - cost to agricultural industries, 18, 116
 - management, 172
 - weed invasion after fire, 125
 - wellbeing *see* human health and wellbeing
 - wetlands, 31, 33, 35, 47, 48, 49, 100–101, 125, 134, 153
 - whales, 66–67
 - Wildlife and Threatened Species Bushfire Recovery Expert Panel, 156t
 - wind energy, 109–110, 112
 - Working on Country programs, 144; *see also* Indigenous land and sea management
 - World Bank Zero Routine Flaring by 2030 initiative, 108
 - World Economic Forum, 18
 - World Heritage places, 74, 77, 80–81, 112, 133, 146, 152, 166
- Y**
- yarlbun (water lily), 49
 - yellow crazy ant (*Anoplolepis gracilipes*), 117, 173, 174
 - yellow lac scale (*Tachardina aurantiaca*), 174
- Z**
- Zero Routine Flaring by 2030 initiative, 108
 - Zyomys palatalis* (Carpentarian rock-rat), 57
 - Zyomys pedunculatus* (central rock-rat), 57

