Australia
State of the Environment 2016

Coasts

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Acknowledgement of Country

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

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Contents

Executive summary

Australia's coast is vast and diverse. It is the sixth largest of any nation, and contains a variety of habitat types, including sandy beaches and dunes, rocky shores, tidal flats, and estuaries and bays. Our coast is intimately linked to our national economy, industry, arts, social lifestyle and cultural identity, with more than 85 per cent of Australians living within 50 kilometres of the sea. We do, however, risk 'loving our coast to death', as its amenities and resources attract intensive human use. Most of Australia's population growth is near the coast, and we rely on the coast for almost all our international trade. The coast is subject to pressures operating on a range of spatial and temporal scales, and it is the cumulative and interactive effects of these pressures that determine human impacts on coastal ecosystems. Now, more than ever, it is important that we understand the environmental consequences of how we use the coast, but significant gaps remain in our understanding of the state of coastal health. Urbanisation, agriculture and resource extraction have already modified much of the coast, and impacts associated with climate change are beginning to emerge. There is still much to protect, however, even in heavily modified ecosystems. Australia is also fortunate to retain large stretches of relatively untouched coast, containing ecosystems with exceptional natural values.

Current pressures on the coast are largely related to land use and climate change, and the state and trends of coastal biodiversity are tightly linked to these pressures. Eastern and southern coasts are most affected by urbanisation and agriculture, whereas resource extraction has grown as a pressure in the less modified west and north-west. Urban and agricultural land use cause habitat loss, habitat fragmentation, loss of native biodiversity, and contamination of coastal land and waterways. Resource extraction has increased in the past few years, with the mining boom causing severe, but highly localised, habitat loss and degradation. Trade associated with resource-extraction activities is also linked to the introduction of invasive species. The ecological integrity of the dynamic land–water interface is diminished through continued development of shorelines and the spread of invasive species. Aquatic habitats are affected by the alteration of flow and water quality through upstream development, modification of entrance dynamics, and climate-related changes in precipitation patterns. Many of the ecological services and processes that ecological communities deliver and depend on are disrupted by human-driven deterioration of the coast. For example, widespread nutrient enrichment of coastal waterways has substantially altered the processes of nutrient cycling, sulfur metabolism and carbon fixation. Destruction of critical nursing, roosting and nesting sites has broad-reaching ramifications for species that rely on networks of sites to maintain populations (e.g. shorebirds). Critical habitat-forming species groups, such as saltmarsh, seagrass and shellfish, have failed to fully recover from extensive historical losses, although restoration programs are currently under way.

The outlook for the coast focuses on the escalating trajectory of climate-related pressures. These are expected to become increasingly prominent, and, unlike most other pressures, affect the entire coast. Since 2011, climate change has manifested as increased frequencies of marine heatwaves and severe storms, such as the Ningaloo heatwave and tropical cyclone *Yasi* of 2011, and the 2016 marine heatwave that caused severe bleaching in large sections of the northern Great Barrier Reef. Sea level rise is a key pressure that Australia is only just beginning to experience, and one that will have increasingly conspicuous impacts in future decades. If greenhouse gas production is not rapidly reduced, the rate of sea level rise is predicted to reach almost 12 millimetres per year or higher by 2100, depending on the behaviour of the Antarctic ice shelves. Increased sea level will not only shift the position of intertidal and aquatic habitats, it will also cause extensive erosion and recession. Of particular concern are low-lying islands, which are highly vulnerable to even small changes in sea level. For urban centres, options for human populations to cope with sea level rise include managed retreat, or engineering the coast to withstand impacts. However, engineering coastlines can also have negative impacts on coastal ecosystems. The key challenge in the short term is to implement strategies to mitigate the effects of climate change, while conserving the natural integrity of the coast.

Aerial view of the cliffs and rugged coastline of the Shark Bay World Heritage Area, Western Australia

Photo by Nick Rains, © Nick Rains, all rights reserved

Key findings

Key finding	Explanatory text
The current state of the coastal environment is mixed, being largely good in the north-west and far north-east of the country, and poor in parts of the east, south-east and south-west	Direct impacts are centred on urban and agricultural developments, which are predominantly on the east, south-east and south-west coasts of Australia. Other parts, such as the north-west, are less heavily modified, but may be threatened by development plans and are currently subject to localised pressures associated with resource extraction. In the long term, the entire coast is under threat from climate change.
Given the likelihood of major climate-related stress during the coming decades, environmental areas that are already under high pressure are likely to become further degraded	Australia is beginning to see the impact of the pressures of climate change on our coasts, and pressures are expected to grow substantially in coming decades. These will add stress to systems that are already stressed by a range of human activities. Recent climate-related stress resulted in a major dieback of mangroves in the north.
The current state of degradation is tightly correlated with human population, and agricultural or industrial development	Pressures and impacts on the coastal environment are associated with urbanisation, land-use change and industrial activity. Increasing activity on the coast means that pressures are growing in most areas.
Many coastal systems and processes are subject to multiple interacting pressures, which are predicted to act in additive or synergistic ways that increase impacts	When multiple pressures occur at the same place and time, there is potential for them to interact and exacerbate impacts. Such is the case in areas of the coast with dense human settlement, agriculture or industry.
Pressures occur at a variety of spatial and temporal scales	Some activities create pressures that are widespread and can have medium-term to long-term impacts (e.g. coastal agriculture and climate change). Other activities are more localised, but may severely affect local processes (e.g. spills and port development).

Key finding	Explanatory text
Species and ecological groups are variable in recent trends, with the most concern being for shorebirds	Nationally, there are currently 1257 floral and 425 faunal species listed as threatened under the *Environment Protection and Biodiversity Conservation Act 1999*, many of which occur on the coast. Several protected species are now stable or improving, demonstrating the benefits of good management. Crocodiles, for example, are increasing everywhere within their natural range, and mangroves have been increasing in extent in most parts of Australia. In contrast, migratory shorebirds are deteriorating, despite protection in Australia, likely because of the destruction of critical habitat in other countries along their migratory route. Continued decline of saltmarsh and seagrass habitats is a significant concern, given their role in coastal productivity, biodiversity maintenance, sediment stabilisation and carbon sequestration.
Data are insufficient to assess many aspects of the state of the environment of the coast	Data deficiencies are particularly clear for biodiversity, and the population density of most species groups. Data deficiencies increase with decreasing size of organisms, regardless of their importance to ecosystem services (e.g. there are major data deficiencies for invertebrates and microbes). Data are also deficient for the pressures of contaminants, invasive species, recreational fishing and marine debris. The ongoing issue of data deficiency stems from a lack of investment in broad spatial-scale and temporal-scale projects featuring rigorous and consistent methodologies, collaboration and sharing of information between organisations, and publication of findings in the scientific literature.
There is a need for comprehensive monitoring of coastal systems, processes and effectiveness of management practices	Although there are many experts on the Australian coastal environment, almost none are confident to make assessments for the entire coast. This reflects the absence of nationally consistent, or coordinated, environmental health assessments for the coast. It also speaks to the diversity of Australia's coast, and the inherent differences between processes operating in tropical and temperate regions.
Coastal heritage documentation focuses on European settlement, rather than Indigenous culture	With coastal settlement comes a rich heritage of Indigenous and European history and culture that has yet to be fully documented or understood. Pressures on coastal environments also affect coastal heritage, and there are substantial gaps in our understanding of the extent and cultural meaning of many coastal heritage sites and activities. Information on coastal heritage is largely restricted to shipwrecks, middens and heritage buildings, and could be complemented by national programs to document and assess other sacred sites, and sites for cultural gatherings and fishing.

Key finding	Explanatory text
Remote sensing offers an increasingly powerful way to gather data about coastal environments	Satellite data have been used for the first time to assess trajectories of estuarine water quality and coastal vegetation change across the entire coast of Australia. These approaches use the newly developed Australian Geoscience Data Cube (a national collation of Landsat imagery) to assess trends in coastal environments across multiple decades.
Integrated management and better understanding of the cumulative impacts of multiple uses are key to improving coastal management	Management effectiveness could improve with a move towards integrated management that can simultaneously assess and mitigate the impacts of multiple activities and pressures. This would also be likely to reduce human-use conflict on the coast.

Approach

The 2016 state of the environment (SoE) report is the first in the series to include a full report devoted to coasts. The 'Coasts' chapter of SoE 2011 was an overview that covered coastal cross-cutting issues, but, for 2016, there was sufficient subject matter to warrant a full report. The full report is more substantial, has increased breadth of topics and has added visual assessment summaries. These changes bring the format into line with the other thematic reports.

Many of the topics covered in the 2016 *Coasts* report were covered in the 'Marine environment' chapter in 2011. In 2016, the *Coasts* and *Marine environment* reports have been carefully coordinated to partition subject matter and minimise overlaps. Guiding principles used to partition subject matter were that:

- *Coasts* covers aquatic environments within the heads of estuaries and bays, all areas of the intertidal zone, and all habitat up to 50 kilometres inland from the shore
- *Marine environment* covers subtidal marine habitats more generally, including those in gulfs and coastal marine waters outside the heads of estuaries and bays. Some land-based pressures that also affect the marine environment are covered in the *Coasts* report
- aquatic species covered by *Coasts* are those that are strongly dependent on coastal habitat for some proportion of their lifecycle.

There is some overlap between *Coasts* and other SoE reports, particularly *Land*, *Atmosphere*, *Built environment* and *Inland water*. This is unavoidable given the concentration of human settlement and environmental modifications at the coast. Where the potential for overlap was substantial, such as for 'airborne emissions' and 'coastal land use and pollution', topics are dealt with briefly in the *Coasts* report, and readers are directed to other reports for more detail.

To gain expert opinion and to populate the assessment summaries used in this report, more than 150 experts were consulted by online survey and email. Each expert was asked to provide assessments for the state and trend of one or more topics within their field of expertise, as well as the level of confidence in their assessments. They were also asked for supporting information to explain the reasoning behind their estimated scores. The final gradings given to each assessment were determined after considering responses from all experts in light of supporting information, and in conjunction with other data sources, where available. We are greatly indebted to all experts who contributed to this report. Contributing experts are listed in the acknowledgements.

Introduction

Australia's coastal zone holds tremendous national significance. It contains many of the country's most prized environmental and ecological assets, some of which are World Heritage listed, and accommodate habitats and species found nowhere else on Earth. The biological and landscape diversity of the coast is immense, encompassing a wide range of climatic, geological and oceanographic regions that contain interacting terrestrial, estuarine and marine ecosystems. Australia's Indigenous history and culture are closely tied to the coast, which hosts invaluable heritage sites, and is fundamental to past and contemporary Indigenous practices.

In addition to its environmental and heritage values, the coast is central to our economy, lifestyle and cultural identity. Most Australians choose to live near the coast for its recreational amenities and economic opportunities—a trend that shows no sign of slowing. With this population density comes environmental pressures, and the danger of 'loving our coast to death'. Major pressures include habitat loss for urban development, pollution, resource extraction, invasive species and unsustainable fishing. Mitigating the effects of these pressures through proper management is essential to ensure the ecologically sustainable use and development of the coastal zone.

The coastal zone of Australia is notoriously difficult to define, as its boundaries depend on the biological or environmental components in question. Urban centres can extend tens of kilometres inland and still be considered coastal, while some areas of vegetation diminish in coastal characteristics within a few kilometres of the shoreline. There is also difficulty in defining the shoreline for some parts of Australia, particularly in the north-west of the country, where high tides and low-lying land cause the intertidal zone to extend many kilometres inshore.

For this report, we will follow the definition used in SoE 2011, which considered the coast to be the zone of interface between terrestrial, aquatic and marine environments, while acknowledging that the size of that interface differs between components. For analyses that track quantitative trends on coastal land, we use a 50 kilometre buffer inland from the shore, noting that the strength of maritime influence will vary between places, and between biota and environmental components. Subtidal waters seawards of bays and estuaries are covered in the *Marine environment* report.

Australasian gannet at its coastal breeding colony

Photo by Alan Danks, © Alan Danks, all rights reserved

Coasts: 2011–16 in context

The past 5 years have been characterised by extreme weather events, many with strong impacts on the coast. In 2011, a marine heatwave in Western Australia decimated kelp forests, causing profound changes in ecosystem structure that have yet to be reversed. Tropical cyclone *Yasi* caused extensive damage to Queensland's coast, affecting seagrasses and, consequently, dugongs, and flooding caused an estimated $440 million damage to Brisbane. In 2016, higher than usual sea temperatures caused mass coral bleaching of the Great Barrier Reef, and approximately 10 per cent of Australia's mangroves were lost to heat in the north. At no time in recent history have the effects of climate change on Australia's coast been as apparent as they were from 2011 to 2016.

In addition to ongoing pressure from metal and nutrient pollution, coastal waterways are facing increasing threats from new classes of pollutants. These include microplastics and nanoparticles used in consumer products such as clothing and cosmetics. Such emerging contaminants remain largely unregulated, and their effects are poorly understood. In 2015, the Australian and state governments announced an industry partnership for the voluntary removal of microbeads from personal care, cosmetic and cleaning products sold in Australia by July 2018.

Advances in coastal management include the threat and risk assessment framework for the New South Wales marine estate, and development of CoastAdapt by the National Climate Change Adaptation Research Facility. The National Marine Science Plan was delivered in 2015, outlining the consolidated views of the scientific community on the future of marine and coastal research in Australia.

Cape Huoy, Tasmania
Photo by Megan Watson

Pressures

affecting the coastal environment

At a glance

Pressures on the coastal zone are strongly related to catchment land use and development. In urban areas, the intensity of pressures is generally correlated with human population densities. Australia has continued to increase in population since the 2011 state of the environment report, and most of that growth has been on the coast. Pressures resulting from coastal urban areas include direct habitat destruction, hydrological modifications, pollution (organic, inorganic, light, sound and debris), and the construction of artificial structures and reefs. In general, the state of most of these pressures ranged from low to high impact, but has been worsening, during the past 5 years.

Pressures on coasts outside urban areas include those associated with resource extraction and agriculture. The commodities boom has increased pressures because of mining, and oil and gas production, particularly through the addition and maintenance of coastal infrastructure for processing and export. Some of this development has occurred or is planned for relatively remote areas, such as the north-west of Australia, affecting otherwise undeveloped coast.

Agricultural land use replaces diverse native ecosystems with monospecific crops, and often increases the input of nutrients, sediments, acids, salts, herbicides and pesticides to nearby waterways. Although pressures related to resource extraction have grown in the past 5 years, their effects are generally localised. In contrast, increasing agriculture is having widespread impacts through habitat loss, diffuse pollution and changes to water availability.

Some pressures apply to all areas of the coast, although the impact of these pressures depends on the specific area and context. The most important of these overall pressures is climate change. Coasts are particularly sensitive to climate change because of rising sea levels, which are predicted to cause extensive erosion and inundation in coming decades. Since 2011, coasts have experienced more frequent and severe extreme weather events, such as heatwaves and large storms, and these have had significant ecological impacts. Attribution studies have been used to estimate how climate change is increasing the likelihood of such extreme weather events.

Pandanus growth on the coast of the Roebuck Bay wetland area near Broome, Western Australia

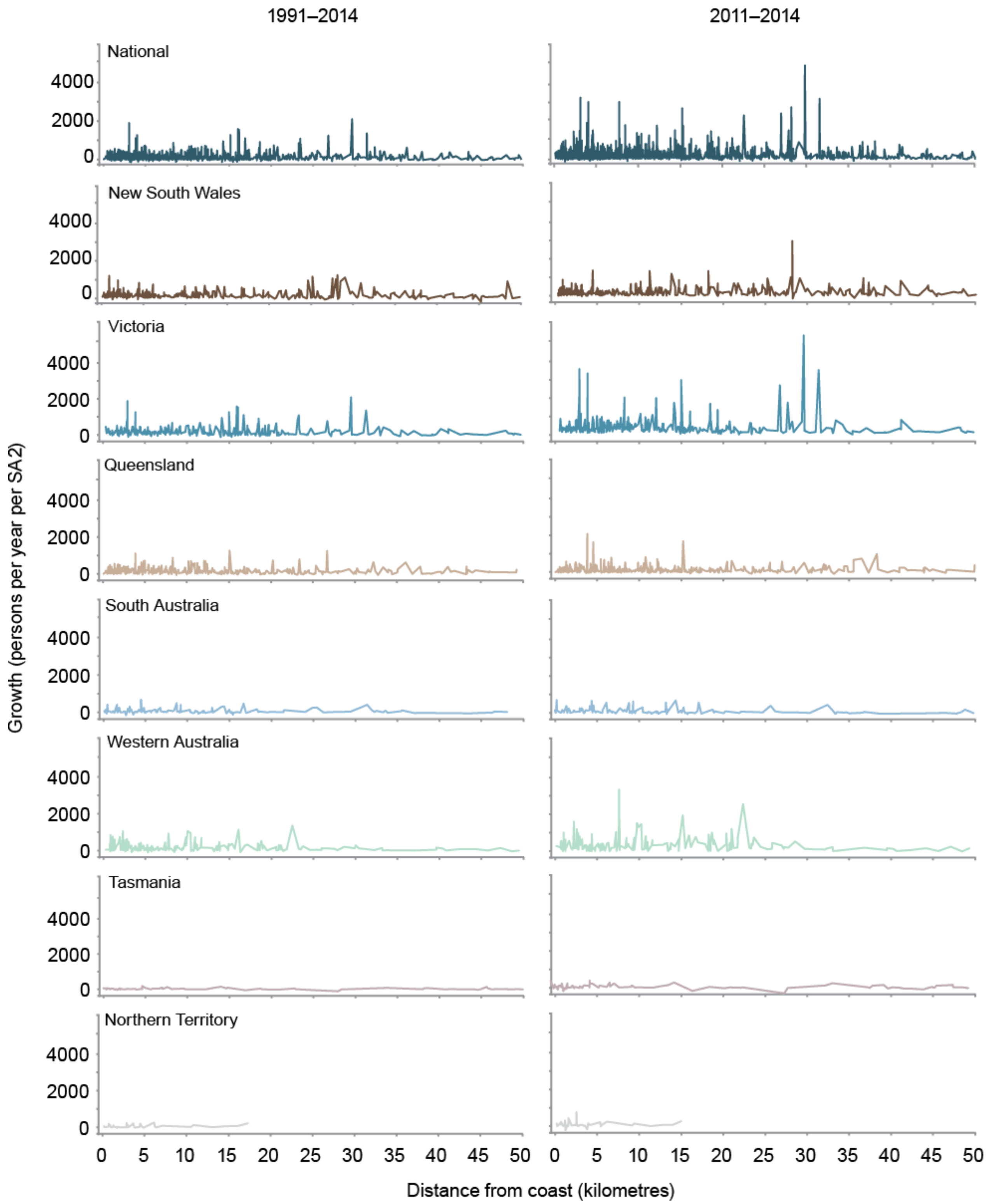
Population growth and urban development

Population growth

The coast has many qualities that make it attractive for living, including economic, social, recreational and cultural benefits. Human populations have been growing in Australian coastal areas since European colonisation, and this growth has not slowed since 2011. With increasing coastal population comes increased pressures on the environment, many of which are discussed in the following sections. Of particular importance is urban sprawl, which results in natural habitats being lost to housing, roads and supporting facilities. Simultaneously, native vegetation is converted to agriculture as food production intensifies to meet growing demands.

Data from the Australian Bureau of Statistics show that, at the national scale, since 1991, population growth has been fastest near the coast (Figure COA1, left column). This trend was even stronger from 2011 to 2014 (Figure COA1, right column), indicating that coastal population growth is accelerating. Nationally, and especially in New South Wales and Victoria, there are also some signals of rapid population growth approximately 30 kilometres from the coast, which likely reflects growth of suburban residential areas close to major coastal cities.

There are strong differences in population density between tropical and temperate regions in Australia; most areas of tropical coast have low population densities. In contrast, temperate coasts host most of Australia's major cities—such as Newcastle, Sydney, Wollongong, Melbourne, Geelong, Hobart, Adelaide and Perth—and considerable lengths of urbanised coasts. Although population growth is large in some parts of northern Australia, it is increasing off a very low base compared with the south.



Note: Distance from the coast is the distance from the centroid of an SA2 zone to the closest point of the coast.
Source: Australian Bureau of Statistics

Figure COA1 Mean annual growth in population of Statistical Area 2 (SA2) parcels versus distance from the coast, 1991–2014 and 2011–14

Coastal development and land use

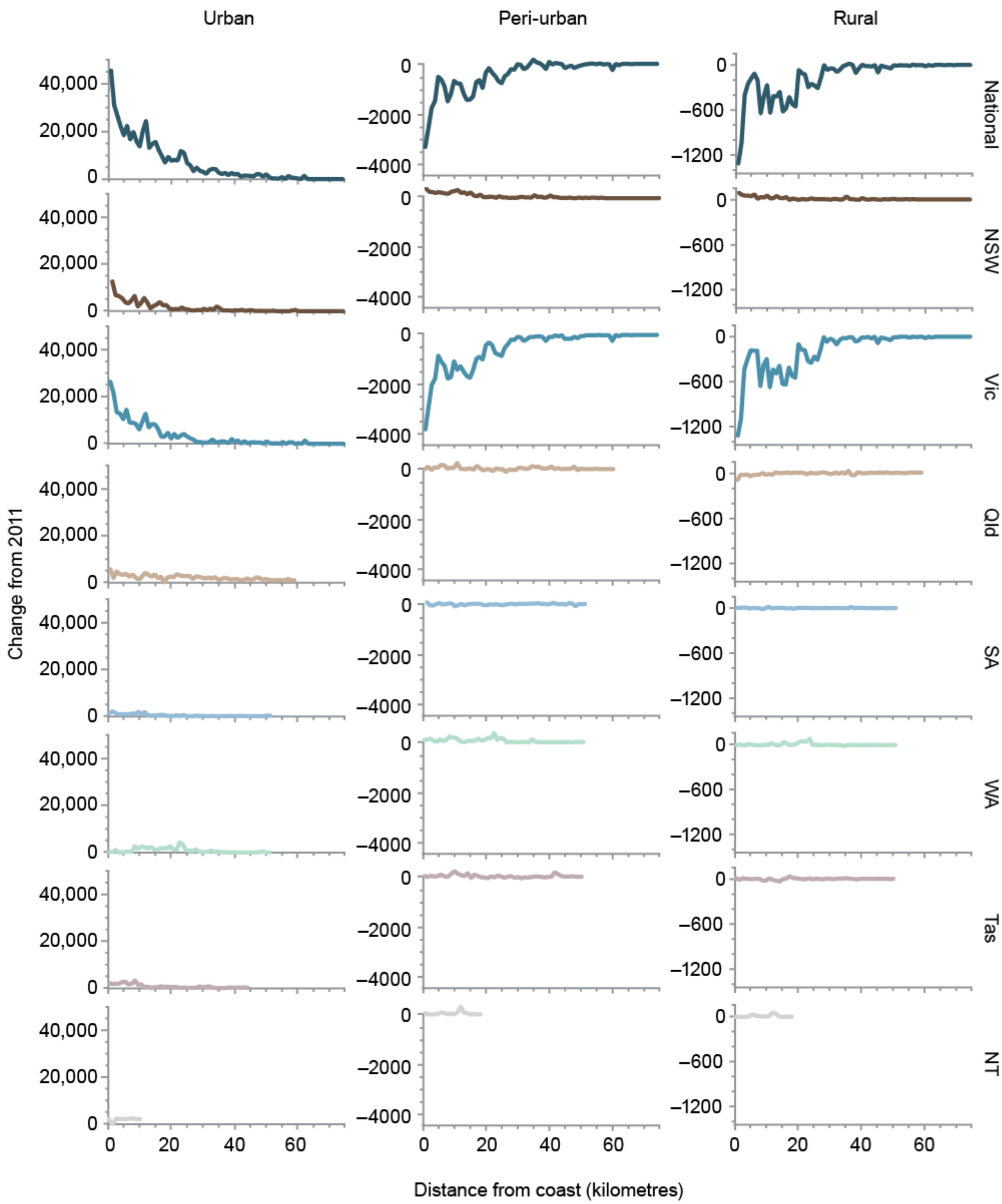
Coastal population growth exerts strong pressure on coastal land by increasing the need for both agriculture and housing, and land-use demands often come at the expense of natural habitats and native species. Agriculture reduces biodiversity by replacing native communities with monospecific crops, and urbanisation causes direct habitat loss. Remaining vegetation is then affected by diffuse pollution, habitat fragmentation, competition from weeds, predation by invasive pests, and Allee effects associated with catchment land-use activities (see Native vegetation and habitat).

Trends in coastal development and land use can be observed through change in the number of registered properties, known as cadastral parcels. Nationally, since 2011, the highest overall increase in the number of urban parcels has occurred nearest the coast (Figure COA2). This was the case in New South Wales, Victoria, Queensland and Western Australia, where population growth was greatest, while other states showed little trend relative to distance from the coast. The opposite patterns were seen for peri-urban (on the outskirts of cities and towns) and rural parcels, indicating that these types of properties are being replaced with urban development near the coast, but less so inland.

The largest change for rural and peri-urban to urban land use was seen in Victoria, approximately 30 kilometres from the coast (Figure COA2). This corresponds with an increase in population in these areas (Figure COA1), and is driven by land-use change in the outer suburbs of Melbourne. In contrast, expansion of some other large coastal cities is occurring parallel to the coastline, rather than inland or equidirectional from the city centre. In Perth, for example, development has expanded north and south along the coast, and future plans continue expansion in these directions (see Perth and Peel Urban Land Development Outlook). Growth immediately adjacent to the coast was also seen in Queensland.

Aerial view of coastline of the Kimberley rangelands, Western Australia

Photo by Dragi Markovic,



Note: Urban, peri-urban and rural panels show number of parcels
Source: Data supplied by the Australian Bureau of Statistics

Figure COA2 Change in cadastral parcels relative to distance from the coast, 2011–15

Surveys of 48 estuaries in New South Wales between 1999 and 2006 found that 60–80 per cent of catchment land has been cleared for agricultural, residential or industrial development (Roper et al. 2011). In coastal south-east Queensland, urban density and extent increased with the clearing of vegetation from 1972 to 2010 (Lyons et al. 2012). The western catchments of south-east Queensland are generally in poor condition, having suffered extensive clearing of riparian vegetation (Healthy Waterways 2015). The central and southern catchments are in fair condition, whereas the condition of northern catchments ranges from fair to excellent (Healthy Waterways 2015).

Increased coastal development amplifies most pressures discussed in this report, as well as a suite of other pressures related to urbanisation. Urbanisation of the coast, for example, creates the need for stormwater drainage, and an estimated 3000 gigalitres of storm water (the equivalent of 2.1 million Olympic-sized swimming pools) are produced in Australia each year (SECRC 2015). Most of the pressures discussed in the remainder of this chapter can be considered to increase, either linearly or disproportionately, with increases in coastal population and development.

Tourism and recreation

The tourism industry is important for the Australian economy, comprising approximately 3 per cent of gross domestic product (GDP) in 2014–15 (Productivity Commission 2015). It contributes more than $47 billion and more than 550,000 jobs to the Australian economy (2014–15), and growth in this sector is more than 3 times the growth of the total economy (ABS 2016). Australia accomodates more than 6.9 million international (Tourism Research Australia 2015a) and 87.1 million domestic (Tourism Research Australia 2015b) overnight visitors each year, which account for 72 per cent and 28 per cent of tourism GDP, respectively (ABS 2016). A large proportion of tourism is based on the coast, where most of Australia's major cities and tourist hotspots are located. Tourism at the Great Barrier Reef, for example, attracts approximately $5.2 billion per year (Deloitte Access Economics 2013).

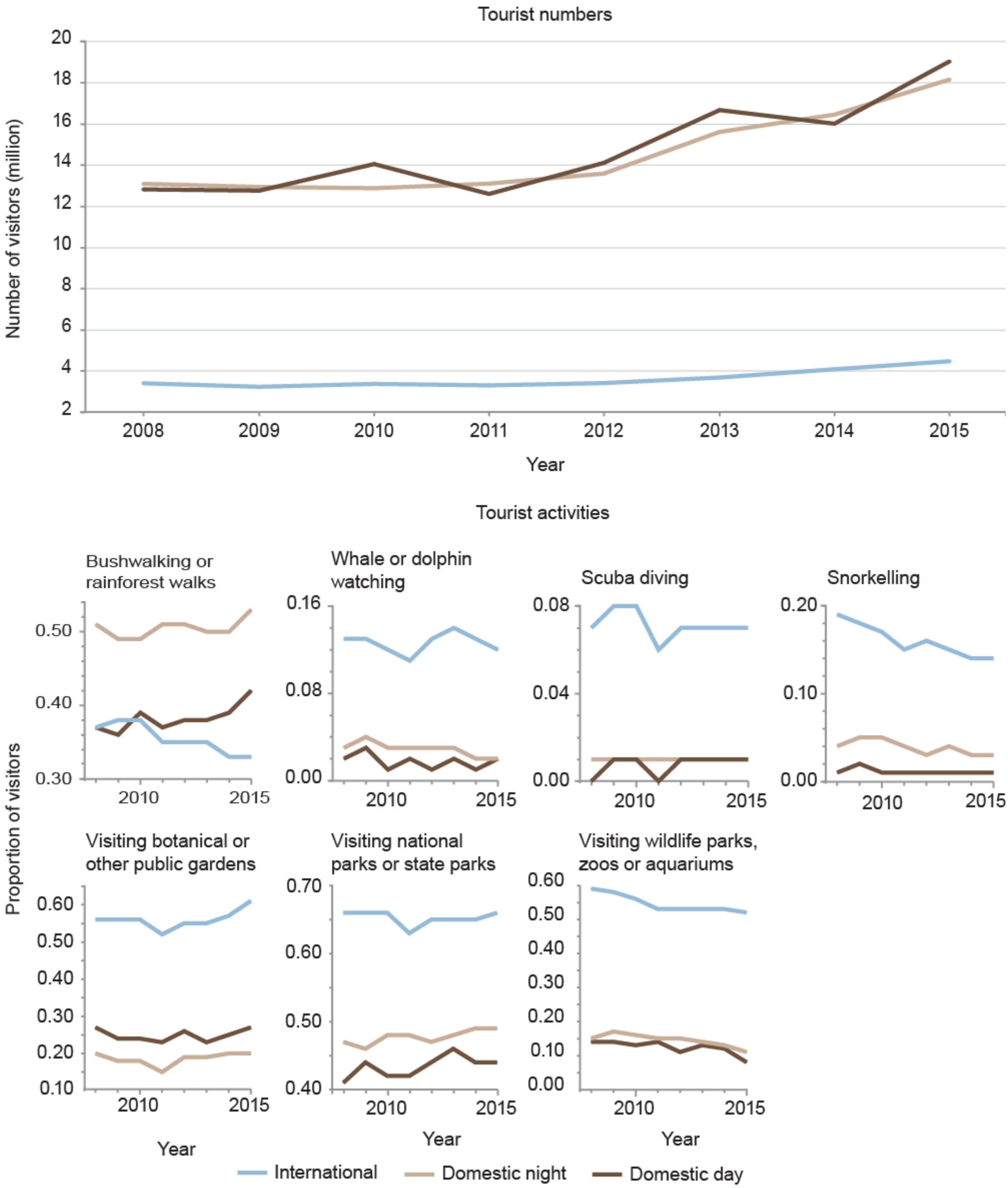
Beaches are the most popular coastal attractions for visitors. Popular nature activities and attractions include bushwalking and rainforest walking, whale and dolphin watching, scuba diving, snorkelling, botanic and public gardens, national and state parks, and wildlife parks, zoos and aquariums (Figure COA3). Recreational fishing is also a major drawcard for some areas (see Fishing).

Some tourism impacts, such as influxes of tourists arriving on cruise ships, are localised and sporadic, whereas others, such as camping and recreational fishing, are dispersed along the coast and occur seasonally or year round. High-quality quantitative data on recreational activities have only been gathered in a few locations (e.g. Ningaloo Marine Park, Box COA1; Smallwood et al. 2011), and disentangling cause and effect of impacts is complex because of many co-occurring pressures (Smallwood et al. 2012).

Pressures associated with tourism include human trampling, removal of flora and fauna, debris, damage or compaction by 4WD vehicles, development or pollution associated with transport, and infrastructure and development to support tourists. The magnitude of the pressures is often linked to access. Accessible areas can have high visitor numbers but low per-person impact, whereas remote areas are generally visited by small numbers of 4WD users who impose different types of pressures. Retirees who travel independently for extended periods are an important component of tourism in remote areas (Onyx & Rosemary 2005), such as the Kimberley region.

Ecotourism is a significant and growing sector of the tourism industry, and provides a way to reconcile tourism and conservation (Weaver 2001). By marketing natural values, ecotourism can maintain the aesthetic appeal of coastal tourist areas while deriving economic value, and simultaneously produce environmental benefits. However, although ecotourism is often touted as a win–win model, tourism development and conservation can have conflicting interests, resulting in compromises that lead to some level of environmental impact (e.g. Higgins-Desbiolles 2011).

Looking forward, pressures associated with tourism are expected to increase with population growth and coastal development, particularly near urban centres. Climate change is predicted to shift the distribution of tourism southwards, as the northern parts of Australia become increasingly unpleasant during warmer months (Amelung & Nicholls 2014).



Source: Customised data from Tourism Research Australia, Canberra, used under CC BY 3.0

Figure COA3 Annual proportion of visitors by type of nature activity, 2008–15

Box COA1 Spatiotemporal distribution of reef use in Ningaloo Marine Park, Western Australia

Understanding where, when and how many people use the coast is imperative for managing and monitoring natural coastal assets, conserving marine biodiversity, coastal planning, and assessing options for the location of infrastructure for tourism and recreation.

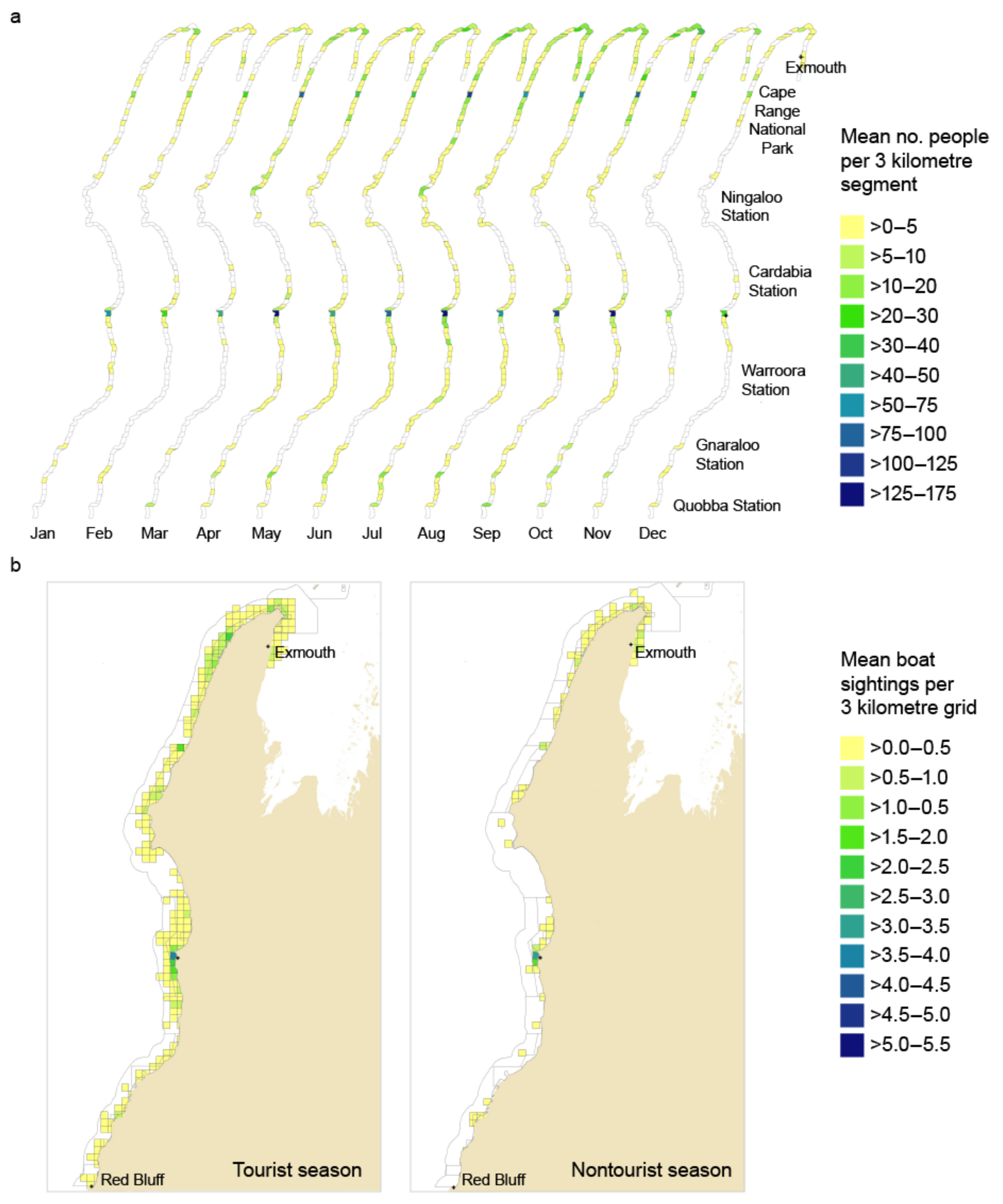
The spatiotemporal distributions of recreational activities within the reef lagoon system at Ningaloo Marine Park (NMP) were studied using georeferenced aerial surveys, coastal surveys (4WD, GPS and a laser rangefinder) and interviews conducted along the entire 300 kilometre length of the NMP, from Exmouth to Red Bluff. The use of the park is markedly seasonal, with a clear increase in the number of users, and expansion of their spatial extent to cover most of the park, during the noncyclone period from April to October (Figure COA4).

In the tourist off-season (November to March), fewer people conduct activities in the park, and these are largely concentrated in Coral Bay and around North West Cape. A wide range of extractive activities, such as recreational fishing (both from the shore and from boats), and non-extractive activities, including snorkelling, surfing, sailing, wildlife interaction (particularly with whale sharks and manta rays), coastal camping, relaxing on the beach and beach walking, are undertaken in the NMP. Although some are ubiquitous in distribution, others are highly dependent on the current NMP zoning plan, the biophysical attributes of sites, bitumen road or track access, accommodation opportunities, and tenure of the land adjacent to the park.

Ongoing monitoring of use by managers is difficult because of the large area, diffuse access points and differing land tenures. Indicators that can be used to monitor use have been explored, and these include calibrated surrogates such as vehicles parked along the coast adjacent to the NMP, occupancy of coastal campsites, and boat trailers at boat ramps and along the beach. The results of this study provide a robust benchmark of human use as a basis for enhanced management, and readily measurable indicators for monitoring tourism and compliance, and are well suited to marine spatial planning.

Source: Professor Lynnath Beckley, Murdoch University

Box COA1 (continued)



Source: Data obtained from regular aerial surveys by Murdoch University

Figure COA4 Human activities in Ningaloo Marine Park, 2007. Data are (a) spatiotemporal variation in mean number of people engaged in shore-based recreational activities and (b) spatial distribution of recreational boats averaged during the tourist and nontourist seasons

Energy and resource extraction and processing

Impacts of energy and resource extraction on the coast mostly result from the development, expansion and maintenance of ports for processing and export, and the infrastructure needed to extract diffuse energy sources such as coal-seam gas. The main contributors of processing and export are nearshore liquefied natural gas (LNG) processing plants, LNG and minerals (coal, iron ore) export, and refineries for aluminium and other minerals. Some pressures result from oil and gas development (production facilities) and exploration (seismic surveying), but these activities are mostly offshore and are thus discussed in the *Marine environment* report. The impacts of energy and resource extraction can be high, but most are spatially restricted (to areas less than 10 square kilometres).

Mining

Direct effects of mining are a weak pressure at the national scale, since the areas affected are relatively small. However, cumulative impacts can be significant for states or territories with large mining industries, and the indirect effects related to greenhouse gas production represent a strong pressure at a global scale. Most ore bodies and extraction operations are inland, and coastal processing of mining products (smelting and refining) has been declining in Australia for decades, so most direct mining pressures on the coast stem from the transportation of goods.

Most mining impacts on the coast result from the outwards shipment of materials, bulk handling of products and supplies, and discharges and earthworks. Port development and operations incur their own suite of pressures, including capital and maintenance dredging, increased risk of fuel spills because of higher vessel activity, and increased land reclamation (see Vessel activity and infrastructure). Pressures requiring more attention are the noise and light emitted by operations, particularly in the north and north-west, where mines and ports are built in previously unmodified environments. Coal dust at ports is an ongoing problem at east-coast coal ports near urban areas, including Newcastle, Brisbane, Gladstone and Hay Point.

There has been a substantial increase in mining activities during the past 5 years in the more mining-intensive jurisdictions of Queensland, Western Australia and the Northern Territory. A historically high number of port developments and expansions have been built to accommodate the export of coal from Queensland, and iron ore and natural gas from Western Australia. In contrast, there has been little change in the less mining-intensive states.

Coastline view of North Keeling Island

Photo by Fusion Films,

Mining pressures in New South Wales predominantly relate to port infrastructure for coal exports (e.g. Port of Newcastle), and have expanded but remain small compared with other states. In South Australia, there have been severe but localised impacts from the Port Pirie zinc refinery, and other developments have been planned but have not yet begun. Little new development has occurred in Tasmania, but historical legacies of copper-mining and zinc-mining activities continue to affect Tasmanian estuaries (Saunders et al. 2013). Coastal discharge has improved from historical mines in Tasmania's north-west, but remains an issue elsewhere in the state.

Local impacts of large mines are usually well documented because of regulatory monitoring and reporting requirements. However, only a small proportion of environmental impact studies on major energy and resource developments have been published in the peer-reviewed literature, and more studies are needed to predict environmental impacts of major ports and facilities. Management plans may use data collected on inappropriately small spatial and temporal scales, and may be inaccessible for independent analyses.

In the short term, with a depressed commodity market and recently expanded capacity, pressures from mining and associated port developments are unlikely to increase substantially. Pressures may even decrease through better environmental practices and plant closures. In the longer term, on the back of the operational capabilities inherited from the mining boom, pressures are likely to increase as production tracks rising commodity prices. In Queensland and New South Wales, the likelihood of coal prices remaining low should mitigate potential increased pressure from this sector; however, gas extraction may increase (see Oil and gas).

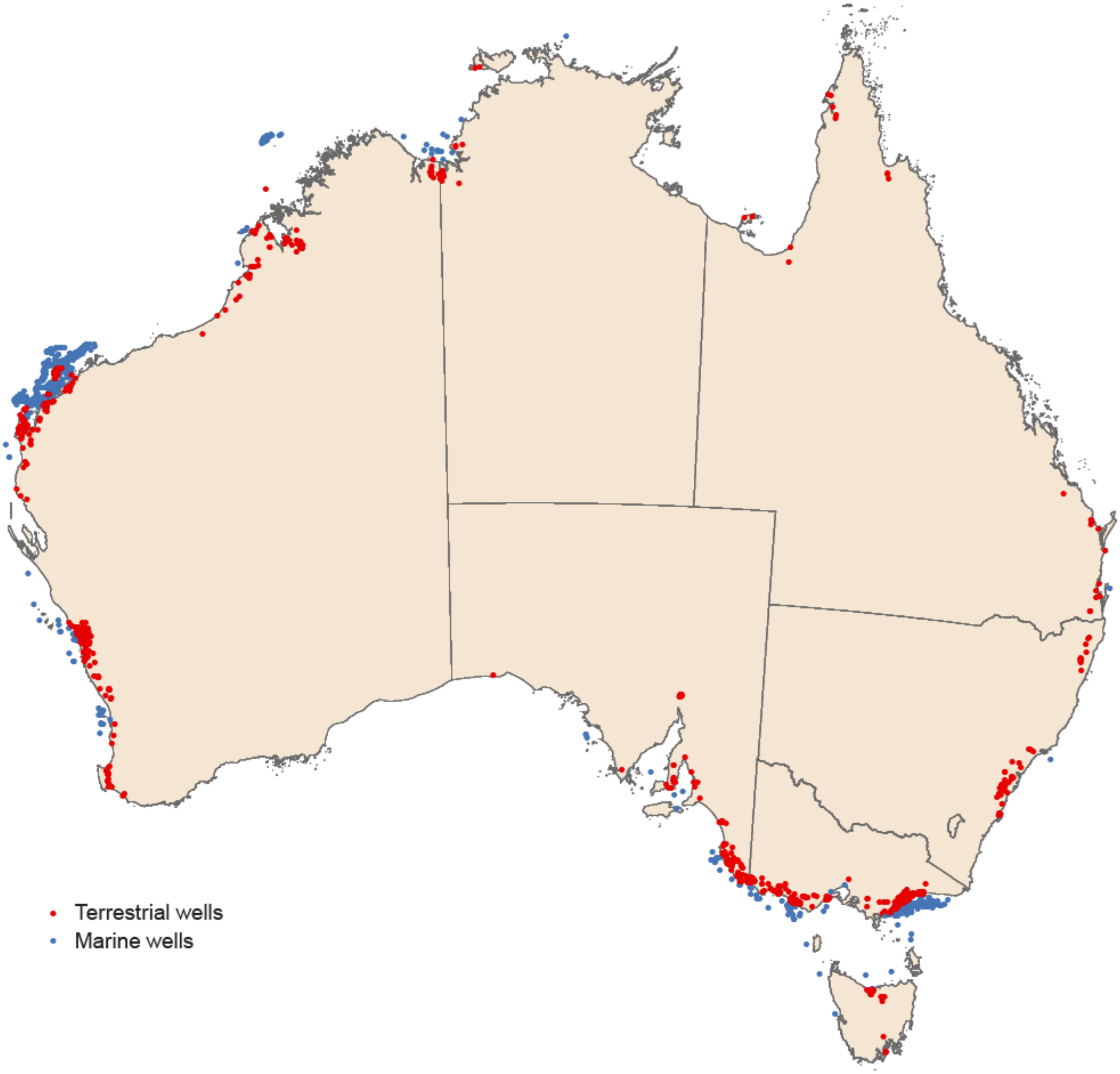
Oil and gas

Recent growth of the petroleum industry in Australia has largely been in Queensland, Western Australia and the Northern Territory, and LNG projects worth approximately $200 billion are currently under construction across Australia (APPEA 2016). Queensland has seen the installation of new LNG export ports and expansion of existing ports, and there has been development and expansion of LNG export greenfield ports and onshore pipelines in Western Australia. In Victoria, there have been minor increases in oil and gas development in the Bass, Gippsland and Otway basins during the past 5 years, and some seismic exploration. There are some impacts from oil and gas import and export facilities in South Australia, but these are minor compared with other states. Oil and gas production wells around Australia are shown in Figure COA5.

Coal-seam gas is another sector of the oil and gas industry with significant impacts on the coast. It affects coastal land and ports through piping, wells, groundwater and produced water. In 2012, an Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development was established to inform decisions concerning coal-seam gas and large coalmining development proposals. Sandmining also occurs on some sections of coast and imposes direct localised impacts, although these operations are relatively minor compared with other parts of the world.

The Australian Petroleum Production & Exploration Association publishes the 'Blue Books' that summarise environmental work of the oil and gas industry, and a third volume is in progress. Currently, understanding potential effects of dispersants following oil spills is a major focus. The potential pressure associated with decommissioning facilities that are no longer needed is attracting increased attention, particularly in Bass Strait. There is a push to convert old rigs into artificial reefs (Fowler et al. 2014; see also the *Marine environment* report); however, the ecological implications of doing so are still a matter for research.

The outlook for oil and gas pressures is relatively stable in the short term, because proposed expansion of facilities and trains for existing LNG plants is not likely until oil prices rise. In the medium term, there is potential for oil and gas developments in the Great Australian Bight, and further exploration and development of existing areas, particularly in Western Australia, the Northern Territory and Timor-Leste. Floating LNG plants may see an increase in offshore operations, but will not incur the pressures of coastal export facilities.



Source: Geoscience Australia

Figure COA5 Oil and gas production wells within 50 kilometres of the coast

Coastline of the Coorong National Park at Long Point, near Meningie, South Australia

Atmosphere

Airborne emissions

Australia's coast bears the brunt of national airborne emissions, because the vast majority of people and large cities are on the coast. In addition to these land-based sources are emissions from shipping activities, which are most significant in ports that support both domestic and international trade. Major sources of emissions in Australia are stationary energy (52 per cent), transport (17 per cent), agriculture (15 per cent) and fugitive emissions (7 per cent). Given the density of human population in coastal areas, the impacts of emissions on coastal air quality are an issue of national concern.

Airborne emissions contribute to climate change, with impacts outlined in Climate and weather (in this report) and in the *Atmosphere* report. On both a per-person and per-dollar-of-GDP basis, Australia's carbon dioxide emissions are above the average for Organisation for Economic Co-operation and Development member countries.

Localised impacts of airborne pollutants can be exacerbated near the coast, because of their interaction with salt spray. Aged salt spray suspended in the air eventually breaks down into components that bind with pollutants (e.g. those from emissions), thereby creating more persistent airborne particles that can contain toxic elements.

An emerging issue in some major coastal cities is emissions from visiting cruise ships, which add fine particles and sulfur dioxide to the air. An example is the White Bay Cruise Terminal that began operating at Balmain in Sydney in 2013. There is concern about the deteriorating air quality in residential areas near the terminal, although monitoring has so far not detected impacts beyond permissible levels (Sydney Ports 2014).

See the *Atmosphere* report for more information about airborne emissions.

Climate and weather

Coastal Australia has experienced many extreme weather events in the past 5 years, consistent with predicted effects of climate change. Pressures associated with climate change include rising air and sea temperatures; rising sea level; altered precipitation; ocean acidification; and increased frequency and intensity of storms, floods and bushfires.

Temperatures in Australia have risen slightly faster than the global average, and extreme heatwaves are becoming more frequent (Alexander et al. 2006, Perkins & Alexander 2013). From 2011 to 2016, there were several brief but extreme climatic events, and a shift from La Niña (periodic cooling of the central and eastern Pacific Ocean associated with increased probability of wetter conditions in eastern Australia) to El Niño (periodic warming of the central and eastern Pacific Ocean associated with an increased probability of drier conditions in eastern Australia). Bushfire frequency and intensity have increased, partly because of higher air temperatures (Clarke et al. 2013). Other pressures on the coast related to climate change are the effects of flooding on water quality, including suspended sediments, and increased sedimentation in waterways when severe bushfires are followed by rain.

Since 2011, New South Wales has experienced higher temperatures, bushfires, east coast lows and storms (BoM 2011). Queensland has been struck by tropical cyclones (*Marcia*, *Yasi*, *Ita*, *Hamish* and *Nathan*), drought and floods, and has been heavily influenced by El Niño–Southern Oscillation (ENSO) forcing (BoM 2011, 2015). For example, the Brisbane floods of 2011 occurred during a La Niña event and caused an estimated $440 million damage, and Queensland experienced a long-term drought exacerbated by an El Niño event (BoM 2015). Both Victoria and South Australia have been relatively hot and dry (Clarke et al. 2013), and Tasmania has experienced warmer conditions than usual (BoM 2015). The Northern Territory was drier than usual during the reporting period, especially from 2013 to 2015 when the monsoon season was delayed and did not reach its normal intensity (BoM 2015). In Western Australia, there was a heatwave in Ningaloo in 2011 (Feng et al. 2013), which was at least partly driven by warm continental air being blown offshore, tropical cyclones and dry conditions in the far south-west.

Extreme heatwaves have affected both terrestrial and marine species and ecosystems (Wernberg et al. 2013). Fruit bats, for example, have a finely tuned internal body temperature (Welbergen et al. 2008), and have been observed falling from trees during heatwaves in Sydney and Brisbane. Some species rapidly evolve to tolerate heat, but the capacity of most species to adapt is unknown. Species are shifting their ranges in response to climate change, with growing evidence of range expansions and contractions in coastal ecosystems (see Rising sea temperatures). Increased temperatures also have the potential to alter ecological interactions by changing metabolic rates and relative competitive abilities (Dillon et al. 2010).

Climate change will almost certainly remain the primary global environmental pressure in both the short and long term. By 2070, atmospheric warming is predicted to reach between 1 and 2.5 °C under a low-emissions scenario, and between 2.2 and 5 °C under a high-emissions scenario (BoM & CSIRO 2014). Effects of ENSO and the Interdecadal Pacific Oscillation make prediction more difficult, adding uncertainty to predicted changes in periodicity and intensity (Collins et al. 2010).

Rainfall predictions are highly variable among models, although rainfall is expected to increase in the tropics and decrease at temperate latitudes (Head et al. 2014). More heatwaves and bushfires are predicted, but change in other processes is uncertain. Translation of large, national-scale climate change projections to small, regional scales needs to be appropriately conducted (Ekström et al. 2015). Climate change also needs to be assessed with regard to its impact on, and interaction with, other pressures on coastal systems, as is currently being done on the Great Barrier Reef.

See the *Atmosphere* report for more detailed information on atmospheric climate change and weather.

Coastal land

Terrestrial pollution

Terrestrial pollution occurs when solid or liquid waste is deposited on land or underground, and has the potential to contaminate soil and groundwater. It directly affects terrestrial habitats, but can also have flow-on effects on coastal waterways and marine habitats when contaminants are transferred from land to aquatic environments (Allinson et al. 2014). Because of the concentration of human activities near the coast, a disproportionate amount of coastal land is polluted compared with the rest of Australia. Two major types of terrestrial pollution on Australian coasts are landfill and chemical pollutants.

Australia generates a large volume of domestic waste, and much of this ends up as landfill. In 2013, Australians generated 647 kilograms of municipal waste per person, of which 58 per cent ended up in landfill (OECD 2015). This amount of waste per person is a reduction from previous years. Information on landfill is collected by local governments, but there is no national dataset that consolidates the volume of landfill or the area affected. Microplastics are an increasing source of contamination in soils to which ground solid waste is added, sometimes with the intention of improving nutrient content and reducing water loss (Browne et al. 2011).

Chemical pollutants can be divided into historical and contemporary sources. Most contaminated sites are the result of historical sources, particularly areas that have been used for heavy industry or chemically intensive agriculture. State government databases hold information of known contaminated sites (e.g. Western Australian Contaminated Sites Database), but many contaminated sites are undocumented until developers are required to investigate levels of soil contamination. Contaminants can break down over time into substances called residues, which can infiltrate ecosystems and, in some cases, affect human health. Methods of remediating contaminated sites are being researched, including use of new materials such as biochar (Zhang et al. 2013).

Contemporary sources of pollutants have been documented by the National Pollutant Inventory (NPI) since 1998, although data are contributed by companies producing the emissions, and some industries are excluded. Ammonia is the most abundant agricultural pollutant recorded by the NPI; the total amount of ammonia reported entering land in 2014–15 was 73 million tonnes, which is less than in previous years.

Nutrients, herbicides and pesticides are particularly problematic for the Great Barrier Reef catchment because of intensive agriculture (King et al. 2013). These pollutants are released in large quantities from farming in the catchment, and are transported to the coast, where they create diffuse pollution on the Reef (see Nutrient pollution). Initiatives are now under way to reduce inputs of land-based pollutants to the Reef, although it will be many years before the effectiveness of management can be determined.

Invasive species (terrestrial)

A large number of non-native plants and animals have invaded coastal land since European colonisation. Many invaders were introduced intentionally for food, agriculture or aesthetics, before their populations expanded and became difficult or impossible to eradicate (see Box COA2). Invaders tend to benefit from disturbance and assisted dispersal (e.g. seed adherence to vehicles, species transport in ballast water), and such conditions are often created in urban and agricultural areas. Some native species can also expand in range and explode in population in response to a human activity.

Significant terrestrial animal invaders include cane toads (*Rhinella marina*), European red foxes (*Vulpes vulpes*), feral European rabbits (*Oryctolagus cuniculus*) and feral cats (*Felis catus*). Cane toads have mostly invaded the tropical north, but are now spreading from Queensland to the west and increasingly south. Cane toads are toxic to many native Australian predators and have severe impacts on coastal native fauna (Shine 2010). Black rats (*Rattus rattus*) are also a significant invader; however, see Box COA3 for an example of competitive interactions between invasive and native species of rat.

Invasive coastal weeds are a major concern in dune systems (see Beaches and sand dunes). They compete with native vegetation and affect coastal morphology by changing the stabilisation of sand and soil. The top 5 species being actively controlled by local governments are African boxthorn (*Lycium ferocissimum*), sea spurge (*Euphorbia paralias*), bitou bush/boneseed (*Chrysanthemoides monilifera*), Geraldton carnation weed (*Euphorbia terracina*) and bridal creeper (*Asparagus asparagoides*). A national threat abatement plan was released in 2012 to reduce the impacts of 5 listed grasses on northern Australian biota.

A recent review found that there is scant knowledge about the impacts of coastal weeds, because most studies focus on a small number of high-profile species or are not scientifically rigorous (Cousens et al. 2013). Most weeds invade native habitats easily, with minimal resistance besides removal by community action groups. The bulk of management and control is done by volunteers or community groups (e.g. Coastcare Victoria), but efforts are rarely coordinated regionally. There is little research about impacts on native species or postcontrol recovery, and weed control activities are usually only assessed for herbicide efficacy.

In Victoria, foredunes are now composed of a mixture of exotic and native species, with exotics replacing natives at most sites. The dominant invasive species are marram grass (*Ammophila arenaria*), sea spurge and sea wheatgrass (*Thinopyrum junceiforme*), and, as these invade, they change dune morphology. Marram grass tends to produce higher and narrower dunes, whereas sea wheatgrass lowers foredunes and moves them seawards. Marram grass also affects nesting habitat for beach-nesting birds, such as hooded plovers (see Shorebirds and Nursing, roosting and nesting).

Solutions to weeds in Australia require a long-term, integrated, multistakeholder and multidisciplinary approach. Where control is implemented, assessment of the impacts of management decisions would support more adaptive and effective management. Additionally, the response of dunes dominated by weeds to storm events needs to be quantified to enable managers to respond appropriately to potentially increasing rates of coastal erosion.

Box COA2 Macquarie Island: a history of invasion and recent eradication

Invasive species cause havoc when they encounter a productive environment with few or no predators. Such has been the case at Macquarie Island, an Australian subantarctic island that teems with marine mammal and bird life. Macquarie Island is a biological oasis in the Southern Ocean, with beaches often covered by pupping seals and densely packed penguin breeding colonies (DoE 2014). The extraordinary natural values of Macquarie Island have been recognised, with World Heritage listing since 1997.

Timeline

1810—Rats and mice were accidentally introduced by early fur sealers. Cats were introduced to control the rodents, but these had devastating effects on seabirds (DoE 2014)

1870—Rabbits were left on the island by sealers to breed for food

1970—Rabbit numbers had grown (to around 130,000) and caused tremendous damage to vegetation

1983—Myxomatosis was introduced, and rabbit numbers declined to around 10,000

1985—Efforts began to remove cats, which were causing an estimated 60,000 seabird deaths per year

2000—The last of the nearly 2500 cats were culled to save the seabirds (Robinson & Copson 2014). Seabird populations responded rapidly, but rats and rabbits continued to cause widespread environmental damage

2006—Rabbit numbers had grown to more than 100,000, likely in response to the eradication of cats and reduction in the use of myxoma virus. Rabbits removed grass and led to soil erosion and cliff collapses; large portions of the Macquarie Island bluffs are eroding as a result. Erosion and cliff collapses destroyed seabird nests, and rats fed on young chicks. In September 2006, a large landslip at Lusitania Bay was attributed to heavy spring rains and severe erosion caused by rabbits, and partially destroyed an important penguin breeding colony

2011—A mass baiting program began to eradicate rabbits, rats and mice. Species unintentionally affected by baiting included kelp gulls, giant petrels, black ducks and skuas

2012—Hunting teams culled the last remaining rabbits

2014—Macquarie Island was officially declared vertebrate pest–free after 7 years of eradication efforts. This is hailed as the largest successful island pest-eradication program ever attempted

Tasman Island, showing winch used to move building materials for lighthouse construction
Photo by Megan Watson

Box COA3 Native water rats keep invasive black rats at bay

Black rats (*Rattus rattus*) have invaded bushland areas around most of Australia's major coastal cities, often replacing native mammals, which have become locally extinct. Their numbers are kept high by the food and habitat resources that are available in urban areas (Banks & Smith 2015). Black rats are a problem in these systems because, unlike many native rodents, they climb trees to prey on eggs and chicks in bird nests. They also carry novel pathogens such as rat lungworm, which can be lethal to humans and wildlife (Banks & Hughes 2012).

It is possible that some of the remaining native species play a role in keeping black rat numbers down. Research into the nature of competitive interactions between Australia's largest rodent—the native water rat (*Hydromys chrysogaster*)—and the black rat has shown that water rats can potentially exclude black rats from a preferred habitat through aggressive interactions.

Analysis of spatial patterns of abundance and distribution of black rats and water rats in bushland around Sydney has found that both species prefer similar environments (areas of dense vegetation and fresh water), which indicates the potential for interspecies competition for space. Wildlife cameras also showed that, where there were high levels of water rat activity, there was very little black rat activity.

A behavioural study examining the responses of black rats and water rats to each other's odours showed that black rats did not avoid the odour of water rats, nor did they display any recognition or anxiety and vigilance behaviour when in the presence of water rat odour. However, camera footage showed evidence of direct aggressive attacks on black rats by water rats, which suggests that water rats might defend resources or areas from the invasion of black rats. Among animals that differ in size, the larger species is usually competitively dominant.

The findings suggest that there is the potential for the water rat to play a positive role in biotic resistance against the spread of invasive black rats, and a greater understanding of these complex competitive interactions may be able to inform the management of invaded mammal communities in Australia.

Source: Peter Banks and Margarita Goumas, University of Sydney

Land–water interface

Sea level rise

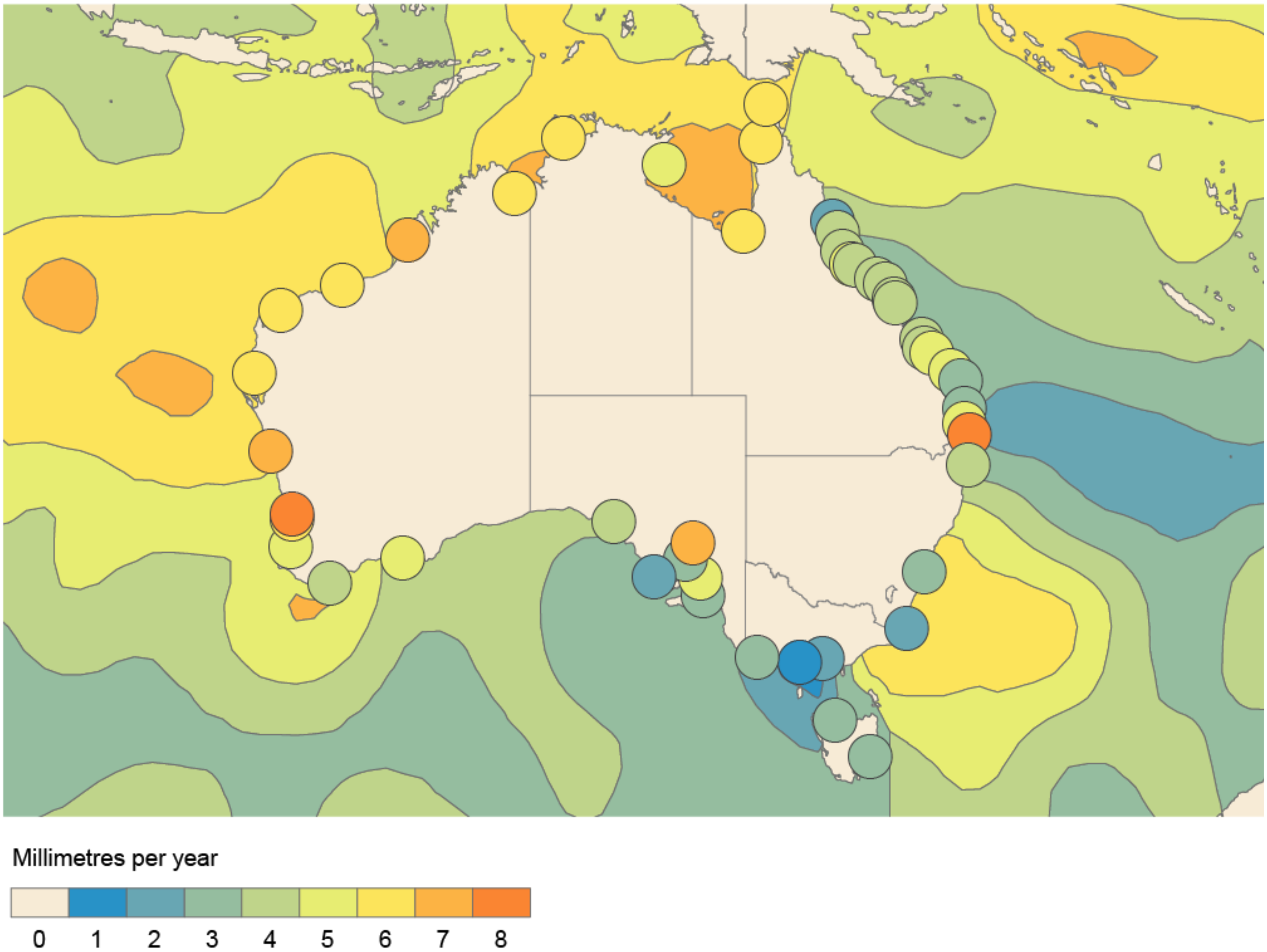
Climate change is driving global and regional sea level rise, and more intense and frequent extreme sea levels. Global averaged sea level has been rising at a significantly higher rate during the 20th and 21st centuries (1.7 ± 0.2 millimetres per year; mm/y) (Church et al. 2013a) than in pre-industrial times, and at an accelerating rate since the late 19th century (Church et al. 2013a, Kopp et al. 2016). The widely accepted estimate of global average sea level rise since the start of the record in 1993 is 3.2 ± 0.4 mm/y (Church et al. 2013a). Rising sea level is a result of the expansion of ocean waters and the loss of land-based ice, because of the increasing temperatures associated with climate change. The depletion of groundwater also plays a role, as most extracted groundwater ends up in the ocean through run-off, evaporation and precipitation (Church et al. 2013b, Slangen et al. 2014).

Sea level rise is felt primarily at the coast, exacerbating erosion, inundation, and loss of coastal ecosystems (Figure COA6). Currently, the impact of sea level rise is slight, but impacts will increase as trends become more pronounced during the background of storm surges and longer-term weather-related variability. Background variability makes it necessary to consider climate-related sea level rise during periods longer than 5 years, particularly at the regional level. For 1966–2009 and 1993–2009, the average trends in relative sea level around the coastline are 2.1 ± 0.2 mm/y and 3.1 ± 0.6 mm/y, respectively (White et al. 2014). The increases in sea level on the east and west coasts of Australia have resulted in a significant increase in extreme high sea levels during the 20th and 21st centuries (Church et al. 2006).

Trends and projections of Australian sea levels for the first decades of the 21st century are related to greenhouse gas emissions and begin to diverge depending on emission trajectory from about 2050. The Intergovernmental Panel on Climate Change (Church et al. 2013a) developed

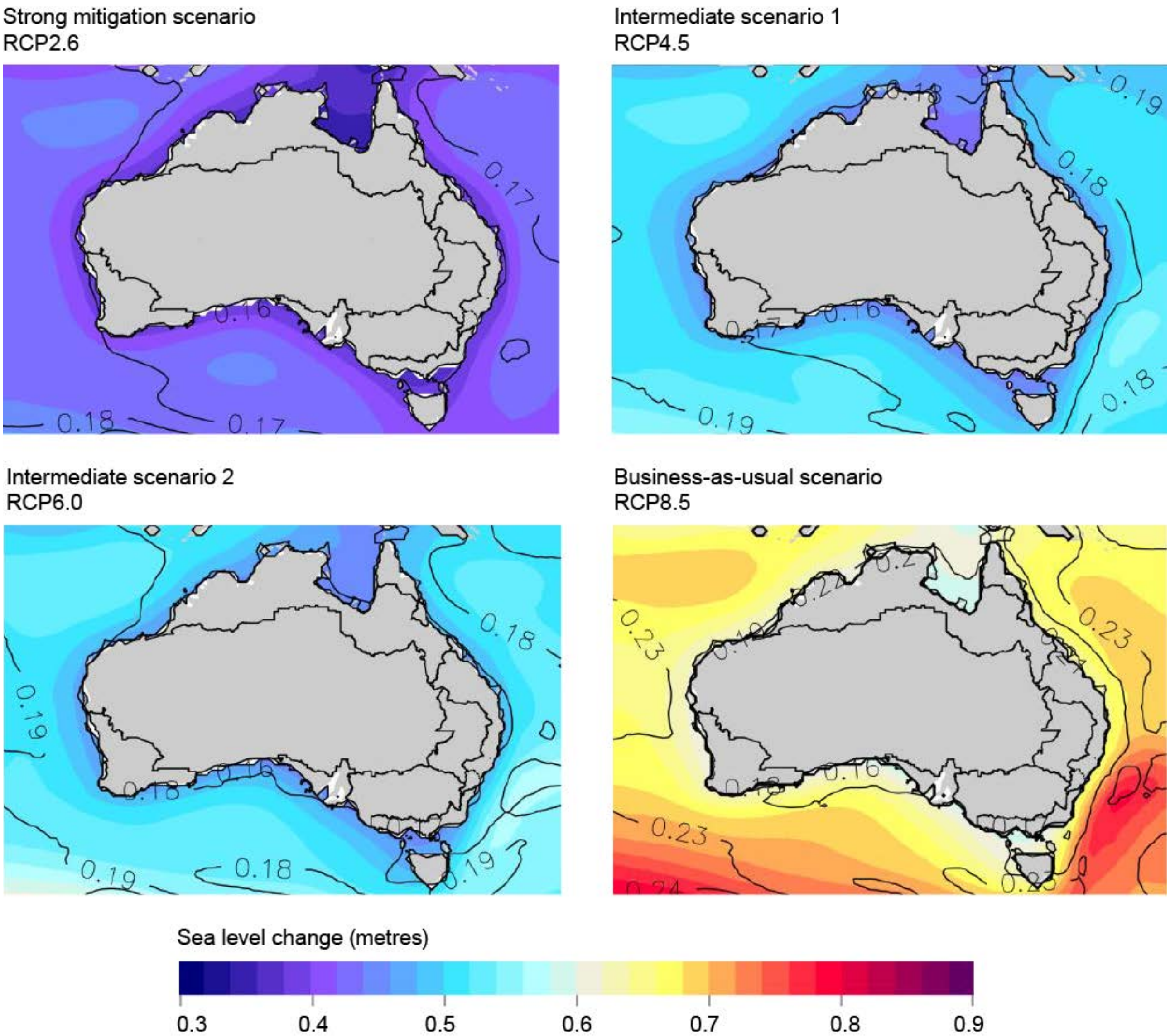
4 greenhouse gas concentration trajectories, known as Representative Concentration Pathways (RCPs), based on possible mitigation scenarios. For the business-as-usual scenario (RCP8.5), the rates steadily increase through the 21st century, reaching 11.2 mm/y by 2100. For the intermediate scenarios of RCP6.0 and RCP4.5, the rates stabilise in about 2090 and 2060 at 7.4 and 6.1 mm/y, respectively. For the strong mitigation scenario (RCP2.6) where significant and urgent action occurs, the rate of rise stabilises much sooner and declines to 4.4 mm/y. Projections for 2090 relative to 1986–2005 are shown in Figure COA7 (based on McInnes et al. 2015).

The largest uncertainty in future sea level trends is the behaviour of ice sheets, particularly the Antarctic ice sheet. There is also uncertainty about the sensitivity of the climate system greenhouse gas concentrations (e.g. whether feedback loops in the system may accelerate or decelerate a warming trend), and the regional distribution of sea level change. Sea level rise is expected to continue for centuries after greenhouse gas emissions reach near zero because of the increased baseline concentrations of greenhouse gases in the atmosphere.



Source: CSIRO, updated based on White et al. (2014)

Figure COA6 Sea level trends from satellite altimeters (colour contours) and tide gauges (coloured dots), January 1993 to December 2010



RCP = Representative Concentration Pathway

Note: The projections (shadings) and uncertainties (solid lines) represent the contributions from thermal expansion, changes in terrestrial ice and ocean dynamics, gravitational response of the ocean to these changes, and an ongoing glacial isostatic adjustment.

Source: McInnes et al. (2015)

Figure COA7 Regional distributions of sea level change (4 emissions scenarios) for the period centred on 2090 compared with 1986–2005

Erosion and inundation

Shorelines naturally erode and accrete sediments, but these processes can be exacerbated by human activities and can present major issues for human settlements. Parts of Australia's coastline are at risk of periodic erosion and inundation because of the impact of extreme storms. Sea level rise is considered to have low impact on these processes at present, but there is the potential for erosion events to worsen in the future and lead to long-term shoreline recession.

Beach erosion, and consequent shoreline recession, increase in response to sea level rise. Originally described by the simplistic Bruun's rule (Bruun 1962), the future response of coasts to sea level rise is now understood in terms of contemporary frameworks that involve sediment compartment and budget concepts, and response models (e.g. Cowell et al. 2003, Woodroffe et al. 2012, Kinsela et al. 2016). However, observations along many sections of the open coast during the past 40 years highlight the capacity of beaches to recover after storm events with no net shift in shoreline position. This highlights the role of local and regional sediment supplies in determining changes in shoreline position over time.

Periodic erosion is of most concern in developed areas, such as urban centres or ports, where property is at risk (see Coastal development and land use). It is most acute during extreme weather events accompanied by sustained periods of high wave action and storms, and is exacerbated by the loss of dune vegetation, shoreline modification, spring high tides, rising sea levels, and changes to hydrodynamics and sediment supply. Inundation is particularly concerning around estuaries with low-lying properties, as documented nationally by the Department of Climate Change (DCC 2009).

Susceptibility of the Australian coastline to inundation and erosion or recession has recently been mapped at a national scale as part of CoastAdapt. This used the sediment compartment approach, and assessed all 354 Australian coastal compartments for their susceptibility to climate change (Thom 2016). Most states have a system of identifying locations that are sensitive to periodic erosion, recession and inundation in association with monitoring programs undertaken by local councils and community groups. In New South Wales, there are approximately 30 individual coastal zone management plans, and 15 coastal erosion hotspots. In South Australia, the Coastal Protection Board established under the *Coast Protection Act 1972* (SA) works to manage erosion and other coastal issues, and Western Australia has a state planning policy that explicitly maps predicted erosion under various sea level scenarios.

Although we have risk assessments and a framework for managing erosion and inundation, monitoring of beach erosion and shoreline change is a major gap in most states, and a national erosion monitoring plan is needed. The best large-scale data could be obtained from repeated surveying using a combination of LIDAR (light detection and sensing; dry land), LADS (laser airborne depth sounder; underwater) and high-resolution satellite images. Intertidal and subtidal imagery is necessary because sediment deposits can provide an important source of beach nourishment and a buffer for the coastal zone. There is value in maintaining field observations because of the broader range of variables that can be measured and for the calibration of remotely sensed data.

Rising sea levels, saline intrusion and coastal erosion are likely to affect coastal ecosystems. Frontal dune systems are likely to be affected by coastal recession, whereas wading birds that breed on low-lying sandy spits are likely to be affected by increased overwash. Landward migration of seagrass beds, mangroves and saltmarshes is likely, but only where terrain and coastal structures allow, although patterns of response are likely to vary depending on sediment supply and local processes. Some wetland systems may be able to adapt to modest rates of sea level rise through vertical accretion.

The short-term outlook is continued impact of extreme storm events, leading to periodic erosion at hotspots where property and infrastructure are exposed, and inundation increasing in line with sea level. In the long term, climate-driven sea level rise is expected to gradually increase exposure of property, infrastructure and coastal ecosystems to the effects of inundation and erosion. Erosion will eventually lead to shoreline recession, and increase the area of inundation as a result of both storm overwash and higher tides in estuaries. Long-term changes in shoreline behaviour will also be dependent on changes in wave climate, cyclone frequency and intensity, tide range and sediment supply, so caution is needed in making predictions based on sea level change alone.

There is, however, potential for long-term improvement if management appropriately considers the dynamic and ambulatory nature of the coasts. Adaptive planning in the context of sea level rise is necessary to manage risks to existing infrastructure and avoid future risk. Some erosion hotspots may require managed realignment, whereby coastal property and infrastructure are moved inland. An important consideration in coastal armouring is the 'pinch effect', which refers to the squeeze on freshwater wetlands from both land and sea directions. Sea level rise and the movement of saline water inland create pressure from the seaward side, whereas barriers erected to protect urban and agricultural lands from rising water and salinisation create pressures on the landward side (Sheaves et al. 2007).

Sediment transport

Sediment input to coastal waterways varies greatly around Australia, and is often site specific. Transport of sediments by wind and water is a natural process that shapes the geomorphology of beaches and estuaries, but anthropogenic factors can change the spatial and temporal patterns of movement, as well as the quantity and type of sediment transported.

Catchment modification is one of the major drivers of change, and generally increases sediment input. High proportions of annual sediment budgets can come from the catchment and be transported during flood flows (Hossain & Eyre 2002). Sedimentation of navigation channels is also a major management issue for ports and harbours. Coastal lagoons and shallow coastal waters are among the most vulnerable habitats, because of their limited volumes and rates of water exchange with the ocean. Sediment input and nutrient input are closely linked processes, and many coastal waterways with elevated sediment input also suffer from nutrient enrichment (see Nutrient pollution).

Sedimentation influences a range of taxa, including mangroves, saltmarshes, corals and other sessile invertebrates, seagrasses, phytoplankton, microphytobenthos, and infauna (Todd et al. 2015). Impacts of excess sediments on pelagic (open-ocean) species include smothering, gill irritation and reduced light penetration, whereas impacts on benthic (ocean-floor) species arise from changes in grain size distribution, light penetration and seabed depth. Increased density of fine suspended sediments can also influence the behaviour and functioning of vertebrates (e.g. fish, turtles and dugongs), or have indirect impacts through changes in prey abundance.

In addition to sediment input, increased resuspension of bottom sediments can have significant ecological impacts (Knott et al. 2009), change water quality parameters and alter patterns of sediment transport. Sediment resuspension is exacerbated by vessel movements in shallow waters, dredging operations, and changes in hydrodynamics because of coastal engineering. Resuspension of contaminated sediments is particularly concerning because it releases contaminants into the water column, increasing their bioavailability and bioaccumulation (Hedge et al. 2009).

For the Great Barrier Reef coast, the Reef Plan report cards (2014) present sediment, nutrient and pesticide loads to the coast, and include modelled estimates of how they have changed because of catchment management works. Modelling of river plumes has been done for the Great Barrier Reef (e.g. Kroon et al. 2012; Álvarez-Romero et al. 2013; Fabricius et al. 2014, 2016). Although some dredge plume modelling has been done, it is generally not published in peer-reviewed literature (but see review by McCook et al. 2014). Sediment and nutrient transport to coastal waters is understood to be one of the major ongoing threats to the health of the Great Barrier Reef. Measures to reduce sediment inputs in Queensland are currently under way, although it is likely to take many years to achieve any outcomes (Reef Water Quality Protection Plan Secretariat 2014).

Sediment inputs from several north coast rivers in New South Wales have been studied by Eyre and Ferguson (2006), among others, but there is no ongoing comprehensive monitoring of sediment inputs to waterways of New South Wales. Research on storm water in Sydney Harbour (Birch & Rochford 2010) and plumes in selected locations near Sydney (Birch & O'Hea 2007) provides some insight into the role of urbanisation in sediment transport. A study of 184 New South Wales estuaries found that total suspended sediments were 16 to 10,594 per cent higher in areas of significant human land use, compared with relatively undisturbed catchments (Roper et al. 2011).

Assessment of the impacts of catchment management decisions on sediment loads requires either modelling of source inputs or monitoring across decades. Such long-term monitoring programs are economically costly, and have only been implemented at a small number of locations (e.g. Great Barrier Reef, Port Phillip Bay, Moreton Bay, Nepean–Hawkesbury River, Swan River, Blackwood River). More information on the effect of sediment transport on bedded sediments is crucial, as they are often the dominant habitat type and are good indicators of integrated environmental condition over time (Burton & Johnston 2010).

Coastal sediments around Australia have recently been mapped in the Coastal Sediment Compartments Project, which aims to improve coastal risk assessment by classifying coast based on landforms and patterns of sediment movement. It uses 3 levels to capture processes at different scales, and each level is suitable for different types of decision-making:

- primary—based on the influence of large landforms and offshore processes; suitable for regional planning or positioning of large-scale engineering such as ports
- secondary—based on medium landforms and regional sediment processes; useful for smaller engineering or local planning decisions
- tertiary—based on individual beaches; suitable for very small projects that are unlikely to restrict sediment movement, such as deciding the exact location of a groyne or sea wall within a broader management plan.

The outlook for sediment transport varies around Australia. Sediment quality is improving in some urban areas, particularly where organic inputs have declined because of changed waste management and/or the restoration of riparian vegetation, but coastal sprawl into previously undeveloped areas is increasing sediment and contaminant transport. Continued land clearing and poor agricultural practices result in increased transfer of terrestrial sediments to aquatic systems. Management should focus on combined sediment and nutrient input reductions, since the 2 inputs often co-occur, and can have compounding or interactive effects on sediment and water quality.

Artificial structures

The addition of artificial structures is one of the first modifications made to estuaries and coastal foreshores. Structures include marinas, ports, seawalls, groynes, wharves, aquaculture facilities, stormwater pipes and breakwaters. An estimated 20 per cent of New South Wales estuaries have between 4 and 20 per cent of their perimeter modified by a foreshore structure (Roper et al. 2011), and, in some estuaries, more than 50 per cent of the foreshore is artificial (e.g. Sydney Harbour; Chapman 2003). Approximately 10 per cent of the Great Barrier Reef World Heritage Area coastline has been modified—an increase of 70 per cent in 3 years in some areas because of port developments (Waltham & Sheaves 2015).

Pressures associated with artificial structures (reviewed by Dafforn et al. 2015) include:

- removal of soft-sediment, rocky reef and mangrove habitats
- structures acting as stepping stones and havens for invasive species
- increased shading underneath structures during the day
- artificial light surrounding the structures at night
- introduction of contaminants
- altered hydrodynamics and erosion.

Artificial seawalls often support lower biodiversity than natural rocky shores, which is potentially related to their vertical orientation, lower surface area and fewer microhabitats (Chapman 2003, Ferrario et al. 2016, Bishop et al. in press). A recent meta-analysis found that seawalls supported 23 per cent less biodiversity and 45 per cent fewer organisms than natural shorelines (Gittman et al. 2016). In some instances, built structures can contain higher densities of introduced species than adjacent natural rocky reefs as a result of the novel habitat they provide and their proximity to vessels that may carry introduced species. It remains unclear whether populations on these structures function as well as they would in natural habitats. In addition to the direct effects of structures themselves, there are also pressures from associated activities such as shipping and fishing.

Aerial view of Big Lagoon (an inundated birrida) in the Shark Bay World Heritage Area, Western Australia

Eco-engineering, as has been implemented in parts of Sydney Harbour, aims to incorporate ecological principles into the design of artificial structures to reduce their impact and provide useful functions such as increased biodiversity (Browne & Chapman 2011). Until eco-engineering principles are adopted more widely, however, artificial structures at a national scale will continue to remain poor substitute habitats for marine communities. Best-practice guidelines that are supported by comprehensive research are a priority, to improve the design, deployment and monitoring of artificial structures. This research priority was outlined in the National Marine Science Plan 2015 (Treloar et al. 2016), and the Hawkesbury Shelf marine bioregion assessment identified eco-engineering as a key solution-based research need.

Looking forward, as artificial structures continue to spread as coastal features, there is a need to balance engineering needs with environmental protection and conservation. In many cases, implementing eco-engineering designs early in the development and construction phase can be less expensive than hard engineering solutions. The benefits of eco-engineering can also extend to include social and economic stability in coastal areas across Australia.

Desalination

Desalination plants are increasingly common in major Australian cities. Most are designed to serve as secondary water supplies for use during drought. Desalination plants draw in large volumes of sea water from which fresh water is extracted, creating a byproduct of highly saline brine. Impacts on the coastal environment include the footprints of desalination plants on coastal land, the intake of large volumes of sea water with associated plankton, and the release of the brine effluent into coastal waters. The brine can affect marine biota through higher salinity (often double that of ambient sea water), changed flow conditions and, in some cases, contaminants (Roberts et al. 2010). Environmental impacts are somewhat proportional to the size of the plant, which varies from small community potable water supplies to large plants for major cities. However, impacts can be ameliorated if brines are discharged into high-energy or highly dispersive waters.

Pressures associated with desalination are marginally increasing because more large-capacity desalination plants are being commissioned, although several of these are currently nonoperational. Of the plants that are operating, there is little evidence of impact beyond the vicinity (hundreds of metres) of the outfalls, and affected areas usually represent a small proportion of that habitat type. Technological advances, such as high-velocity diffusers that promote mixing of brine with surrounding sea water, are also helping to minimise the impacts of hypersalinity.

Ecological impacts are generally monitored by changes to water quality parameters, such as salinity and dissolved oxygen. Impacts are usually attributed to the stress of hypersalinity, although there have not been manipulative tests at the appropriate scales to separate salinity stress from other potential stressors. Uncertainty still surrounds potential impacts of increased flow and shear stress, chemicals used to protect the membranes of desalination cells when the plants are not operating, and antiscalants used during the commissioning and maintenance of pipework (Roberts et al. 2010).

Substantial environmental impact assessments are performed for large desalination plants, although the amount of monitoring following construction varies. The Sydney Desalination Plant implemented a robust monitoring program (Clark & Johnston 2014), and the Victorian, Western Australian and South Australian major desalination plants were well assessed at the environmental impact statement stage. The Victorian plant is yet to become fully operational. The surrounding waters of the Western Australian plants are monitored for water quality; however, monitoring data are not available for ecological impacts apart from effects on seagrass. In South Australia, the Adelaide (Gulf St Vincent) and proposed Point Lowly (Spencer Gulf) plants were well assessed initially, but there is ongoing debate about the potential impacts of the Point Lowly plant. There is concern that the calm waters of the South Australian gulf increase the risk of negative impacts (Kämpf et al. 2009), but only a minor salinity rise (less than 0.5 parts per thousand) was recorded within 100 metres of the Adelaide plants. This, together with cuttlefish toxicological studies, suggests that the risk posed by the hypersaline effluent is low (Dupavillon & Gillanders 2009). The Perth and Adelaide desalination plants have ecological monitoring (before–after control–impact), although data are generally not publicly available.

The short-term outlook for desalination as a pressure is stable, because many existing plants are not operating at capacity and the addition of new plants is unlikely. In the longer term, impacts from desalination are expected to rise, given increasing human population and climate-driven aridity (particularly in south-eastern and western Australia). This will likely be a low-risk pressure, however, because desalination plants are economically costly to build and maintain, and their impacts are highly localised. It is likely that ongoing global research will improve the management and design of desalination plants to further minimise direct environmental impacts.

Coastal waters

Coastal river and estuary pollution

Pollution is a longstanding pressure on coastal rivers and estuaries, particularly in areas of urbanisation, industrialisation, mining and agriculture. There remains a legacy of pollution associated with early European history in Australia (Wolanski 2014), and both legacy chemical contamination and contemporary inputs to poorly flushed systems are among the most significant pressures on coastal waterways. Common contaminants found in coastal rivers and estuaries include excess metals, nutrients and organic matter (see Nutrient pollution), and industrial chemicals, pesticides, herbicides, terrigenous sediments and debris (see Marine debris).

Ecological consequences of pollution in coastal rivers and estuaries include loss or change of biodiversity, habitat, ecosystem function and ecological processes (Johnston & Roberts 2009, Johnston et al. 2015). Bioaccumulation of toxicants in the food chain can also affect vertebrate population viability and human health (Hamilton et al. 2016). Most pollution results from historical legacies, ongoing diffuse sources (e.g. agricultural run-off and storm water) and waste management. There is a need for greater understanding of the bioavailability and toxicity of toxicants in both sediments and the water column, and for the development of sensitive biomonitoring tools such as those achieved for estuaries in south-eastern Australia (Edge et al. 2014).

New classes of contaminants such as plastics, cosmetic products and therapeutics are growing concerns (Galloway & Lewis 2016). There is little knowledge about the chemical compounds that many of these emerging contaminants degrade into once in sea water or sediment, and we do not know the full suite of their potential impacts. Detecting new contaminants and forming national-scale assessments are hindered by lack of national-scale data agencies, standardised monitoring programs, and the communication and accessibility of data.

Nationally, pollution pressure on many estuaries is moderate to strong, but both pollution levels and data availability vary greatly among locations. Existing data for most jurisdictions focus on modified estuaries, leaving knowledge gaps regarding effects of pollution in relatively unmodified estuaries (Hallett et al. 2016b,d). In New South Wales, the condition of heavily developed coastal waterways is poor, and nutrients, metals, pesticides and other contaminants are found at high levels in some estuaries (e.g. Sydney Harbour, Port Kembla Harbour; Dafforn et al. 2012). Metal enrichment of sediments was found to be related to population density across 38 central New South Wales rivers and estuaries (Birch et al. 2015a). Between 1999 and 2010, sediment metal concentrations in Sydney Harbour declined in large sections of the upper and central estuary, but slightly increased in the lower estuary following urban and industrial shifts (Birch et al. 2013). Pesticide distributions in Sydney Harbour are linked to stormwater inputs (Birch et al. 2015b).

For estuaries in Queensland and northern New South Wales, major pollution sources are a combination of agriculture, mining, industry and urban land use. Several Queensland and New South Wales rivers and estuaries are moderately to strongly affected by sediments and pesticides. Agriculturally modified estuaries continue to suffer water quality issues, including major fish die-offs because of organic enrichment (see Nutrient pollution), and drainage of floodplains to cause acid sulfate soil run-off. Report card systems are in place for south-east Queensland, Gladstone Harbour, the Great Barrier Reef and Mackay, but monitoring has revealed little improvement in water quality during the past 5 years because of the scale of the problem and the cost of agricultural reform (GBRMPA 2014).

Pesticide contamination in the Great Barrier Reef catchment is widespread, and concentrations of the herbicide diuron exceed guideline trigger values at multiple sites (Smith et al. 2012). Diuron is used in the Queensland sugar cane industry and interferes with the photosynthetic activity of a wide range of organisms (Duke et al. 2005). Current understanding of nontarget effects of toxins is limited, and there is a need for greater knowledge of the risks of toxins in coastal areas to inform guidelines and management. Ideally, management should target the source of inputs, such as the Queensland bylaw that limits the use of diuron by the sugar cane industry.

Pollution in southern states receives less attention than issues related to flow regulation, but it is still a major problem in some areas. A high proportion of South Australian estuaries are in poor condition, and pollution as a legacy of industrial activity, land clearing and mining is common in Tasmania. In Victoria, pollution is not part of the Index of Estuarine Condition program (DEPI 2013), despite being a significant pressure in some estuaries. There are large and obvious impacts of pollution in the southern half of Western Australia, particularly in the south-west (Brearley 2005, Ward et al. 2010).

Much of far northern Australia is relatively unaffected by pollution because development pressure is low. Most of the Northern Territory coastline is unmodified and largely free from contaminants, although Darwin Harbour is an exception (DLRM 2013, 2014). Water quality in Darwin Harbour and its tributaries is generally good, but increased sedimentation and nutrients arise from dredging, sewage discharge, and wet-season stormwater flows (DLRM 2014), and herbicides and metals have been detected at low concentrations (French et al. 2015). In the dry season, the potential for poor water quality increases with water residence time (the length of time a parcel of water resides in a particular area) (Fortune 2010). The Northern Australia Development initiative will present various challenges in the form of pollutants from agricultural and extractive industries.

Improvements have been made in managing point-source pollutants, but diffuse pollutant sources (e.g. agriculture and storm water) make it difficult to reduce pressure in the presence of a growing population and catchment development. Remediation of contaminated sediments is expensive, so is usually only attempted for high-priority issues, such as the removal of dioxins from sediments in Homebush Bay, New South Wales. Management improvements exist or are planned in some states and regions, but lack of research funding and monitoring limits our understanding of their effectiveness. Legacy effects may continue for decades after management begins, which is detrimental to the public and political will required to sustain efforts. Australia has no national program of measurement or monitoring of contaminants in aquatic or terrestrial environments; however, the National Pollution Inventory does consolidate the reporting of emissions of 93 toxic substances from medium and large industries.

The input and environmental impact of pollutants are expected to rise with increasing catchment modification to support growing populations. Pollution is also likely to increase with land reclamation, dredging, waste disposal, agriculture and storm water (including floods and high flows), all of which increase with coastal population and development. Water quality could be improved by better water and sediment quality guidelines, monitoring, risk assessment tools, analytical techniques and measures to address the shortage of management action.

Nutrient pollution

Nutrients such as nitrogen and phosphorus are necessary for ecological functioning in coastal waters (Howarth & Marino 2006). They are required by algae for photosynthesis at the bottom of food webs, are transferred up the food chain by higher-order consumers, and are eventually recycled by detritivores (animals that eat detritus, including decaying plant and animal remains) (Moore et al. 2013). The definition of excess nutrients can be ecosystem dependent, rather than based on universal loads or concentrations, since ecosystems vary in their requirements and cycling rates. Excess nutrients can have severe negative environmental consequences (Chislock et al. 2013) and lead to:

- eutrophication (where excess nutrients encourage algal growth)
- harmful algal blooms (see Algal blooms)
- high turbidity (see Water quality [turbidity, physiochemical properties])
- creation of coastal low-oxygen dead zones (see Coastal low-oxygen dead zones)
- disruption of natural biogeochemical cycling (see Microbial processes and nutrient cycling)
- crown-of-thorns outbreaks, coral bleaching and coral disease in tropical areas.

Nutrients enter coastal waters through 2 main pathways: point-source effluent such as sewage outfalls, and diffuse sources such as agricultural run-off. Practices that contribute to diffuse nutrient pollution include clearing of native vegetative (which decreases sediment stability), the creation of impervious surfaces in urban areas (which increases the quantity and water velocity of run-off) and the use of bulk quantities of nutrients in the form of fertiliser in the agricultural industry. These practices have facilitated large quantities of nutrients entering coastal waters, particularly during large flood events.

Intensive agriculture in the Great Barrier Reef catchment has resulted in substantial nutrient input into the naturally oligotrophic (low primary productivity) coastal waters (Kroon et al. 2016). Since 2003, the Australian and Queensland governments have implemented a range of policy initiatives to reduce land-based pollution of the Great Barrier Reef. The most significant of these is the Reef Plan, which includes projects to monitor, model and experiment with management options for pollution sources and pathways in farms and catchments. In particular, the Great Barrier Reef Catchment Loads Monitoring Program measures water quality entering the Great Barrier Reef lagoon from priority catchments, and estimated that 12,000 tonnes of nitrogen and 2900 tonnes of phosphorus came from monitored catchments in 2014–15 (Wallace et al. 2016). Despite management efforts, however, total nitrogen entering the Great Barrier Reef continues to increase, and it is doubtful that current management actions are sufficient to reach Reef Plan targets (Kroon et al. 2016).

In New South Wales, temporal trends in chlorophyll-a, an indicator of total nitrogen, are being researched (Roper et al. 2011). Satellites provide a means of measuring surface chlorophyll-a across extensive areas, but data are at the 1 × 1 kilometre scale and are patchy because of cloud cover, so often have high uncertainty. In the short term, nutrient monitoring will depend on in situ measurements, whereas, in the long term, more accurate methods should be developed to measure phytoplankton biomass and primary productivity. Efforts may be best focused on improving methods for detecting and avoiding the release of excess nutrients.

Marine debris

Coastal marine debris is a term for human litter in the coastal zone. Most debris enters the water in urban areas, but is often transported to remote locations by wind and currents (Reisser et al. 2013, Critchell et al. 2015). The majority (82 per cent) of impacts from debris are attributed to plastics (Rochman et al. 2015), and approximately three-quarters of the debris found along the Australian coast by a recent CSIRO survey was plastic. The Australian plastic industry produces about 1.2 million tonnes of plastic each year, some of which ends up in waterways and does not biodegrade. It does, however, photodegrade under sunlight, and some animals can break the material into small pieces (Davidson 2012).

In 2009, a national threat abatement plan was implemented to address marine debris impacts on marine vertebrates. Debris can entangle marine animals, such as in the Gulf of Carpentaria where an estimated 5000–15,000 turtles become ensnared in discarded fishing nets (Wilcox et al. 2015). Debris can also be ingested by shorebirds (Verlis et al. 2013, Lavers et al. 2014), turtles (Koelmans 2015) and invertebrates (Canesi & Corsi 2016), and accumulate inside individual animals (Browne et al. 2008).

Policy-makers are requesting that populations (and assemblages), rather than just individual organisms, should be protected from debris (SECRC 2015). Population models provide a means to assess whether a population is declining; the cause of decline, if occurring; the parts of the lifecycle requiring managerial action; and the likely fate of the population. Where these models are not possible, alternative models can be used as a precautionary measure to manage mortality or serious injury of some threatened and endangered vertebrates caused by debris, using the concept of 'potential biological removal' (Browne et al. 2015). Models are also being developed to synthesise pathological data that might link debris to mortality (Baulch & Perry 2014). Regardless of such problems, using these approaches to estimate the likelihood and potential magnitudes of impacts of debris is a useful precautionary action until better information is available.

Of emerging concern are microplastics, which are small particles that are micrometres in size (Browne 2015). These enter coastal waters through sewage contaminated by fibres from washing clothes or from cleaning products; they can also occur from the fragmentation of larger plastics. The ecological effects of microplastics are largely unknown (Vegter et al. 2014), but pathways of impact include blockage of digestive tracts and the transfer of organic toxins through food webs (Browne et al. 2013, Rochman et al. 2013). Research about the impacts of microplastics is growing, although variation in particle size among studies limits the ability to determine generalities.

Aerial view of the spectacular Zuytdorp Cliffs—an amazing geological feature of the Shark Bay World Heritage Area, Western Australia

Little scientific evidence exists to assess the pressure of coastal marine debris in Australia. Most studies focus on distribution or exposure, and do not consider impacts or risk to the environment (Rochman et al. 2015), and there remains a skewed proportion of studies on sandy beach habitats. Inconsistency in methodology, definitions of marine debris and the scale of studies hinders identification of general patterns in marine debris globally (Browne et al. 2015). In recent years, research has increased at the local and national levels, with a focus on determining baseline conditions.

Public awareness and concern regarding coastal debris are high. Various clean-up initiatives, such as Clean Up Australia, Keep Australia Beautiful and the Tangaroa Blue Foundation (Tangaroa Blue Foundation 2014; see Box COA4), have gathered data on coastal debris. South Australia's aquaculture industries launched their 'Adopt a Beach' program in 2012, whereby aquaculture companies agree to regularly collect marine debris and accompanying data from 'adopted' beaches. However, well-designed scientific and analytical studies conducted on appropriate spatial and temporal scales are still necessary to determine quantities, accumulation rates, patterns, pathways and sources of debris nationally. This exposure information should then be linked to social, economic and ecological impacts through time (e.g. Pearson et al. 2014).

There is a need to minimise input and improve management practices from sources (urban and agricultural areas) to sinks (waterways and coastal zones). Possible actions include container deposit schemes, plastic bag bans and microbead bans, but microplastics remain a key challenge. There is a need to address human attitudes and behaviour towards product use and littering, and a greater emphasis on designing products that produce less waste (Eagle et al. 2016).

In the short term, debris is expected to increase because managerial responses have been slow to emerge. Managerial activities should reduce inputs in the long term; however, legacy debris will continue to impact the ecosystem. An important issue is whether the impacts of marine debris should be managed under existing legislation and policies, or whether they warrant separate attention.

Rising sea temperatures

Since the beginning of the 20th century, the average temperature of Australia's coastal waters has risen by 0.9 °C (BoM & CSIRO 2014). Rising sea temperatures are associated with shifts in species distributions, coral bleaching, increased risk of harmful algal blooms (see Algal blooms), and impacts on fishing and aquaculture (Welch et al. 2014). Increasing climatic variability, observable as extreme events such as marine heatwaves, may be as important as change in average temperature. Marine heatwaves are increasing in intensity, duration and frequency, with potentially dire consequences for organisms already stressed by higher average temperatures.

Sea temperature affects both growth and reproduction of marine organisms. Species can respond to rising temperatures in 3 main ways: by shifting in range, changing the timing of life history events or changing in physiology (Bellard et al. 2012). Rising sea temperatures are extending the range of populations southwards (Vergés et al. 2014), and gradually resulting in the tropicalisation of temperate ecosystems. Tropical fish are now commonly found in Sydney Harbour during late summer, and have even been found surviving winter (Figueira & Booth 2010).

In Western Australia, the impact of temperature change is most concerning in the mid-latitudes between Ningaloo and Jurien. The La Niña of 2011 resulted in a marine heatwave off the Western Australian coast, which led to widespread impacts, including the decimation of kelp forests (Wernberg et al. 2013). This event caused profound changes in marine ecosystems that have yet to be reversed, including coral bleaching, fish and invertebrate deaths, and changes to species distributions and community structure. South-western Australia has lower seasonal variability and evolutionary stability than tropical areas, making it more sensitive to change. Differences in the sensitivity of ecological communities to temperature change limit the potential to generalise assessments across the east and west coasts of Australia.

Box COA4 Tangaroa Blue Foundation and the Australian Marine Debris Database

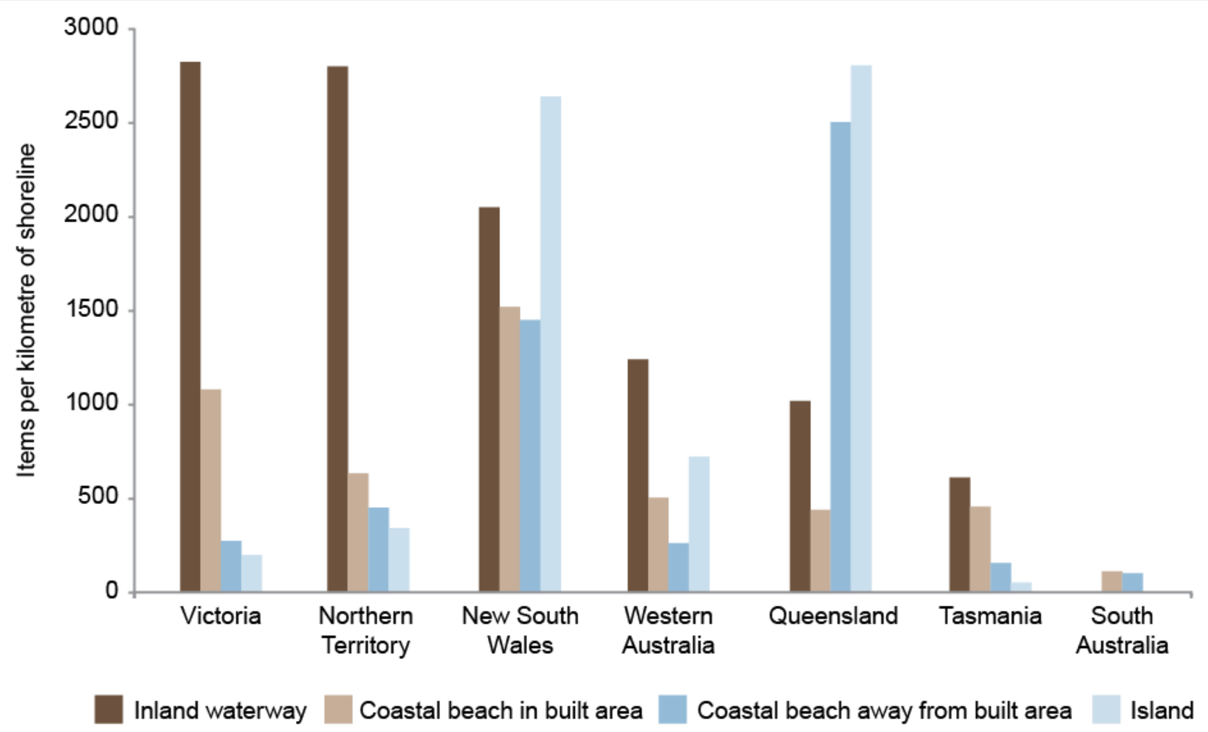
The Tangaroa Blue Foundation (TBF) has been involved in an expanding range of citizen-science marine debris activities since 2004. During the past 12 years, it has established the Australian Marine Debris Database to house beach and inland waterway clean-up data submitted by individuals, communities and organisations around Australia. The following discussion on the state of marine debris in Australia is based on TBF data and experiences.

Marine debris is found on every Australian coastline, and litter and waste with the potential of reaching the ocean are present in most, if not all, major estuaries and waterways (Ceccarelli 2009). Occasions when no debris is found on beaches are rare (currently 6 out of 6821 clean-ups). Most marine debris by count of item is plastic, and this material presents a range of sublethal and lethal threats to life in the marine environment (Browne et al. 2015, Rochman et al. 2015).

The estimated percentages for each of the broad sources of debris from coastal and estuarine systems are:

- plastic remnants that are mobile in marine environments—32 per cent
- land-sourced litter—32 per cent
- garbage washed ashore from shipping or distant places—23 per cent
- commercial fishing—7 per cent
- recreational fishing—3 per cent
- shipping—2 per cent.

The abundance of debris by type of location (inland waterway, coastal beach in built area, coastal beach away from built area, and island) varies across Australia (Figure COA8).



Notes:
1. The measure is the average count of items per 1000 metres of coastal or estuarine shoreline.
2. Data are missing for inland waterways and islands in South Australia.
Source: Tangaroa Blue Foundation data collected during 2004–15

Figure COA8 Abundance of shoreline litter and debris

Box COA4 (continued)

Inland waterways, including estuaries, rivers, creeks and drains, are spatially confined environments. Most of Australia's population is in their vicinity, and these environments are directly exposed to inputs of industrial waste, litter and, in many cases, abandoned aquaculture and fishing gear (Ceccarelli 2009).

Coastal beaches within built areas can be affected by litter and deposits from stormwater and sewage outlets, together with offshore inputs from shipping, fishing and debris conveyed by ocean currents (Browne et al. 2015). Away from built areas, most debris found on beaches appears to be from offshore sources, and local inputs are considerably smaller. These beaches are often dynamic, and debris may arrive and leave frequently. Queensland beaches away from built areas are exceptional in terms of overall abundance of debris. Queensland coasts, particularly in Cape York, receive high to very high levels of debris (TBF 2014). The South Equatorial Current and an inshore northwards migration of debris along the coast deliver this debris load into the far north Queensland coastal regions. Debris tends to remain on many of these beaches because of the relative protection offered by the Great Barrier Reef. Cyclone events, however, recirculate debris across wide areas. The remote nature of many Australian beaches makes clean-up efforts particularly challenging.

The percentage of marine debris items made in part or wholly from plastic is 72 per cent, based on state averages. The top-ranking item found on Australian shorelines is fragmenting hard plastic (28 per cent of all items), followed by plastic lids and caps, mainly from drink bottles (8 per cent); cigarette butts are the third most common item (8 per cent). These are all readily ingested by wildlife.

Indications from TBF data are that the average count of items per 1000 metres of shoreline for Australia is trending upwards, but work on describing trends is yet to be completed.

On a national scale, sea temperature is predicted to continue to rise, together with the frequency of marine heatwaves. In the short term, El Niño may reduce sea temperature increases for the south-west of Australia, whereas the south-east will experience higher mean temperatures (Oliver & Holbrook 2014), more extreme temperatures (Oliver et al. 2014), and larger and more persistent warm core eddies (Oliver et al. 2015). Such patterns were observed in 2016 and caused a mass coral bleaching event on the Great Barrier Reef (see the *Marine environment* report for details). The frequency and intensity of ENSO cycling may double. In the short term, species and habitats will continue to shift southwards and along estuaries. Rising sea temperatures may eventually contribute to the loss of species, assemblages and entire habitats, although some species are expected to benefit from warming conditions.

Separating anthropogenic temperature change from natural climate cycles such as the Interdecadal Pacific Oscillation and the Southern Oscillation is difficult, and adds uncertainty to future sea temperature projections. Better identification of thresholds at which organism level changes result in the loss of species is also important to understand how community structure will change with future sea temperature increases.

Flow regimes

Freshwater inflow delivers nutrients and sediments (see Sediment transport), maintains salinity regimes of rivers and estuaries, and feeds local groundwater sinks. Several habitats and species (e.g. shorebirds, fish, invertebrates) depend on freshwater flows and the functional processes that these flows perform. Fresh water is also a valued resource for human activities, required for irrigation, industry, drinking water and the environment.

Flow regimes are susceptible to impacts from climate change (Teng et al. 2012), population growth and coastal development. Structures that regulate flow (e.g. weirs and dams) have altered natural flow volumes; and flood frequency, duration and variability; and have contributed to the loss of biological diversity and ecological function in aquatic ecosystems (CSIRO 2011).

Flow regimes in the south and east of Australia are dramatically altered from their natural state, largely because of diverting of water for irrigation and regulation (CSIRO 2008). Ongoing low flow to the Murray River, particularly during the millennium drought (which occurred from 2000 to 2010—although in some areas it began as early as 1997 and ended as late as 2012; Chiew et al. 2014), is affecting the Lower Lakes and Coorong Ramsar wetland (MDFRC 2014), and has been the subject of intense political debate for many years. Of note is the associated degradation of a key migratory bird food resource, widgeonweed (*Ruppia* spp.), and the continuing hypersalinity of the South Lagoon in the Coorong (Paton & Bailey 2012).

The coastal freshwater lens aquifers on the Eyre Peninsula, where unconfined aquifers are hydraulically connected to the ocean, are also exploited to maximum capacity. It is unknown whether local ecosystems are dependent on this discharge and, if so, whether they are affected by groundwater extraction reducing discharge. Groundwater extraction may also cause seawater intrusion, and the contamination of aquifers used for irrigation and public use (see Seawater intrusion), although current monitoring shows no evidence of increased groundwater salinity in these locations.

Despite groundwater monitoring being difficult and expensive, South Australia has implemented a network of observation sites that have lowered the risk of significant reductions in coastal discharge. Implementing similar networks in other at-risk areas is important to minimise future changes to natural flow regimes across Australia. Alternatively, the purchase of environmental flows to return waterways to more natural flow regimes can improve conditions.

Long-term monitoring of streamflow and water quality at more locations is necessary to provide important baseline information to assess trends and to establish links between processes. More advanced modelling that integrates data on climate, hydrology, water quality and environmental impacts would increase the accuracy of future predictions.

Seawater intrusion

Groundwater is an important water source for sections of Australia's growing coastal population, but it is under pressure from seawater intrusion, which increases the salinity of freshwater aquifers. Key causes of seawater intrusion are unsustainable groundwater extraction, rising sea levels, variable precipitation regimes, coastal development and land-use change. Groundwater extraction increases with drying conditions (e.g. as has occurred in south-western Australia), population growth and industrialisation (Wada et al. 2010). Groundwater extraction pressure is strongest around large population centres, such as Perth and Adelaide.

Because of the difficulty and cost of monitoring, empirical data on groundwater extraction rates, volumes and salinity are often not available. Consequently, very little is known about the impacts of seawater intrusion beyond theoretical predictions of increased groundwater and soil salinity. The degree of research and knowledge among jurisdictions is linked to the relative economic value of groundwater. Groundwater reserves can support diverse and valuable ecosystems (Goonan et al. 2015) depending on land use (Korbel et al. 2013), but consideration of ecological impacts of seawater intrusion is usually secondary to human water needs.

In a national assessment of coastal aquifers with data to estimate vulnerability to seawater intrusion (i.e. hydrologic, hydrogeologic and physiographic data), 47 per cent had high vulnerability—a value predicted to increase to 57 per cent in the future (Ivkovic et al. 2012). There are signs of current or potential seawater intrusion in all states, except Tasmania, where data are lacking. New South Wales, Victoria and Tasmania are less dependent on groundwater than other states, and the risk of seawater intrusion is therefore of less concern. However, these states still have some potential hotspots (Ivkovic et al. 2012). In Queensland, Western Australia and South Australia, seawater intrusion risk is high and has been observed in several locations (Ivkovic et al. 2012). Extensive areas of low-lying coast in the Northern Territory are vulnerable to intrusion because of sea level rise and inundation (see Box COA5), although data are lacking in the Northern Territory to make adequate assessments.

Box COA5 Climate change and seawater intrusion in Kakadu National Park

Kakadu National Park is located 240 kilometres east of Darwin in Australia's tropical north. Kakadu is Australia's largest terrestrial national park and supports an immensely diverse biological community (DoEE 2016). The catchment of the South Alligator River extends from the coastal floodplains in the north of Kakadu National Park to the sandstone plateau in the south, covering 11,700 square kilometres. Located in the monsoonal zone of northern Australia, the area experiences the extremes of an annual wet and dry cycle. The distribution, extent and structure of coastal ecosystems in the area are regulated by the interplay between oceanographic (sea levels and tides) and riverine (surface water and groundwater) processes, as well as local soil, geomorphological and vegetation patterns. Consequently, the balance of fresh water and salt water in the South Alligator River exists in dynamic equilibrium between these processes.

Climate change is predicted to have serious impacts on the South Alligator River catchment. There will be significant changes in the number of days each year classified as either 'wet' or 'dry', and a significant alteration in the frequency, duration and extent of large floods (Léger et al. 2010). The likelihood of saltwater intrusions is greater because of increased tidal pressure in the lower catchment, and more frequent levee overtopping in response to sea level rise and larger storm surges (Léger et al. 2010).

Diversity of native species (including migratory and threatened) is likely to be affected by a decline in freshwater flora and fauna, which may also impact cultural values through a decrease in species of cultural significance (Léger et al. 2010). Further impacts on cultural values may include reduced access to Country (including sites of cultural significance) for Indigenous people, as well as reduced recreational opportunities for local people and tourists (Léger et al. 2010). The regional economy may also be affected by declining environmental condition. Tourism is a significant contributor to the regional economy, and a decline in Kakadu's environmental appeal could reduce numbers of visitors to the region (Léger et al. 2010).

Many aquifers around Australia are managed, but groundwater management tends to only use freshwater models and ignore seawater intrusion. In the short term, poor management is expected to continue unless decisions are informed by appropriate monitoring and research. The National Coastal Groundwater Management Knowledge Transfer Workshop 2013 identified a need for national guidelines, ongoing monitoring, increased research and the retention of information (Cook et al. 2014). In 2013, the Australian Government released guidelines for groundwater quality protection in Australia. In the longer term, climate change is expected to reduce regeneration rates of groundwater supplies, particularly in the south-west, while sea level rise should increase salinisation rates in low-lying regions. The permanent salinisation of groundwater resources may force the exploration and exploitation of new aquifers.

Water abstraction

Fresh water is removed (or 'abstracted') from waterways for many purposes, including irrigation, industrial applications and public use. In many cases, abstraction occurring upstream has profound ecological impacts in coastal regions downstream, including eutrophication, hypersalinity, algal blooms and reduced productivity in estuaries. Altering freshwater input to coastal waters can cause saline waters to move upstream into previously fresh areas, affecting biological diversity and productivity.

The degree of water abstraction is linked to development intensity, being greatest in the south-east and south-west of Australia. Cooperative efforts across some states (e.g. New South Wales, Victoria and Queensland) to better manage water abstraction and environmental flows may act to mitigate impacts, and to stabilise environmental impacts in the short term. Some rivers, such as in parts of northern Australia that are less developed, are not yet affected by water abstraction. Data on water abstraction are poor, particularly for small dams in farms, limiting the ability to make Australia-wide assessments.

Most rivers in New South Wales, Victoria and south-east Queensland, and some in south-west Western Australia, experience upstream abstraction, although it is generally low in the north of each state. No major dams have been recently built in New South Wales, Victoria or Queensland, although there have potentially been some recent increases in abstraction for irrigation or construction of small dams. The Murray River is the main river feeding the coast in South Australia and has experienced substantial abstraction; however, in the past 5 years, greater flooding and environmental flows have improved the condition in the lower Murray–Darling Basin. Although many Tasmanian rivers are dammed, water abstraction there is low; however, it has been increasing in recent years. Similarly, in the past 5 years, there has been a small increase in abstraction in the Northern Territory, where abstraction pressure has historically been low.

The outlook for water abstraction as a pressure is stable in the short term, barring small increases predicted in Tasmania. The long-term outlook is for increasing abstraction as development and the accompanying need for water increase in northern Australia. Demand for water will only increase in the future as coastal populations rise (Wolanski 2014), necessitating more infrastructure to remove water otherwise intended for downstream coastal ecosystems. A major option for reducing this pressure in line with global trends is the increasing use of recycled water, including for drinking water, as suggested by recent studies (Khan 2013).

Dredging

Dredging is the practice of removing and relocating sediment from the seabed, and is used to increase water depth for vessel movements, maintain flushing of estuaries, extract construction materials (e.g. sand for concrete or land reclamation) and supplement locations with a negative sediment budget. In Australia, nearshore dredging is most often associated with port maintenance and development, and clean dredged sediment is dumped to another area of seabed if not needed.

Dredging removes soft-sediment habitat and causes sediment resuspension, which increases turbidity. If sediments are contaminated, disturbing them by dredging can cause toxicants to be released into the water column (see Water quality [turbidity, physiochemical properties]), where they can cause ecological impacts (Knott et al. 2009) and become bioavailable and spread beyond the immediate dredging zone (Hedge et al. 2009). Taxa directly or indirectly affected by dredging include seagrasses, seaweeds, corals, fish, epifauna (animals living on the surface of the seabed or riverbed) and infauna (animals living within ocean or river sediment). Deposition of dredge spoil also requires careful management to avoid the creation of large plumes.

The *Environment Protection (Sea Dumping) Act 1981* regulates the disposal of waste in the marine environment, and works in conjunction with the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) on impacts of national environmental significance. In 2015, a new regulation under the Great Barrier Reef Marine Park Regulations 1983 came into effect, prohibiting the dumping of spoil from capital dredging (removal of large amounts of material for the passage of shipping) projects in the Great Barrier Reef Marine Park. This prohibition was broadened to encompass the Great Barrier Reef World Heritage Area (GBRWHA) by the Queensland *Sustainable Ports Development Act 2015*, which prohibits the construction of new ports or expansion of existing ports outside identified priority ports, and prevents disposal of capital dredge in the GBRWHA. This regulation does not cover the disposal of maintenance dredging material, which may be produced frequently and in substantial quantities (McCook et al. 2014).

Impacts of dredging are usually restricted to within a few kilometres of dredge and dumping sites, but range in severity from moderate to high. However, this depends on the size of the activity and specifics of the deposition location, and considerable uncertainty often surrounds likely impacts of proposed dredging (Fisher et al. 2015). Furthermore, dredging impacts need to be considered in the context of background suspended sediment and 'natural' sediment dynamics, such as those associated with storms and river run-off. The temporal window of impacts usually ranges from weeks to months, but longer-term issues of legacy, chronic and cumulative impacts arise if dredging is frequent or disposal sites are not suitable. Dumping of contaminated sediments is now banned, and contaminated sediments must be disposed of as toxic waste, which has dramatically reduced toxic impacts from dredging beyond the initial suspension of sediments.

Maintenance dredging in New South Wales is common, and, although potential impacts are considered as part of the development approval process, they are rarely quantified. Release of contaminants from resuspended sediments is possible where port expansions are occurring and bedded sediments include a substantial legacy of contaminants, as is the case for most existing ports (Knott et al. 2009). In Port Phillip Bay in Victoria, dredging has occurred in uncontaminated and contaminated sediments over short spatiotemporal scales, in some cases potentially releasing contaminants into the water column.

Capital dredging in tropical Australia in the past 5 years has largely been related to the resource boom and the accommodation of large vessels (Ports Australia 2014a). Much dredging activity has recently occurred in Queensland ports, with extensive environmental assessment required before permission is granted. In general, monitoring of impacts of Queensland dredging activities on corals and seagrasses has been adequate, although concerns remain about instances where best practice has not been implemented, and/or there are potential indirect impacts such as disease. Similarly, many large dredging projects have been undertaken in Western Australia, many of which received considerable monitoring and had tightly regulated impacts (Hanley 2011). Although the number of dredging proposals and approvals has increased in Queensland and Western Australia, so too has awareness of, and adherence to, environmental regulations.

Detailed information on dredging volumes, deposition sites and potential impacts is required before commencing dredging operations. However, in many cases, not all alternatives to dredging (e.g. longer jetties) are fully explored. Additionally, following approval, environmental impact monitoring is not always conducted, or is restricted to physicochemical data only. Consistent and interpretable up-to-date data on environmental impact and sediment dynamics collected at all stages of the dredging process would help facilitate decision-making, and ultimately reduce environmental impacts. Policies are needed to encourage learning, objective assessment of short-term and long-term spatial impacts, and the application of this information.

Assessing future impacts of dredging is a difficult task without specific information on areas where dredging is likely or planned in the future. The outlook for dredging in the short term is stable but potentially increasing, because most work is currently maintenance. However, this may change if climate-related coastal impacts require an increased dredging response, including more frequent beach nourishment from offshore sands. Maintenance dredging will always be required and is expected to increase with the predicted increases in shipping activity. Capital dredging will be needed for new ports, developing existing routes and accommodating larger vessels. Continued research into the impacts of dredging, and improved management and regulation should help reduce long-term effects, although increasing developments in relatively pristine regions, if poorly planned or managed, may have unacceptable detrimental effects.

Fishing

Australia has a long history of fishing, extending back to traditional practices of Indigenous communities. Some traditional fishing practices continue, and represent an important component of Indigenous culture (Feary 2015; see Box COA6). This report covers fishing practices specifically associated with the coast, such as shore-based line fishing, and fishing within bays and estuaries. Fishing is now one of Australia's most popular recreational activities and is argued to be a lucrative enterprise, with an estimated value nationwide of $1.85 billion in 2000–01 (Henry & Lyle 2003, Campbell & Murphy 2005), although contention remains around how to accurately calculate the economic value of this activity (Figure COA9; Table COA1). Fishing pressure is concentrated around population hotspots and centres of commercial operations, with remote coastal waters generally under lower fishing pressure.

Pressures from fishing can include:

- overharvesting (including for bait collection)
- associated impacts from off-road vehicles and foot-traffic disturbance of vegetation
- litter
- disruption of food webs
- alteration of species and genetic compositions
- habitat destruction
- entanglement with fishing gear.

The rugged coastline between Ceduna and Port Lincoln on the Eyre Peninsula, South Australia

Photo by Dragi Markovic, © Australian Government Department of the Environment and Energy, all rights reserved

The removal of top-order predators through overharvesting can have cascading effects on the structure of food webs, particularly through selective fishing of key species (Bascompte et al. 2005). Impacts of fishing depend on factors such as the method of capture, and residency and life history of the species. Public understanding of the consequences of fishing pressure in Australia is increasing as no-take marine park zones are established around the coast.

The amount of shore-based fishing or fishing from boats in estuaries is believed to be declining or stable in most states during the past 5 years, although it is difficult to quantify since it is often unmonitored. State and territory governments are responsible for managing recreational fishing in their jurisdictions, and some, such as the Victorian Government, are actively trying to increase recreational fishing. In Queensland, the Northern Territory, Tasmania and South Australia, recreational fishing pressure is high near boat ramps and accessible locations near population centres, but is much lower in remote areas (e.g. Gulf of Carpentaria, western Tasmania, west coast of South Australia).

Coastal commercial fishing is patchy, being concentrated near productive sites or near ports. The trend during the past 5 years varies between fisheries. Abalone fisheries are declining because of disease and legacy overfishing, whereas snapper catch (recreational and commercial) in Port Phillip Bay has increased during the past 20 years. The decline in some commercial fisheries is partly attributed to tightening regulatory controls, including restrictions on the number of entrants, total effort and/or total catch, and the activities and methods allowed. Commercial netting is planned to be phased out of Port Phillip Bay by 2022, and other areas may follow suit.

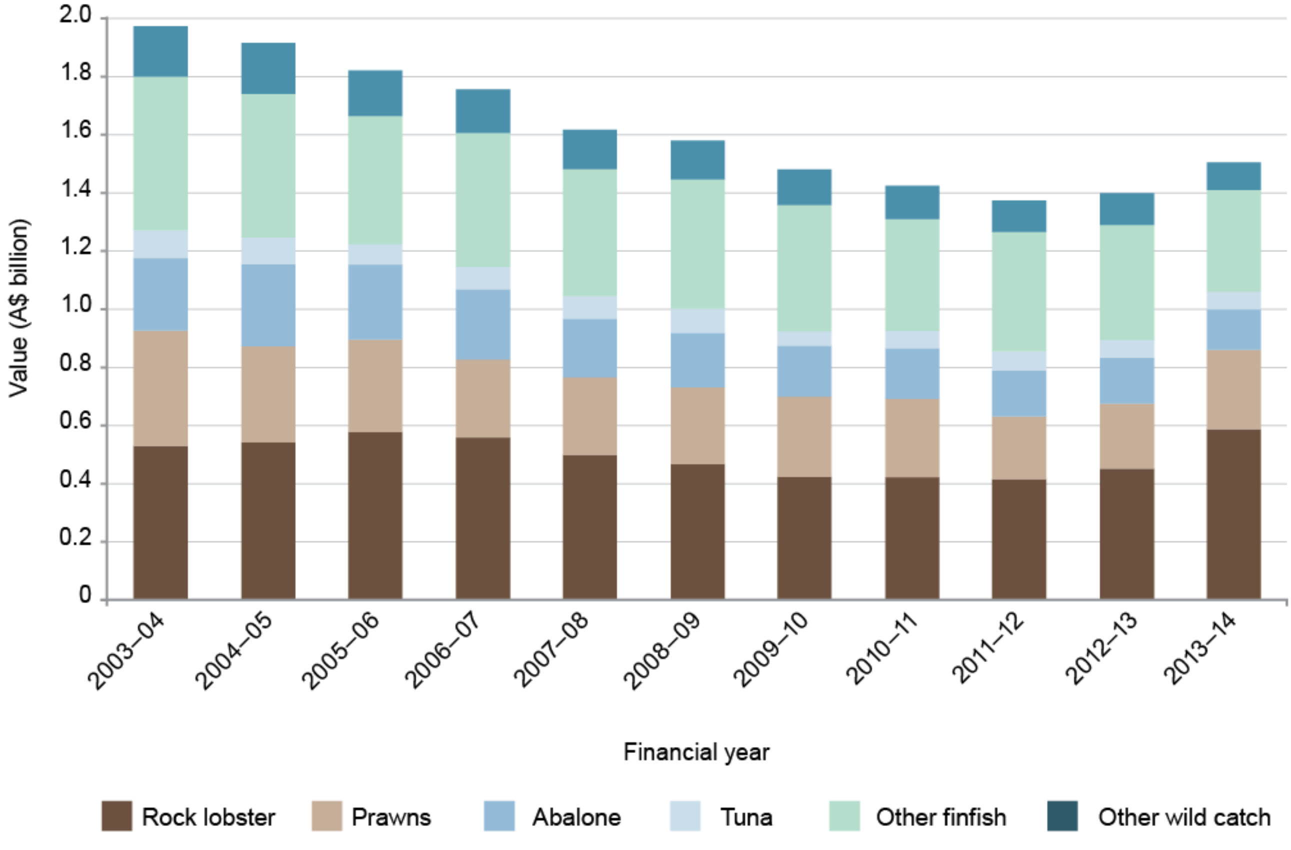
Interaction between recreational and commercial fisheries is an issue of concern, and both stakeholders have concerns about the activities of the other. This is partly because of limitations in recreational fishing data, because monitoring is scarce for certain types of fishing (e.g. shore based) and data quality varies between states. For example, no shore-based recreational licence is required in Western Australia or Tasmania, making it difficult to quantify the number of fishers. Monitoring is often dispersed and ad hoc, particularly in remote areas. Developments in aerial surveys may alleviate this data gap, as indicated by recent studies of recreational fishing in remote Western Australia (Smallwood & Beckley 2012).

In the short term, recreational fishing pressure may rise as coastal populations grow and new technologies for finding fish become widely available. Some such increases may be offset by improvements in stock sustainability, recovery programs, ecosystem management and public awareness. In the long term, uncertainties exist about the impacts of multiple pressures, such as climate change and technological progress, and there are increasingly divided views on what are acceptable impacts from fishing.

Table COA1 Participation statistics from the National Recreational and Indigenous Fishing Survey and statewide surveys, 2000, 2007, 2010 and 2012–13

Item	Units	Australia, 2000	Qld, 2000	Qld, 2010	SA, 2000	SA, 2007	Tas, 2000	Tas, 2012–13	NT, 2000	NT, 2010
Participation	’000	3,400	747	700	317	236	125	92	44	32
	%	19.5	23.0	17.0	23.4	16.1	29.4	22.0	31.6	22.3
Fishing days	’000	20,600	3,600	2,600	1,800	1,100	700	507	198	151
Average days	per fisher	6.1	5.4	4.0	5.9	4.5	6.4	5.5	5.0	4.9

Note: Participation and fishing days data for South Australia (SA), Tasmania (Tas) and Queensland (Qld) are only for residents of each state. Northern Territory (NT) data are for all residents surveyed in 2000, but 2010 data exclude Aboriginal and Torres Strait Islander people.
Sources: Savage & Hobsbawn (2009), Fisheries Research and Development Corporation



Note: Some species shown are not strictly coastal, but are displayed for comparison.
Source: Fisheries Research and Development Corporation

Figure COA9 Real value of Australian wild-catch production, 2003–04 to 2013–14

Box COA6 Blue Mud Bay decision

Blue Mud Bay is a remote, shallow bay in Arnhem Land, Northern Territory. The primary source of non-Indigenous visitation to the land is professional fishers harvesting mud crabs (*Scylla serrata*) and barramundi (*Lates calcarifer*) in the mangroves and river estuaries. These activities led the Djalkiripuyngu people and the regional Indigenous representative body, the Northern Land Council, to pursue a claim for sea territory through the courts (Barber 2010).

Under the *Aboriginal Land Rights (Northern Territory) Act 1976* (ALRA), Indigenous freehold land extends down to the low-water mark. In a historic majority decision on 30 July 2008, the High Court of Australia ruled on appeal in the Blue Mud Bay case that, in effect, the ALRA also applies to the column of water above the intertidal zone. In practice, this means that it is now illegal for the *Northern Territory Fisheries Act 1988* to allow licences to be issued for fishing in waters that fall within the boundaries of land covered by the ALRA. Both recreational and commercial fishers are now required to seek permission from traditional owners or the Land Council before entering Aboriginal-owned water.

The Blue Mud Bay decision has changed the local fisheries in a variety of ways. Local crab fishers who use small watercraft rely on access to land with roads and airstrips to transport their catch to Darwin for sale (Barber 2010). Barramundi fishers, on the other hand, use large self-sufficient boats that do not require land access. This means that crab fishers have reached formal agreements with the Djalkiripuyngu about royalty payments for access to their land, while barramundi fishers have resisted agreements since they can operate independently (Barber 2010). The Blue Mud Bay decision has shifted the economic access and management responsibility of traditional Aboriginal lands away from the Northern Territory Government, and to the Indigenous people.

Artificial reefs

Artificial reefs include materials of opportunity (scuttled ships, rubble piles), as well as designed underwater structures providing complex hard-surface habitat for fish and benthic invertebrates. Installing artificial reefs often aims to increase biomass of fish targeted by anglers, with the added potential to increase productivity of other fishes or trophic levels. Artificial reefs can also be deployed for recreational purposes such as diving or surfing, or for shoreline protection. Although artificial reefs often have high social value, the ecological benefit of localised increases in fish biomass is debated, and they can also cause localised impacts on nontarget communities (Bohnsack 1989, Koeck et al. 2014, Smith et al. 2015). Artificial reefs alter the sea floor, typically changing it from sand to hard substrate, but also cause shading and create a ‘halo’ effect of increased scouring, predation and organic matter deposition in an area of soft sediment that extends beyond the physical constraints of the reef (Dafforn et al. 2015). Note that this assessment differs from that of the *Marine environment* report, which focuses only on the effects of artificial reefs on fish.

Recent research has aimed to assess impacts of artificial reefs on various components of the ecosystem (Jebreen et al. 2003), but there is lack of agreement on what constitutes a positive or negative change (e.g. increased productivity) and the appropriate metrics to quantify these effects (Claisse et al. 2014; Smith et al. 2015, 2016). Many studies of artificial reefs are fish orientated, and the varied design, construction and monitoring of artificial reefs limit understanding of impacts (Ushiama et al. 2016). Artificial reefs can be exposed to considerable fishing pressure (Keller et al. 2016), but it is uncertain whether this leads to increased harvest rates.

In the short term, more reefs are planned for deployment, but it is unknown whether these will reach numbers that have more than localised impacts. It is possible that designed reefs on the open coast are not merely a fish attraction device, but facilitate a productive food chain from zooplankton to forage fish and reef invertebrates (Champion et al. 2015, Smith et al. 2016). In the long term, artificial reefs are set to become a more widespread feature of coastal waters as they become increasingly popular with key stakeholders, particularly recreational anglers.

Aquaculture

As of 2013–14, the aquaculture industry employed approximately 5000 people and had an estimated value of $994 million, an increase of $41 million since 2004 (Savage & Hobsbawn 2015). Tasmania and South Australia accounted for most of the aquaculture production (74 per cent) in 2013–14 (Savage & Hobsbawn 2015). Aquaculture production value and volume decreased from 2012–13 to 2013–14 (Savage & Hobsbawn 2015), although it is uncertain whether the cause was environmental or market related. The Australian aquaculture industry is currently small and relies on high-value products rather than bulk-production volumes.

Environmental impacts from aquaculture can be severe, but are usually local in extent. Large-scale impacts are rare, except where they result in the introduction and spread of disease or introduced species. Nutrient addition to coastal waters as part of finfish and prawn farming has high potential for environmental impacts and, accordingly, is highly regulated to minimise risk. For example, impacts below or adjacent to fish pens are managed by regular movement of the pens and feed control, so impacts of pens are usually contained. Pressures related to aquaculture vary between states; however, the impacts of feral Pacific oysters (*Crassostrea gigas*) are a significant concern for several states (Scanes et al. 2016).

In both New South Wales and Tasmania, the Pacific oyster industry has been severely affected by Pacific oyster mortality syndrome (POMS). Abalone is the main aquaculture product of Victoria, and both cultured and wild populations are affected by exotic disease and associated issues (Gorfine et al. 2008). In Queensland, all aquaculture is land based, with farmed prawns the major product. This is a relatively stable industry, but also vulnerable to disease and other environmental pressures. In Western Australia, pearl oysters are the major aquaculture sector, and are potentially susceptible to stress related to resource-extraction industries and climate change. The Northern Territory aquaculture industry is small and predominantly consists of land-based barramundi farming, although there are plans to develop and expand aquaculture in the north. In South Australia, tuna is ranched in coastal pens, creating some localised pressures on the coast. Tasmanian salmon farming in the D'Entrecasteaux Channel and Huon River has minor impacts on water quality (Ross & Macleod 2013). This industry is also challenged by rising water temperatures associated with climate change.

Research is needed into several topics, including patterns in, and causes of, mass mortality events, the dynamics of introduced diseases, interactions between these factors and environmental conditions, effects of aquaculture on ecosystems, and the effects of climate change on production and management. Harmful algal blooms threaten aquaculture operations and are discussed in more detail under Algal blooms. Another issue is appropriate biosecurity to deal with introduced species, and management of introduced species and disease transfer between aquaculture and wild populations. Addressing these questions should help inform best-practice management actions.

Rising demand for aquaculture indicates that environmental pressures resulting from the industry are likely to increase, with projections of stable growth in the short term accompanied by the development of new industries in seaweed production. In the long term, climate change will have a negative impact on many aquaculture species, particularly through ocean acidification, rising sea temperatures, altered precipitation regimes, inundation and extreme weather events.

Vessel activity and infrastructure

Vessels operate in Australia's coastal waters for a range of purposes, including recreational boating, commercial shipping, transport and cruise shipping. Onshore infrastructure, such as moorings, marinas, boat ramps, sheds and large-scale ports, are required to store vessels and support operations. The distribution of vessel activity and associated infrastructure is patchy along the Australian coast, but this activity imposes considerable environmental impacts in heavily used ports and harbours.

The intensity of commercial vessel activity has increased since 2011, with many ports being expanded or built to accommodate the increase. In 2013–14, the busiest port in terms of total throughput was Port Hedland (Western Australia), which moved 373 million tonnes, most of which was bulk commodity exports (Ports Australia 2014b). Darwin Port Corporation received the highest number of commercial vessel calls for the year, accommodating 3115 visits (Ports Australia 2014b).

Exceptions to commercial shipping growth are harbours where urban populations have pushed out trade (e.g. Sydney Harbour), or where activities are transitioning from industrial to recreational (Mayer-Pinto et al. 2015) There is a need for larger spatial-scale and temporal-scale assessments of vessel and infrastructure pressures using a consistent approach.

Recreational vessel pressure is related to both the number of vessels and the mechanism of storage. In Sydney Harbour, recreational boat density has increased at a rate of approximately 2 per cent per year, with additional moorings needed to secure boats when not in use. Almost 22,400 registered recreational vessels are expected for the harbour by 2021, which represents an increase of more than 5000 from a 2013 baseline (Transport for NSW 2013). Moorings affect the seabed because their attached chains scour the sediment, often disturbing seagrass and sediment infauna. Seagrass-friendly moorings (those without chains to disturb the seabed) have been installed at some locations, but still represent the minority of moorings in Australia.

Pressures related to vessel operations in coastal waters include propeller damage, wash, noise, debris, leaching of antifouling paints, oil spills, animal strikes, sediment resuspension, anchor drag, and vessels acting as vectors for the transport of introduced species. The activities of vessels are often less environmentally damaging than their associated infrastructure, although regular resuspension of sediments from engine activity can cause a localised chronic impact in shallow areas of high traffic (Knott et al. 2009). The environmental impacts of infrastructure and capital works to support vessels are discussed in Artificial structures and Dredging. Chronic impacts have received relatively limited research, and more studies are required to understand the potential for ports to disrupt connectivity and ecosystem functioning along coastlines.

In the short term, present pressures are likely to increase as vessel activity and port size continue to expand to accommodate increasing trade and vessel numbers. There are opportunities to develop and adopt better practice to reduce environmental impacts, and a few notable rehabilitation works have occurred on the mid-north coast of New South Wales and the Swan River of Western Australia. The long-term outlook depends on climate change and the economic situation for Australia, particularly the state of iron ore and coal industries (see Mining), and activities that increase agricultural trade resulting from the northern Australia development agenda (Australian Government 2015). Current management practices and procedures of ports need to be adapted to accommodate future consequences of climate change (Ng et al. 2013).

Invasive species (aquatic)

Estuarine and marine non-native species are typically introduced and spread through coastal waters by vessel movements (see Vessel activity and infrastructure) and, to a lesser extent, the aquarium trade and aquaculture (Minchin 2007, Savini et al. 2010). Once introduced, some non-native species successfully spread and increase in abundance, with potentially devastating consequences for native biodiversity. Not all non-native species become pests, but, when they do, they are classified as invasive.

Invasive species often occur in high proportions on artificial substrates (see Artificial structures) (Dafforn et al. 2012, Airoldi et al. 2015), and introduced diseases are one of the main pressures on the aquaculture industry (see Aquaculture). Although there are numerous historical and recent invaders to Australian coastal waters, only a restricted set of conspicuous invasive species are well studied, and very little is known about impacts. Rarely do studies of invasive species examine impacts on ecological processes or the cumulative impacts of co-occurring invasive species.

There have been relatively few new incursions of known invasive species recorded in New South Wales in the past 5 years, and a decline in both the range and abundance of the invasive marine alga *Caulerpa taxifolia*. European fan worm (*Sabella spallanzanii*) invaded Botany Bay in 2013; since that time, 10 individuals have been found and removed. The Barker Inlet and the Port River estuary of South Australia have rising abundances of invasive European shore crabs (*Carcinus maenas*). The colonial ascidian (*Didemnum perlucidum*) has extensively spread throughout Western Australia in the past 5 years and is assumed to have detrimental impacts on ecological processes (Muñoz & McDonald 2014). Tasmania has incurred substantial ecological impacts from a range of invasive species, including the northern Pacific starfish (*Asterias amurensis*) and Japanese kelp

Aerial view of the coastline of the Kimberley rangelands, Western Australia

Photo by Dragi Markovic,

(*Undaria pinnatifida*) (Valentine & Johnson 2003), although both of these established before 2011. In Victoria, monitoring and transport modelling have shown that *A. amurensis* larvae are being transported and spread out of Port Phillip Bay, expanding the invasive species' range along the south-east coast and even establishing in pristine or remote environments such as Tidal River (Hirst et al. 2013).

The technical background for invasive species risk management is strong in Australia, and is the basis for many national and state biosecurity and management frameworks. However, this work needs to be updated to account for shifting likelihoods and risk profiles across regions and environments. Many government agencies have plans to deal with potentially invasive species once they are detected, but there are little baseline data to determine if a species is non-native, and a robust, coordinated research and monitoring effort to detect invaders and determine their environmental impacts does not exist. Ballast water regulations have been in effect for some time, but, until recently, Australia lacked national biofouling regulations.

The *Biosecurity Act 2015* came into effect in June 2016 to replace the *Quarantine Act 1908*, with the intention to modernise national biosecurity and address some of these issues. Deficiency in data collection limits our ability to manage invaders, and perpetuates the assumptions that there are few new incursions and that many invaders do not cause environmental impacts. Scientific studies on invasive species should consider the unique Australian environmental context, and be reported in terms that are interpretable in a management context. Marine biosecurity is a large-scale and diverse Australian issue, but is centrally underfunded, and therefore requires effective communication and cooperation among researchers and agencies.

Pre-emptive management of invasive species involves:

- understanding, monitoring and regulating important vectors of introduction and spread
- limiting the suitability of early entry points for establishment (e.g. pollution and artificial structures)
- increasing the capacity to identify invasive species
- increasing ecosystem resilience by reducing other pressures.

The short-term outlook for invasive species in coastal waters is one of increasing rates of introduction, establishment opportunities and impacts. In the long term, increasing pressures from invasive species related to increased connectivity through vessel activity, climate change, pollution, reduced native resilience, and disturbances from coastal development and population growth may outweigh potential advances in mitigation.

Diseases, infestations and fish kills

In Australia, there are 49 reportable aquatic diseases (23 for finfish, 13 for molluscs, 11 for crustaceans, 2 for amphibians), 34 of which are exotic (DAWR 2015). Some of these have had significant impacts on native species, such as the chitrid fungus *Batrachochytrium dendrobatidis*, which affects frogs in coastal areas. To aid reporting of disease occurrences, the Australian Government Department of Agriculture and Water Resources has developed a field guide to identify aquatic diseases. New diseases occur intermittently, but many reported mass mortality events are of unknown cause and most evidence is anecdotal. In New South Wales between 1970 and 2010, 38 per cent of fish kills were unattributed. The primary cause of many fish kills may not be infectious disease, but rather environmental conditions, particularly hypoxia (extremely low oxygen; see Coastal low-oxygen dead zones).

In New South Wales, mitigation programs are broadly implemented and well regulated, although damaging epizootics and new diseases (e.g. POMS) continue to occur. Most other notifiable diseases appeared stable during the past 5 years in New South Wales. In Victoria, the last outbreak of abalone viral ganglioneuritis was in 2010, but it was detected in a commercial population in Tasmania in 2011. Tasmania experienced an outbreak of POMS (Gibson 2016) in 2016, and a recent major fish kill of undetermined cause was seen in the Scamander River. In Western Australia, several fish kills of undetermined cause occurred in 2015, and abalone in South Australia continue to be affected by disease.

The National Aquaculture Statement and AQUAPLAN outline the national objectives for managing aquatic animal health relevant to aquaculture, commercial fisheries, recreational fisheries, the ornamental fish industry, tourism and the environment. Reporting is conducted on fish kills and notifiable diseases at a national level and in all states; however, data are generally inaccessible, lack detail and are not collaborated on at a national level. This hinders detection of outbreak trends, as does confounding by changes in report efficiency, diagnostics and regulation. The most detailed information comes from the fisheries and aquaculture industries (see Aquaculture), and World Organisation for Animal Health reports. AQUAVETPLAN, Australia's Aquatic Veterinary Emergency Plan, outlines emergency response procedures for disease threats to Australia.

Introduction of diseases is an ongoing issue, with introductions potentially increasing in frequency. Climate change and the general decline in environmental conditions may amplify problems of disease, infestation and fish kills.

Algal blooms

Many algal blooms, which include blooms of phytoplankton, epiphytic algae and macroalgae, are beneficial natural events that provide food for invertebrates and fish. Harmful algal blooms, on the other hand, can have significant impacts on the environment, tourism, aquaculture and human health. They can de-oxygenate the water, affecting other organisms (e.g. seagrass and their associated communities) and reducing water quality. Toxins produced by the algae can bioaccumulate through the food web and be problematic for fisheries and aquaculture. Distinctive algal blooms, such as 'red tides', can close popular recreational areas (e.g. Bondi Beach) for extended periods of time. Harmful algal blooms have long been noted in Australian coastal waters. Early records include the toxigenic cyanobacterium *Nodularia spumigena* bloom in Lake Alexandrina in South Australia that killed cattle (Francis 1878), and the *Scrippsiella trochoidea* bloom in Sydney Harbour that caused oxygen depletion (Whitelegge 1891).

A primary driver of algal blooms in freshwater systems is poor water quality, such as occurs during drought and reduced flow, and increased organic enrichment as a result of upstream development and agriculture. Some bloom trends may be related to warmer waters associated with climate change (O'Neil et al. 2012), others to human transport via ships' ballast water (Smayda 2007), but few can be definitively attributed to urbanisation. Many coastal algal blooms are more driven by water column stratification than by nutrients. Determining trends for harmful algal bloom frequency is confounded by an increase in reporting that has occurred with the growth of aquaculture.

Monitoring for blooms is handled by the states and territories, and effort varies around Australia, with phytoplankton data collection generally concentrated around large cities. Currently, there is no national-level synthesis of information on estuarine algal blooms, although an Australian phytoplankton database has recently been established (Davies et al. 2016). Collaboration between state and territory agencies needs to be improved, and data need to be made more easily accessible.

The general consensus is that freshwater environments globally are experiencing increased blooms of toxic cyanobacteria, but, apart from certain regional events, there is no clear evidence of an Australia-wide increase in blooms in major estuaries. New South Wales, South Australia and Tasmania have reasonably good microalgae monitoring, from which has emerged a trend of increasingly common algal blooms. The red-tide (nontoxic) dinoflagellate *Noctiluca scintillans* has expanded its range from the early 2000s from New South Wales to South Australia, Tasmania, Western Australia and Queensland (McLeod et al. 2012). Blooms of the dinoflagellate *Alexandrium tamarense* in Tasmania in 2015–16 were the largest (200 kilometres in diameter) and most toxic on record. These microalgae produce a paralytic shellfish toxin that closed the shellfish industry on the east coast of Tasmania for periods of weeks to months (see Diseases, infestations and fish kills). Changes in blooms in Tasmania are putatively linked to climate, whereas there is some evidence of changes in the seasonal bloom period in Sydney coastal waters. Monitoring is currently inadequate in the Northern Territory, Victoria, Western Australia, Queensland and remote areas of South Australia. In 2014–15 in Queensland, a ciguatera fish poisoning event was related to *Gambierdiscus* abundance. In Western Australia, deterioration of the Swan River is primarily because of reduced rainfall, which may increase the risk of algal blooms.

Sampling is usually not frequent enough to allow rapid response to blooms or to detect all outbreaks. Information is limited to a set of well-known species, and Australia is rapidly losing taxonomic expertise. A pressing issue is determining which bloom-forming species are in Australia and the conditions under which blooms of a particular species produce toxins that are harmful to aquaculture, fishing, humans, wildlife or stock (Hallegraeff 2015).

In the short term, algal blooms are expected to remain stable or worsen, depending on the decline of water quality from eutrophication and drought. Algal blooms may spread into new areas and raise immediate concern, although this should be short lived unless blooms recur. Increased water flows, whether naturally or through regulated environmental flows, should help to improve water quality and hence decrease the occurrence of algal blooms. The long-term outlook for algal blooms depends on the management of catchment (in particular, agriculture), freshwater and estuarine conditions, and climate variability (i.e. drought periods).

Jellyfish blooms

Jellyfish are an integral component of healthy marine ecosystems and provide important ecosystem services. However, jellyfish blooms also have the potential to interfere with industry and recreational use of the coast (Purcell et al. 2007) by stinging humans, clogging intake valves (e.g. for mining and desalination plants), and disrupting fishing and aquaculture activities. Almost no data have been collected on jellyfish populations or their distributions to allow confident assessments on their current state, or to detect trends from background natural population cycles operating on 10–20-year scales.

Anthropogenic modification of coastal waterways can facilitate jellyfish blooms in several ways. Artificial structures may increase recruitment of early life stages of jellyfish (Duarte et al. 2012), and overfishing may release top-down pressure on jellyfish (Purcell & Arai 2001). Eutrophication may facilitate blooms, since increased availability of food increases reproduction rates of plankton, and this may benefit jellyfish (Stibor & Tokle 2003). Rising temperatures may also favour jellyfish by increasing fecundity and reducing time until strobilation (reproduction).

In Victoria, 20 years of monitoring suggests stable blue blubber (*Catostylus mosaicus*) abundance in Port Phillip Bay, with indications of a natural population cycle during this period. Similarly, in Moreton Bay in Queensland, monitoring indicates approximately 5–7-year population cycles of blue blubber. Limited sting data indicate a southwards range expansion of Irukandji jellyfish in Queensland and Western Australia, although sting data are not a reliable proxy for jellyfish abundance since they are confounded by the number of tourists and swimmers. In New South Wales, South Australia, Western Australia, Tasmania and the Northern Territory, there are no long-term quantitative data about jellyfish population changes.

Predictions of blooms require further research on jellyfish lifecycles and population drivers (both natural and anthropogenic), and monitoring on a timescale of several decades would be necessary to infer trends over and above natural cycles.

Coastal low-oxygen dead zones

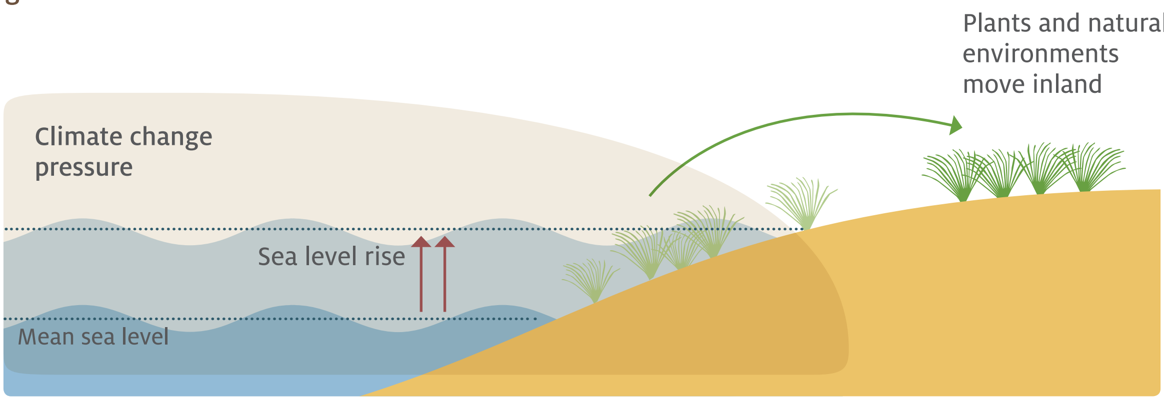
Low-oxygen dead zones, also known as hypoxic events, are caused by oxygen depletion during eutrophication (Diaz & Rosenberg 2008). This occurs when excess nutrients enter coastal areas (e.g. during flood events) and cause algae to flourish to unnatural levels (see Nutrient pollution). When these algae die and are decomposed by microorganisms, oxygen is depleted to the extent that most other animals cannot survive (Breitburg et al. 2009). Coastal hypoxic events in Australia are currently restricted to estuaries (particularly salt-wedge estuaries), and are spatially and temporally variable. They are much less common in Australia than in other parts of the world, such as Europe. The major difficulty in managing coastal low-oxygen dead zones is understanding their cause, then addressing what are usually large-scale and intractable drivers.

In New South Wales, coastal dead zones do occur but are short-lived events. They tend to follow flooding of acid sulfate soils in drained agricultural or pastoral lands. Hypoxic events may result in total deoxygenation of tens of kilometres of river and subsequent fish deaths, as has occurred in both the Richmond and Hunter rivers. Less frequent are nonlethal deoxygenation events in intermittent lagoons, following freshwater stratification.

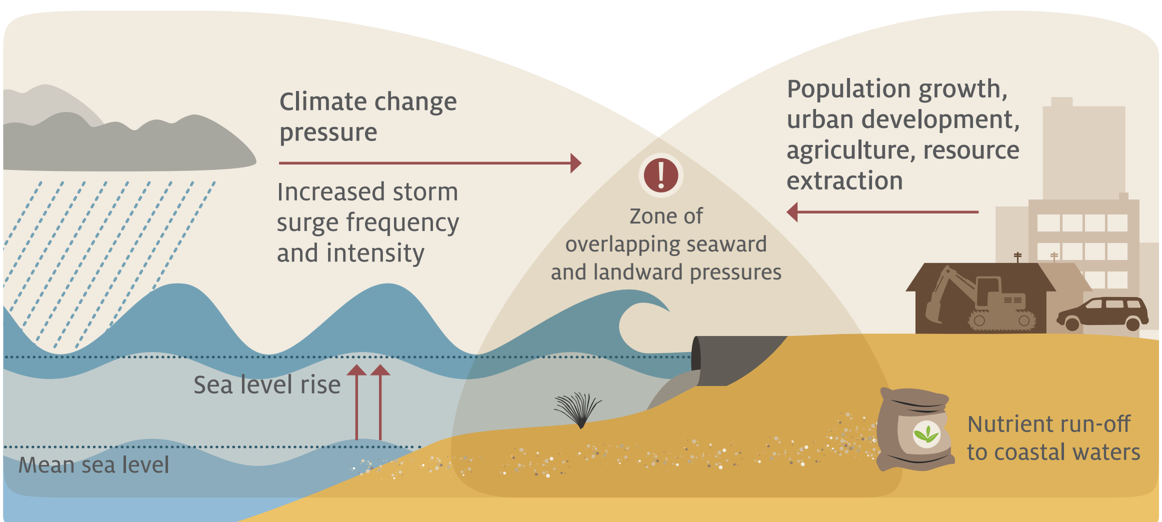
In 2010, the Swan–Canning Estuary in Western Australia experienced hypoxia after an extreme storm and heavy run-off, causing impacts on macroinvertebrate assemblages that persisted until hypoxia had eased (Tweedley et al. 2015). This event highlights the vulnerability of estuaries with small tides and long residence times, and there is a continuing trend of deoxygenation in intermittent lagoons in the south-west. Victoria has annual (natural) deoxygenation in intermittent estuaries in summer, and some areas in the Derwent Estuary of Tasmania suffer from hypoxia.

Sea level rise and urban development are squeezing coastal environments

Rising sea levels cause coastal environments to move inland.



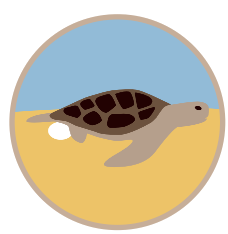
Where there is human activity and development close to the coast, coastal habitats are 'squeezed' between seaward and landward pressures.



This has negative impacts for our coastal environments:

Decrease in water quality

Loss of biodiversity (e.g. mangroves and saltmarsh)



Loss of habitat (e.g. nesting sites for turtles or migratory birds)

Assessment summary 1
Pressures affecting the coastal environment

Component	Summary	Assessment grade				Confidence		Comparability
		Very high impact	High impact	Low impact	Very low impact	In grade	In trend	To 2011 assessment
Tourism and recreation	Growing pressure with increased tourist numbers and easier access to remote locations							
Oil, gas and mining impacts	Pressures are severe but localised, and have increased with the mining boom. A large proportion of coastal pressures arise through transport activities and infrastructure (e.g. ports and shipping) rather than extraction operations							
Climate and weather	Increased frequency of severe weather events, including strong tropical cyclones, heatwaves, droughts and floods							
Sea level change	Sea level is rising around Australia, but is variable between years. Expected to become an increasingly significant pressure in the future							
Erosion and inundation regime	Erosion has been most acute during extreme weather events accompanied by sustained periods of high wave action and storms, and has caused significant damage to coastal properties. Inundation is of most concern around estuaries with low-lying properties							
Sediment transport	Changes in sediment transport are site specific, and often driven by catchment modification or weather events. Closely related to nutrient inputs and occurring for a large proportion of coastal catchments							
Desalination	A growing number of desalination plants is increasing pressure near major coastal cities, but the scale of impact is small							

Assessment summary 1 (continued)

Component	Summary	Assessment grade (Very high impact / High impact / Low impact / Very low impact)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Coastal river and estuary pollution	Large variation around Australia, with waterways near urban centres most affected. Sediments in parts of some urbanised and industrialised harbours are among the most polluted in the world				
Nutrient pollution	Improving where management has addressed excessive inputs from agriculture, sewage and storm water. Deteriorating elsewhere				
Toxins, pesticides and herbicides	Point-source toxin inputs have decreased, but diffuse sources are mixed depending on management approach. Significant efforts aim to reduce diffuse sources in the Great Barrier Reef catchment				
Water turbidity, transparency and colour	In poor condition near or downstream of population, industrial or agricultural centres. Urbanisation and agriculture are the major drivers of poor water quality				
Marine debris	Increasing pressure originating from population centres, but spread to remote locations by wind and currents. Recent survey found three-quarters of debris to be plastic				
Flow regimes	Spatially variable but of most concern in the south and east. Reduced freshwater flow is associated with drought, upstream modification and coastal development				
Water abstraction	Historically a critical pressure in the south, but management is improving in most jurisdictions. May become an issue in the north-west if planned developments occur				

Assessment summary 1 (continued)

Component	Summary	Assessment grade: Very high impact	Assessment grade: High impact	Assessment grade: Low impact	Assessment grade: Very low impact	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Seawater intrusion	Groundwater in some areas is under stress from urban, agricultural and industrial needs, leading to seawater intrusion		↙			◔	◒	
Dredging	Impacts can be severe depending on the frequency and magnitude of dredging, but are generally small in spatial scale			↙		◕	◕	
Fishing	Recreational and commercial fishing pressure is widespread, but is considered stable or decreasing in most jurisdictions. Changes observed following the establishment of 'no-take' zones indicate this pressure modifies ecosystem structure		—			◕	◒	
Artificial reefs	Increasing in number in bays and estuaries. Carry perceived ecological benefits (e.g. fish production), but also affect nontarget ecosystem components (e.g. soft-sediment infauna). Spatial scale of impact is currently very limited			↙		●	●	
Aquaculture	Increasing pressure as industry grows, but most impacts are small in spatial scale			—		◕	◕	
Vessel activity and infrastructure	Increasing pressure with increasing trade and port development, particularly in Queensland and Western Australia		↙			◕	◕	
Invasive species (aquatic)	Ongoing pressure on the aquaculture industry, and a stochastic threat to estuarine and bay ecosystems. Lack of nationally coordinated monitoring		↙			◒	◔	
Diseases, infestations and fish kills	Intermittent pressure, but causes are often unclear		↙			◒	◒	

Assessment summary 1 (continued)

Component	Summary	Assessment grade: Very high impact	Assessment grade: High impact	Assessment grade: Low impact	Assessment grade: Very low impact	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Algal blooms	Severe impacts when blooms occur. No clear evidence of an Australia-wide increase in blooms in major estuaries							
Jellyfish blooms	No evidence of departure from natural cycles, and limited indications of range expansions with strengthening poleward currents							
Low-oxygen dead zones	Potentially increasing in frequency with water quality concerns, but exact cause rarely identified. Spatially and temporally restricted							

Recent trends

- Improving
- Deteriorating
- Stable
- Unclear

Grades

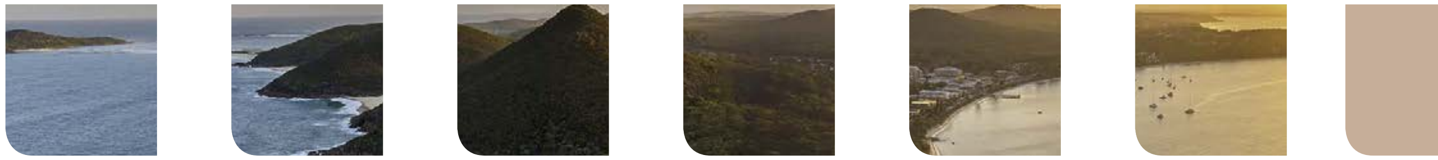
- **Very low impact:** Imposes negligible pressure on the state of habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes
- **Low impact:** Imposes weak pressure on the state of habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes
- **High impact:** Imposes moderate pressure on the state of habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes
- **Very high impact:** Imposes strong pressure on the state of habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes

Confidence

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

Comparability

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



State and trends

of the coastal environment

At a glance

The state and trends of the living (biotic) and nonliving (abiotic) environment in the coastal zone are the result of both historical and contemporary pressures, and our attempts to ameliorate these pressures. The state of most coastal biological components is in decline, particularly habitats and species that overlap with coastal land use. Much of Australia's native coastal vegetation has been lost to clearing, soil quality has diminished, and island flora and fauna suffer from invasive species. The dynamic land–water interface of sizeable stretches of coastline has been altered from a natural state by development, resource extraction, invasive species and recreational use. Several estuaries and bays around the nation are centres of urban, industrial and agricultural activity, and the pressures from such intense development often reduce water quality, and change the fish and invertebrate communities that use these critical coastal features.

The distribution of threatened species around the nation is generally related to the distribution of the human population and the intensity of our activities. The species group of most concern is migratory shorebirds, which are declining because of habitat loss and impacts on critical parts of their migratory route in Australia and overseas. This is occurring despite protection in Australia, and looks to continue unless multilateral management can be achieved. Saltmarshes are also in a poor state. Their extent around urban centres is a fraction of their pre-European settlement state, and they are now subject to further clearing and drainage, and the encroachment of mangroves. Saltwater crocodiles are doing well because they are protected from harvesting, and their predominantly northern distribution spares them from the bulk of pressures associated with coastal development. Vital ecological processes are in a poor state nationally as a result of multiple pressures on coastal ecosystems.

Coastal heritage requires greater documentation, particularly in relation to Indigenous heritage, which is currently under-represented. There have been recent advances in this field, including recognition in the *Great Barrier Reef outlook report 2014*, and incorporation of threat and risk assessment into the *Marine Estate Management Act 2014* of New South Wales, but further progress is needed.

Coastal land

Native vegetation and habitat

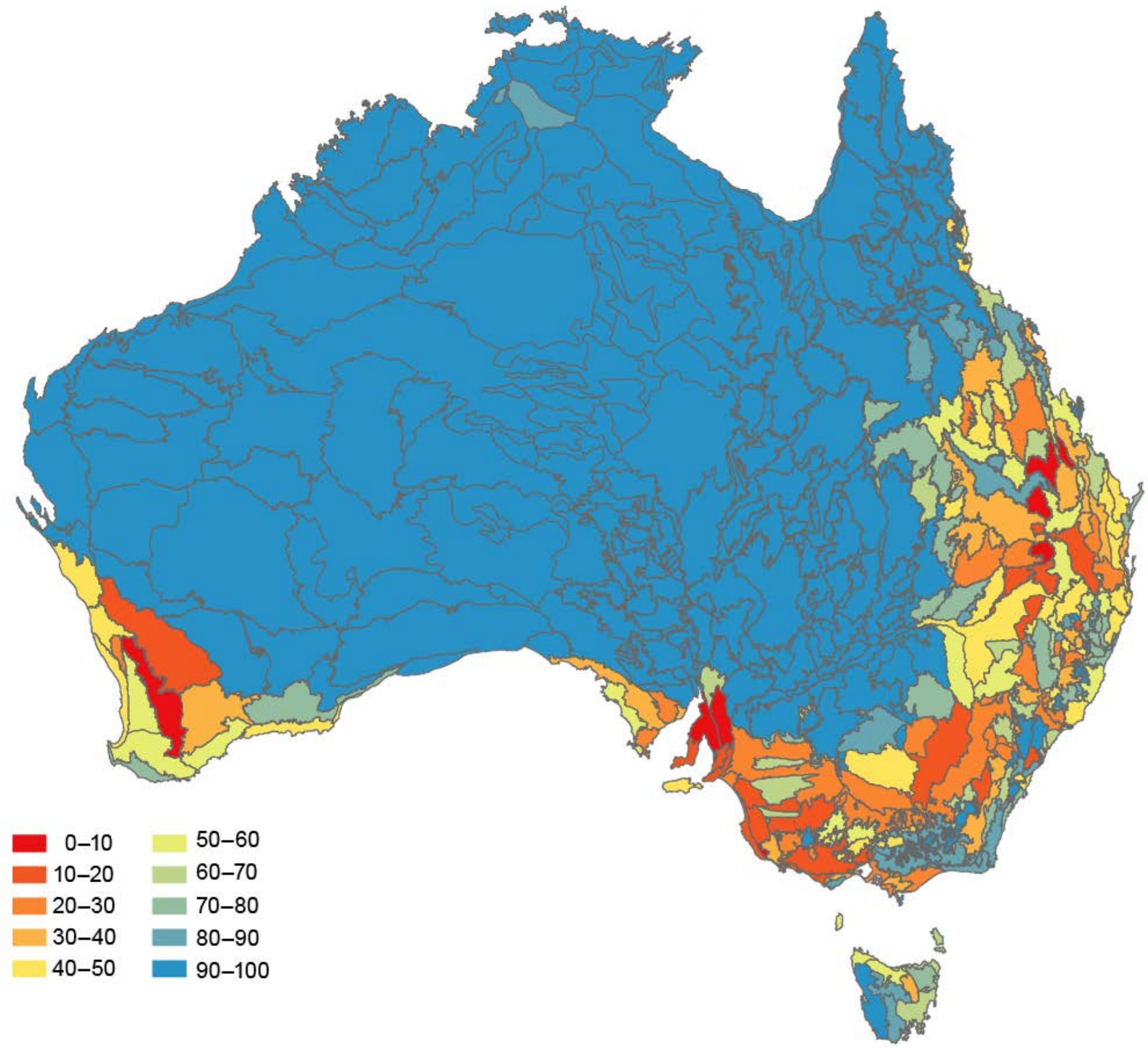
Australia's native vegetation and habitats have been severely affected since European colonisation. Almost 40 per cent of forest (Bradshaw 2012) and more than 90 per cent of grasslands have been lost or heavily degraded. Dunes, which support many plant species, have been transformed or decimated as a result of coastal development and weeds (see Beaches and sand dunes), and foreshores are increasingly modified for human use.

Most of the loss of native vegetation has occurred near the coast, in areas of urban and agricultural land use (Figure COA10). The south-eastern and south-western coastal regions are the worst affected, with less than 25 per cent of native vegetation remaining in many coastal subregions. In contrast, native vegetation on the north and north-west coasts are mostly intact.

The state and trend of major vegetation groups can be viewed by considering what percentage remains versus the previous total extent. Of most concern are vegetation groups that have both low percentage remaining and low total extent, as these are both rare and heavily degraded. The vegetation group with the lowest percentage remaining is the Mallee Open Woodlands and Sparse Mallee Shrublands, which is also small in spatial extent. The percentage remaining has been stable for most groups from 2010 to 2014 (Figure COA11), but 2 that have showed decline are Casuarina Forests and Woodlands, and inland aquatic (freshwater, salt lakes, lagoons) vegetation. Troublingly, the 3 above-mentioned groups are also relatively low in extent.

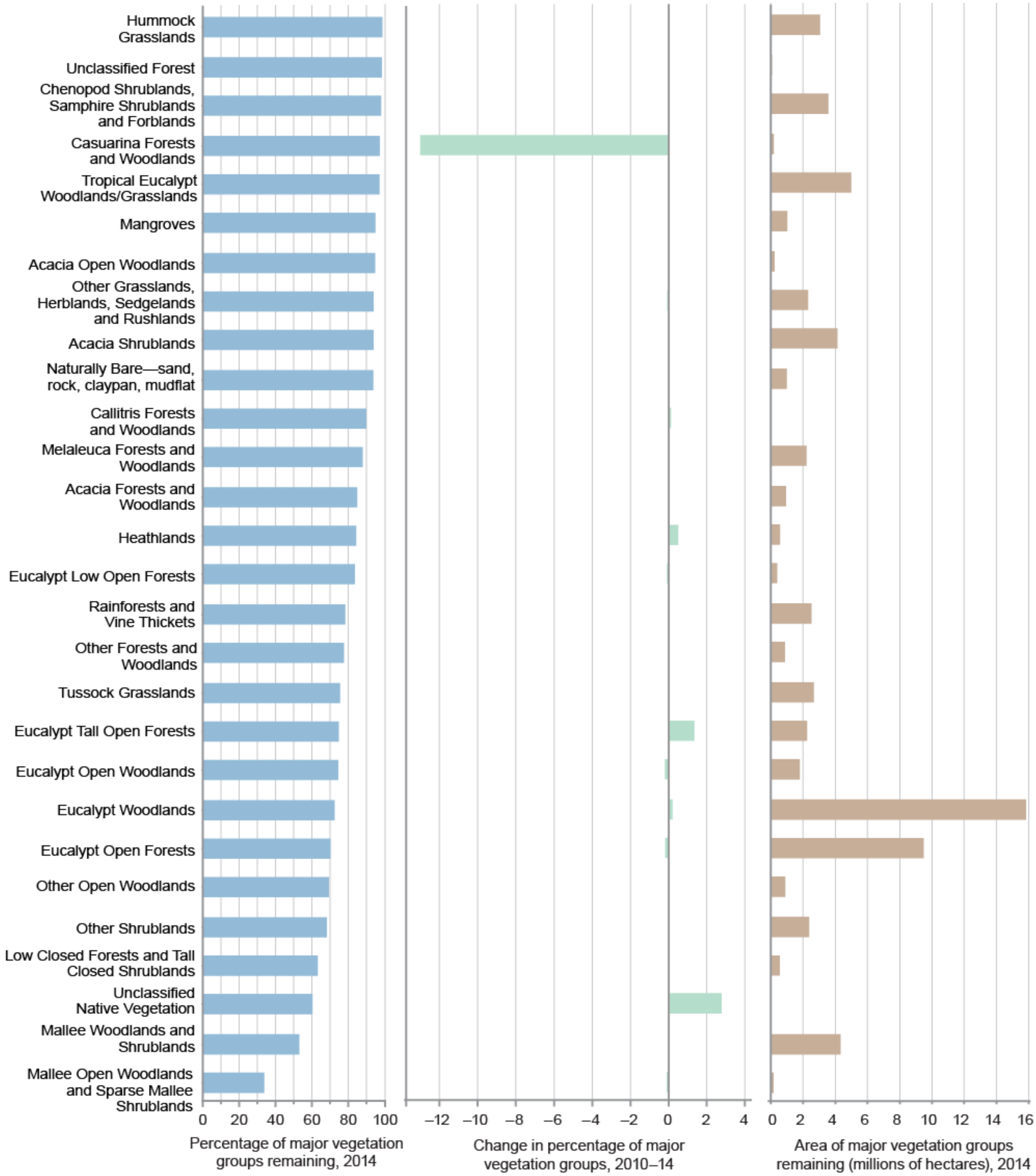
Remote-sensing techniques provide an effective method of surveying vegetation and habitat at a national scale. AusCover, the remote-sensing data facility of the Terrestrial Ecosystem Research Network (TERN), holds a rich repository of various nationwide remotely sensed vegetation data, including the recently released National Biomass Library. Another remote-sensing product that was recently launched is the Data Cube—a collection of Landsat images from the past 30 years that have been processed and curated by Geoscience Australia and CSIRO. These and other products can be used to conduct new analyses of historical change in Australia's vegetation cover, such as investigating relationships between vegetation change and population growth.

See the *Land* and *Biodiversity* reports for more detail on trends in vegetation cover.



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

Figure COA10 Percentage of remaining native vegetation in each subregion of the Interim Biogeographic Regionalisation for Australia



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

Figure COA11 Percentage remaining and change in percentage remaining of each major vegetation group, 2010 to 2014

Soil quality

Soil is a critical resource for water, carbon, energy and nutrient cycling. It provides fundamental support for nearly all coastal land ecosystems, and is a complex ecosystem in itself. Soil quality is determined by a combination of physical, chemical and biological properties. There are several ways to measure soil quality; commonly used indicators include sheet erosion, wind erosion, gully erosion, pH (acidity), organic carbon concentration, structure, salinity and acid sulfate oxidation status (Chapman et al. 2011). Soil quality is important for the microbial communities responsible for nutrient cycling (see Microbial processes and nutrient cycling). The natural quality of Australian soils is generally low because they are deficient in phosphorus, a vital nutrient for vegetation.

The recently developed Soil and Landscape Grid of Australia now provides a nationally consistent soil and landscape database. Development of the grid began in 2011, led by the Terrestrial Ecosystem Research Network in collaboration with researchers from CSIRO; the University of Sydney; Geoscience Australia; and Australian, state and territory government agencies. It combines historical data with new data generated from sampling, laboratory sensing, modelling and remote sensing, and provides access to the best available information about Australian soils and landscapes. Data for at least 11 soil attributes and 8 landscape attributes are available at 90 metre × 90 metre resolution (approximately 2 billion pixels in total), and each pixel also contains estimates of uncertainty. The grid is being used for a wide range of applications, providing information to urban and regional planners, land managers, farming groups, scientists and engineers.

One of the major soil issues for the Australian coast is acid sulfate soils. These occur when soils containing iron sulfide minerals are disturbed and exposed to air, creating sulfuric acid that can leach into waterways and decrease pH (Fitzpatrick et al. 2010). Acid sulfate soils are a natural phenomenon, but are exacerbated by human disturbances such as drainage of floodplains and wetlands. Some efforts have been made to remediate areas affected by acid sulfate soils, such as in the East Trinity Reserve near Cairns, Queensland, and vegetation communities here are responding to large-scale mitigation works (Newton et al. 2014).

Hazard maps are required to provide information on the spatial distribution of acid sulfate soils (e.g. Naylor 1995), although little new information has been collected during the past 5 years and at the field or farm level.

In coastal–estuarine landscapes that are inherently rich in sulfidic sediments and saline watertables, natural resource management data need to be collected to describe the heterogeneous nature of the soil, the underlying regolith and interactions with groundwater. This is because these areas are used for agriculture but, increasingly, also for urbanisation. Geophysical methods, such as electromagnetic induction, are being used to value-add to the limited soil data because they are a cost-effective way of mapping the areal distribution of soil salinity and soil acidity (Huang et al. 2014). Increasingly, they are also being used to generate electromagnetic conductivity images (EMCI) of the soil continuum in 2D (Goff et al. 2014). More detailed work using 3D and 4D EMCI, akin to magnetic resonance imaging (MRI) scanning in health care, has also been shown to be able to measure and map beach face salinity (Davies et al. 2015).

See the *Land* report for more detailed information on soil.

Islands

Australia has 8222 islands, and these represent a significant proportion of Australia's coast. These islands have a combined coastline of approximately 24,000 kilometres, which equates to approximately 40 per cent of Australia's coastline (depending on how the coast is measured) (Geoscience Australia n.d.). Australia also boasts the largest sand island in the world—Fraser Island.

Several islands are biodiversity hotspots, and many support endemic species not found on the mainland. Some are home to critical populations of threatened flora and fauna, such as the land lobster (*Dryococelus australis*), which exclusively occurs on Balls Pyramid—a striking volcanic stack in the Lord Howe Island Marine Park. Many islands contain turtle nesting beaches, and some are important breeding grounds for seabirds, including threatened species of albatross and giant petrel (see Nursing, roosting and nesting). These species have been the subject of recovery plans since 2001, the most recent being the *National recovery plan for threatened albatrosses and giant petrels 2011–16*.

The Cape Du Couedic Lighthouse towering over coastal undergrowth, Kangaroo Island, South Australia
Photo by Georgia Curry,

Threats to Australian islands warrant unique consideration, distinct from the mainland coast. Many islands are relatively unmodified because of their isolation, but others suffer from high rates of tourism and/or support permanent human settlement. Lighthouses are a common form of development on islands, and the maintenance of these can have ongoing impacts. Some larger and more developed islands support agricultural and timber industries. Historically, islands have been used by Indigenous communities and are of high cultural significance.

For islands exposed to human visitation or settlement, the biggest threat to native flora and fauna is often invasive species (Priddel & Wheeler 2014). Macquarie Island is a prime example, with a turbulent history of biological invasion by rodents, rabbits and cats (see Box COA2). However, islands are also the most likely candidates for successful pest-eradication programs and can become refuges for wildlife threatened on the mainland. In the future, a major concern for islands is sea level rise, particularly for low-elevation islands, which will be catastrophically affected by even minor increases in sea level.

Much of the shallow water surrounding tropical islands supports diverse coral communities, including the approximately 1050 islands of the Great Barrier Reef (GBRMPA 2014). Great Barrier Reef islands are vital nesting grounds for turtles and seabirds (Congdon 2008), but are threatened by cyclones, invasive species, marine debris, coastal development and climate change (GBRMPA 2014). One Australian island on the Great Barrier Reef (Bramble Cay) is the first location to record a mammal extinction caused by climate change (the Bramble Cay melomys—*Melomys rubicola*; Gynther et al. 2016; see the *Biodiversity* report), and the Christmas Island forest skink (*Emoia nativitatis*) became extinct in 2014 when the last captive individual died (see the *Biodiversity* report).

Land–water interface

Beaches and sand dunes

Like many features at the interface of the land and water, beaches are dynamic environments and vary widely in morphology, wave climates, tidal regimes, sedimentology and degree of modification. Australia has 10,685 beaches (Short 2006), which Australian culture values highly for their aesthetic qualities and recreational amenity. However, dune systems behind beaches are generally undervalued by society, despite their close link to beach systems. Dunes support important tracts of native vegetation and provide a buffer against beach erosion, and their fresh watertables act as buffers to saltwater intrusion.

A large proportion of Australia's beaches are relatively pristine, but others are exposed to pressures ranging in scale from local (e.g. erosion) to global (e.g. sea level rise) (Defeo et al. 2009). Even remote beaches and dunes are increasingly pressured by off-road vehicles, particularly for tourism and recreational fishing. Some beaches around state capitals and coastal population centres are significantly modified through coastal armouring and recreational infrastructure. The introduction of hard engineering structures (e.g. groynes and seawalls; see Artificial structures) directly alters surf-zone processes and sediment dynamics, displaces beach habitat, imposes connectivity barriers for species and can reduce the aesthetic amenity. Sydney claims some of Australia's most popular beaches (e.g. Bondi Beach), but approximately 23 kilometres of its open coast is modified in some form. Soft engineering practices such as beach nourishment, where eroded sand is replaced from other sources, are often expensive and ongoing, and can also negatively affect invertebrate communities and the organisms that rely on them. Between 2001 and 2011, beach nourishment programs to counter the effects of erosion have been implemented on at least 130 Australian beaches, mostly in urbanised areas (Cooke et al. 2012).

Marine debris is found on beaches primarily near urban population centres, but also increasingly on more rural beaches, depending on local oceanographic conditions (see Marine debris). Mechanical cleaning to remove litter and debris is a common practice on many urban beaches. However, it can physically alter the morphology of the beach, damage fauna, and remove seeds and washed-up seaweed, which can be a resource for other species. High human presence on beaches can disturb the nesting and/or foraging of shorebirds and turtles (see Nursing, roosting and nesting), whereas harvesting can deplete local populations. Invasive species, including dogs and foxes, threaten native fauna and dune vegetation, and are particularly prevalent near major cities.

Dunes have been extensively developed and their vegetation altered, much of which can be attributed to dune stabilisation initiatives in the mid-20th century. Historically, dunes were perceived to require stabilisation, leading to the deliberate introduction of marram grass (*Ammophila arenaria*) in the south. This has now become a widespread and problematic invasive species, as have sea wheatgrass (*Thinopyrum junceiforme*) and sea spurge (*Euphorbia paralias*). These invasive species displace native species, alter dune morphology and potentially disrupt ecological functioning (see Invasive species [terrestrial]). In New South Wales, bitou bush (*Chrysanthemoides monilifera*) is dominant and widespread, displacing all but a few native species, despite well-funded control programs. Dune condition is generally considered poor in southern mainland Australia (south of Perth and Brisbane), whereas it is highly variable in Tasmania.

Because dunes are undervalued and underfunded, they suffer from uncoordinated and transient management programs that are often ineffectual. Local management campaigns can make temporary progress, but usually have short lifespans, and invasive species return once interest fades. In July 2013, national coordination for Weeds of National Significance was suspended, and, even for these species, there is little funding for effective, long-term invasive species control programs. Such downscaling of management scope is concerning, because deterioration of vegetation in one location can have broader consequences for other locations.

In the short and long terms, beaches will continue to receive pressure from coastal population growth on the landward side, and rising sea levels and associated erosion and coastal armouring on the ocean side (see page 49). However, some natural beach and dune systems away from human development may have the opportunity to adapt to sea level rise by moving landwards and replacing other coastal habitats.

The outlook for dunes is similarly poor. Native diversity on dunes is likely to decline as invasive species proliferate, recreational pressures increase and coastal development continues. Dune and beach management could be improved by better understanding of the ecological impacts of invasive species and other pressures. Accurate assessment of trends in the ecology of beach and dune habitats is limited by the paucity of temporal data, and few studies exist other than for a few select systems.

Rocky shoreline

Rocky shorelines are intertidal habitats that support diverse floral and faunal communities. A significant proportion of natural rocky shorelines near urban centres have been replaced or fragmented by artificial structures and foreshores, with consequent biodiversity loss. For example, approximately half of the Sydney Harbour foreshore is artificial (Chapman & Bulleri 2003). Remaining rocky shores near urban centres are being increasingly pressured by contamination (including contaminated groundwater discharge), stormwater and sewage outflows, invasive species, and recreational use. Although the condition of rocky intertidal shores is widely considered to be declining because of multiple pressures, there are limited long-term datasets available to test this belief.

Establishing protected zones is one method of promoting the resilience and recovery of affected shores, but protection of rocky shores is seldom enforced, and unregulated fishing and harvesting are common. A promising approach to ameliorate effects of artificial structures is to incorporate eco-engineering principles into their design (see Artificial structures), which, in principle, can reduce the impact of natural habitat loss on native species. Issues of contamination also require attention, through reduction of contemporary contaminant inputs (e.g. storm water) and the remediation of historical contaminants.

The outlook for rocky shores is poor, as they continue to be subject to multiple pressures. In the future, climate change will increase as a pressure, with rising sea levels reducing the amount of suitable habitat, and rising daytime maximum air temperatures negatively affecting a larger proportion of species. Effective adaptation and management strategies are required to increase resilience in the face of climate change.

Mudflats and sandbars

Mudflats and sandbars are extensive areas of bedded sediment, characterised by fine or coarse grain size, respectively. These dynamic environments are exposed during low tide and submerged during high tide, providing habitat for infauna, and the shorebirds, crustaceans and fish that consume them. Their communities are important for water-column and interstitial (between-grain) water quality through their role in nutrient cycling. However, many areas are believed to be in good condition because they are remote from most anthropogenic pressures, except for climate change.

There are little data on the condition of mudflats and sandbars beyond small-scale studies, so high uncertainty surrounds their current state and trend. Although some data on the spatial area of tidal flats in estuaries are available, studies are generally one-off and do not consider habitat quality. Despite their large areas, tidal flats are rarely included in mapping exercises conducted by state agencies.

Bedded sediments are sinks for contaminants, and the health of tidal flat communities near urban, agricultural or industrial activity is often threatened by contaminant inputs, including organic enrichment. Furthermore, altered hydrology because of upstream dams, weirs and barrages can limit both water and sediment inputs, and ultimately lead to habitat loss. Likewise, dredging can alter sediment dynamics, and there is the potential for spoil deposition to create entirely new artificial mudflats.

Several recreational activities threaten the quality of mudflats and sandbars as habitats. Harvesting of bait, crabs and bivalves can directly affect populations of these ecologically important bioturbators (animals or plants that rework soils or sediments). Boating can also affect these habitats, because propellers physically disturb sediment, boat wake increases erosion and shifts grain size towards coarser compositions, and boat noise disrupts foraging shorebirds.

Growing human populations are expected to increase a range of pressures on tidal flats in the short term. In the longer term, tidal flats will be strongly influenced by climate-related factors, such as sea level rise and altered storm surge, and coastal modifications in the wake of these pressures.

Coastal waterways

Australia has a wide variety of coastal waterways. These include tidal creeks (35 per cent), wave-dominated estuaries (17 per cent), tide-dominated estuaries (11 per cent), wave-dominated deltas (10 per cent), tide-dominated deltas (9 per cent) and strand plains (5 per cent), with the remaining 13 per cent comprising drowned river valleys, bays, coastal lakes, lagoons and creeks (Heap et al. 2001). These proportions are not consistent around the country, with tide-dominated estuaries more common in the north and far south, and wave-dominated estuaries more common in New South Wales, Victoria, South Australia and Western Australia.

Coastal lakes and lagoons

Many of Australia's coastal freshwater resources are intermittently closed and open lakes and lagoons (ICOLLs). The majority are situated in either the south-east or south-west of the mainland, but they also occur throughout the east coast and Tasmania (Timms 1982). The most likely trend in the state of lagoons nationally is declining quality for catchments with significant human use, but a robust assessment is hindered by a deficiency in baseline data (Saunders & Taffs 2009). Large-scale spatiotemporal monitoring would be required to detect trends in the context of the cyclic ICOLL dynamics, which naturally alternate between open and closed, and affect water characteristics. Freshwater lakes are discussed in the *Inland water* report.

Key pressures on lagoons are the input of sediment and nutrients from the catchment, and the alteration of entrance dynamics (Everett et al. 2007). Some lagoons are permanently artificially opened, at greater frequencies or at different times than would occur naturally, and this causes rapid changes in water level, salinity and tidal regime. Modifications to entrance dynamics have biological impacts, such as increased colonisation by introduced species, and hybridisation between estuarine and marine species. Lagoon entrances are restricted when open, and often only a small amount of water is exchanged, making them particularly vulnerable to eutrophication and pollution. Entrance opening has little effect on pollution, but may help manage flooding of margins. Lagoons are also subject to pressures of recreational use, fishing, coastal development and catchment modification (Webster & Harris 2004).

Recent work in northern New South Wales and Queensland indicates that enhanced nutrient input has contributed to water quality decline (Logan & Taffs 2013). The Coorong, Lower Lakes and Murray Mouths system suffered severe deterioration following extended drought and upstream water abstraction (Haynes et al. 2007, Kingsford et al. 2011). Tasmania's lagoons are in much better condition than other states because development pressures are lower (Saunders & Taffs 2009).

Restoration and mitigation measures are rare, apart from small-scale projects that lack the long-term funding required to sustain results. Multistakeholder agreements on water abstraction to restore environmental flows have the potential to improve water quality in coastal lakes and lagoons such as the Coorong. Smaller-scale restoration projects may be unsuccessful because of poor knowledge of the characteristics of specific lagoons and multiple interacting pressures. Understanding and conserving lagoons require studies beyond specific taxonomic groups, and better understanding of ecological processes.

The outlook for lagoons will be tightly coupled with human population growth, and the associated modification of catchments and lagoon entrances. Unless appropriate management actions are taken, ongoing deterioration of lagoons is predicted from poor development and land-use decisions, water abstraction upstream, introduced species, nutrient inputs and saltwater intrusion. The longer-term outlook also depends on the effects of climate change on entrance dynamics.

Estuaries and bays

As productive, aesthetically attractive and relatively sheltered features of the coast, many estuaries and bays are heavily used by humans for recreation, industry and trade. Some estuaries and bays support large and growing urban centres, and are consequently exposed to multiple pressures (Hallett et al. 2016a). The condition of estuaries and bays largely depends on their proximity to population, agriculture and industry, but lack of long-term monitoring and the variability in approach for assessing estuarine condition limit the ability to make national or state-level assessments about their condition (Hallett et al. 2016d).

In the short term, modified estuaries and bays may not experience significant change because they are already severely altered. These areas may improve as legacy contamination issues are slowly addressed and

Gold Coast coastline
Photo by Megan Watson

contamination inputs (both point source and diffuse) are reduced. Bays and estuaries are targeted in marine estate planning aimed at addressing local pressures such as agricultural run-off and unsustainable fishing, but there is insufficient evidence that current habitat restoration efforts are effective, and protection needs to be applied on appropriately large spatiotemporal scales to restore functioning. In the long term, climate change (particularly sea level rise) and urbanisation are likely to continue to affect estuaries and bays. For example, sea level rise threatens urbanised estuaries with little remaining opportunity for habitat retreat (see Sea level rise). However, positive outlooks exist where improvements in management planning frameworks are under way or planned to help mitigate impacts (Koss et al. 2015). For example, although carbon dioxide enrichment increases the probability of biogenic habitat loss, there is evidence that this loss can be managed by reducing eutrophication.

Estuaries

Estuaries are embayments where there is a transition zone between a freshwater river and the ocean. A range of ecologically important habitats and habitat-forming species are found within estuaries, including mangroves, seagrasses, oyster reefs, rocky reefs, soft sediments and beaches. Estuaries are home to a diverse suite of species, even when extensively modified (Clark et al. 2015). In this report, we cover areas within the heads of estuaries, but note that the freshwater influence of some estuaries can extend far offshore at times of high flow. This is the case for some tropical river estuaries, where discharge plumes can reach the continental shelf during strong flow conditions, and thereby influence offshore habitats covered in the *Marine environment* report.

The condition of estuaries and their outlook vary widely around Australia (Wolanski 2014). Approximately half of Australia's estuaries are significantly modified by coastal development and human activities, a large proportion of which are in the temperate south. Tropical estuaries in the north typically differ from temperate estuaries in their physical characteristics (e.g. they are generally high turbidity and experience periodic high flow), and most are relatively pristine.

A recent survey of 10 New South Wales estuaries found some of the highest sediment metal concentrations anywhere in the world, particularly in Sydney and Port Kembla harbours (Dafforn et al. 2012). Despite this, fish (McKinley et al. 2011b), infauna (Dafforn et al. 2013) and hard-substrate epifauna (Clark et al. 2015) were abundant and diverse. This pattern is likely because nutrient enrichment is increasing the total biomass of organisms, and high vessel activity is introducing new species. Therefore, although some modified estuaries support productive and diverse ecosystems, they are significantly altered from their natural state (Clark et al. 2015).

In South Australia, the amount of rural run-off delivering fresh water, sediments and nutrients to estuaries has decreased in recent years, following exceedingly warm and dry conditions. South Australian estuaries are also likely to be negatively affected by pollutant inputs from development and alterations to inflow (Gorman et al. 2009, Dittmann et al. 2015). A similar scenario has unfolded in Western Australia, where hot, dry conditions reduced freshwater inflow and caused some estuaries to display persistent high-salinity conditions.

Historically, the Peel–Harvey Estuary in south-west Western Australia suffered from eutrophication, until the opening of the Dawesville Channel in 1994 increased tidal exchange, and resulted in higher abundance of seagrass, macrophytes and associated fish. These changes have been exacerbated in recent years, as the hot, dry climate has reduced freshwater inflow and created persistent high-salinity conditions, shifting the ecosystem even further towards a marine state (Potter et al. 2016). Although these changes can be viewed as positive from the standpoint of biodiversity, the opening of the channel failed to address the source problem of catchment inputs (Elliott et al. 2016). Reducing inputs at the source could be achieved by improvements in stormwater and agricultural run-off, assistance to landowners to manage inflow, and assignment of priority levels to address urgent hazards.

The environmental impacts of upstream development (e.g. dams and irrigation) on estuaries require greater consideration, particularly in northern Australia (see Water abstraction). Australian Government studies of predicted impacts of northern development have focused on rivers rather than estuaries, despite a history of comparable impacts on estuaries elsewhere in Australia. A recent study estimated that an investment of $350 million into the repair of Australian estuaries would be returned within 5 years from the subsequent increase in commercial fishing productivity and profit (Creighton et al. 2015).

Bays

Bays are moderately sized inlets on the coast, and are typically bedrock lined with high marine influence. Bays have historically been highly productive and diverse locations that supported Indigenous communities, as well as the economic activity and survival of early European settlements. Today, they still offer substantial economic value and lifestyle amenities. With some exceptions, management has largely failed to stem the loss and degradation of these habitats because of insufficient control of the primary drivers of change.

Most bays in New South Wales are exposed to limited catchment input, and many are ocean dominated (e.g. Byron Bay) and effectively open coast in terms of water quality. Although these bays are only exposed to limited contaminants from small nearby estuaries or the ocean, many are a focus for human activity and development (e.g. Coogee Bay, Bate Bar [Cronulla], Long Bay) and are hence exposed to urban run-off and pollution. No bays in New South Wales are pristine, but those on the south coast surrounded by national park (e.g. Bittangabee Bay) are less modified. Even these bays experience some human influence, however, including commercial and recreational harvesting of lobster, abalone, fish and other marine organisms. Exposure to contamination is likely to be relatively low for these bays except for widely dispersed contaminants (including litter) and shipping-related and boating-related contaminants.

Several of the largest embayments in New South Wales are the focus of large population centres and industry, usually because of their provision of safe harbours (e.g. Botany Bay). These have:

- substantial contamination issues
- high numbers of introduced species
- elevated physical disturbance (e.g. frequent boat wake)
- been subject to land reclamation
- many artificial structures (e.g. piers, wharves).

However, like modified estuaries, many of these embayments support diverse and abundant marine life (Clark et al. 2015).

Victoria has a similar pattern to New South Wales in embayment state, distribution and pressures. Water quality improvements have been made for Port Phillip Bay; however, the bay is subject to pressure from recreational and commercial fishing, the ongoing urbanisation of catchments, the introduction of invasive pests (e.g. sea stars and fan worms) and development proposals that are evaluated individually rather than within the context of cumulative stressors.

A lower proportion of bays in Queensland are degraded, since the high-population and industrial areas are positioned further inland and away from the embayments (e.g. Moreton Bay). However, some bays are affected by eutrophication and sediment input, which is reflected in the decline of their seagrass, and fishing has also modified the ecosystem of Moreton Bay. Most bays in Western Australia are considered pristine or very good, and none are heavily modified (in contrast to some Western Australian estuaries). In the Northern Territory, effects of human modification are predominantly restricted to Darwin Harbour. The large bays or gulfs of South Australia have lost 1500 kilometres of oyster reef throughout their range, and urbanised coasts have experienced some of Australia's most extensive and intensive losses of seagrass beds and kelp forests.

The value of bays to society creates impetus for their protection, and some bays have been focal points for conservation via marine parks (e.g. Jurien Bay, Jervis Bay, Moreton Bay). Furthermore, a series of catchment and urban input strategies and management approaches have been developed to reduce pressures. These include initiatives by Landcare, catchment management authorities, and state and national environment and primary industry agencies, for progress in areas such as stormwater management and public education. Whether management can reverse the decline is an ongoing debate, as attempts are made with variable success.

Pressure from increasing populations and associated development means that the most likely outlook is for slow deterioration of bays as a habitat for species, despite mitigation and restoration efforts. Short-term change is, however, likely to be small, given that large changes have already taken place (e.g. Connell et al. 2008, Alleway & Connell 2015). In the longer term, effects of ocean warming and acidification will exert greater pressure, particularly in combination with existing local stressors. A recent global quantitative analysis suggests that bays may be disproportionately sensitive to future climate change (Nagelkerken & Connell 2015). Although direct and top-down effects of climate have attracted considerable attention and we are learning their effects (e.g. Karelitz et al. 2016), the bottom-up effects are barely recognised—yet potentially powerful (Connell et al. 2013).

Water quality (turbidity, physicochemical properties)

Water quality refers to the physiochemical properties of water, including salinity, temperature, turbidity, oxygen saturation and dissolved organic matter. Water quality is highly variable through space and time, and is often indicative of recent pressures. Processes that alter coastal water quality include catchment modification, agriculture, urbanisation, erosion, dredging and sediment resuspension.

Water quality is in good condition in many coastal areas, but is in worse condition near or downstream of population, industrial or agricultural centres. Although diffuse pollution from urbanisation and agriculture is the major driver of poor water quality, the expansion of major ports is often a higher-profile trigger for public concern. For example, in Queensland, a $20 million compensation claim was lodged by fishers and business owners in response to continued dredging (McCosker 2012).

Photosynthetic organisms such as benthic microalgae, seagrasses and macroalgae are directly affected by changes in the optical properties of water (i.e. turbidity, transparency and colour). Optical conditions are highly variable in space and time, but are affected by suspended sediments, tannins and phytoplankton. Heavily dredged and developed areas typically have poor water transparency.

Only a small proportion of the Australian coast has been field sampled for water turbidity, transparency and colour. Water quality information is typically collected at small spatiotemporal scales, or is collected as part of large disturbance monitoring programs, such as for dredging operations (however, see Box COA7). Ocean colour imaging is broadscale, but requires substantial field calibration. The Great Barrier Reef has received significant attention, where a large body of work describes the effects of increased sediment from rivers on lagoonal turbidity (e.g. Fabricius et al. 2014, 2016).

The outlook for water turbidity, transparency and colour in the short and medium term is good. Management is increasingly recognising the importance of water quality when considering future projects, and is implementing catchment stabilisation initiatives. In some areas, management actions have already led to improvements in water quality. In the longer term, climate change, particularly the alteration of precipitation and drought patterns, is expected to negatively affect coastal water quality.

Box COA7 National assessment of estuarine water quality using satellite data

Large-scale assessment of water quality change using traditional measurements is expensive. Modern methods such as remote sensing (analysis of data collected by satellites) have great potential for scaling up monitoring in powerful and efficient ways.

The analysis presented here uses colour measured by satellites as a proxy for water quality change. It is based on the idea that water with reduced quality tends to have an increased reflectance of red wavelengths. The aim was to study net trends of change (positive change, no change or negative change) in water colour in every Australian estuary, from 1987 to 2015.

Light reflectances of water in each estuary were obtained from the Data Cube, which is a collection of Landsat images processed and curated by Geoscience Australia and CSIRO. Spatial resolution is limited to areas of 30 metres × 30 metres, and days with cloud covering more than 50 per cent of the estuary were discarded. Land areas, very shallow waters and very coastal waters were masked out, and pixels were filtered using near-infrared reflectance. In addition, modelling was done using mean values per estuary per day. The effects of temporal periodicity and weather (rain) were first accounted for, and therefore the net trends observed in the results are caused by other factors, including human impacts.

Change in the ratios of reflectance of green light versus red light and blue light versus red light were used to estimate change in water colour. Increases in the ratio indicate positive change in water quality, whereas decreases indicate negative change. The results showed that most estuaries have the same trend for both the green–red and blue–red light ratios, although some differ (Figure COA12).

Box COA7 (continued)

Note: Increases in the ratio (i.e. decrease in red reflectance, positive change) are shown in green, and decreases (negative change) are shown in red. Estuaries with no significant change are shown as crosses, and those that showed different trends for each ratio are in grey.
Source: AB Bugnot, M Lyons, G Clark, EL Johnston (University of New South Wales); S Fyfe, A Lewis (Geoscience Australia); P Scanes (NSW Office of Environment and Heritage), all rights reserved

Figure COA12 Map of the estuaries studied and their trends in water colour change, 1987–2015

Box COA7 (continued)

Model predictions were validated by correlating trends in time as shown by the model with trends in data collected by traditional turbidity measurement methodology, such as Secchi disks, turbidity sensors and total suspended solids, for 22 Australian estuaries. This validation method shows that the temporal trends of the ratios are positively correlated with those obtained for increasing Secchi depth (increased water clarity), and mostly negative correlated with increasing turbidity, total suspended solids and chlorophyll. These results indicate that reflectance ratios may be a useful proxy for water quality conditions.

Source: AB Bugnot, M Lyons, G Clark, S Fyfe, K Griffin, A Lewis, P Scanes, E Johnston (collaboration between the University of New South Wales [NSW], the NSW Office of Environment and Heritage, and Geoscience Australia).

The beach and coastline of the Sea Acres Nature Reserve in Port Macquarie, New South Wales

Photo by Dragi Markovic,

Biodiversity

Threatened species

The distribution of threatened species around Australia provides an indication of current human impacts on native biota. The 2014 data on threatened species listed in the EPBC Act that occur within the coastal zone (50 kilometres from shore) show the highest density of threatened species on the east coast of Australia, particularly around the urban centres of Sydney, Brisbane and Cairns (Figure COA13). Other areas of high density are the east coast of Tasmania, the Northern Territory around Darwin, and isolated pockets of south-west Western Australia. Not surprisingly, these patterns are correlated with areas of dense human population, except for patches in the north of Australia (e.g. the Kimberley region), which are relatively unmodified. SoE 2011 suggested that the high number of threatened species in the north may reflect the high overall diversity of tropical systems, rather than areas of elevated impact. However, differences in the intensity of sampling, pressures such as cane toads affecting northern reptiles and mammals, and overseas pressures on migratory shorebirds may contribute to this pattern.

Species groups

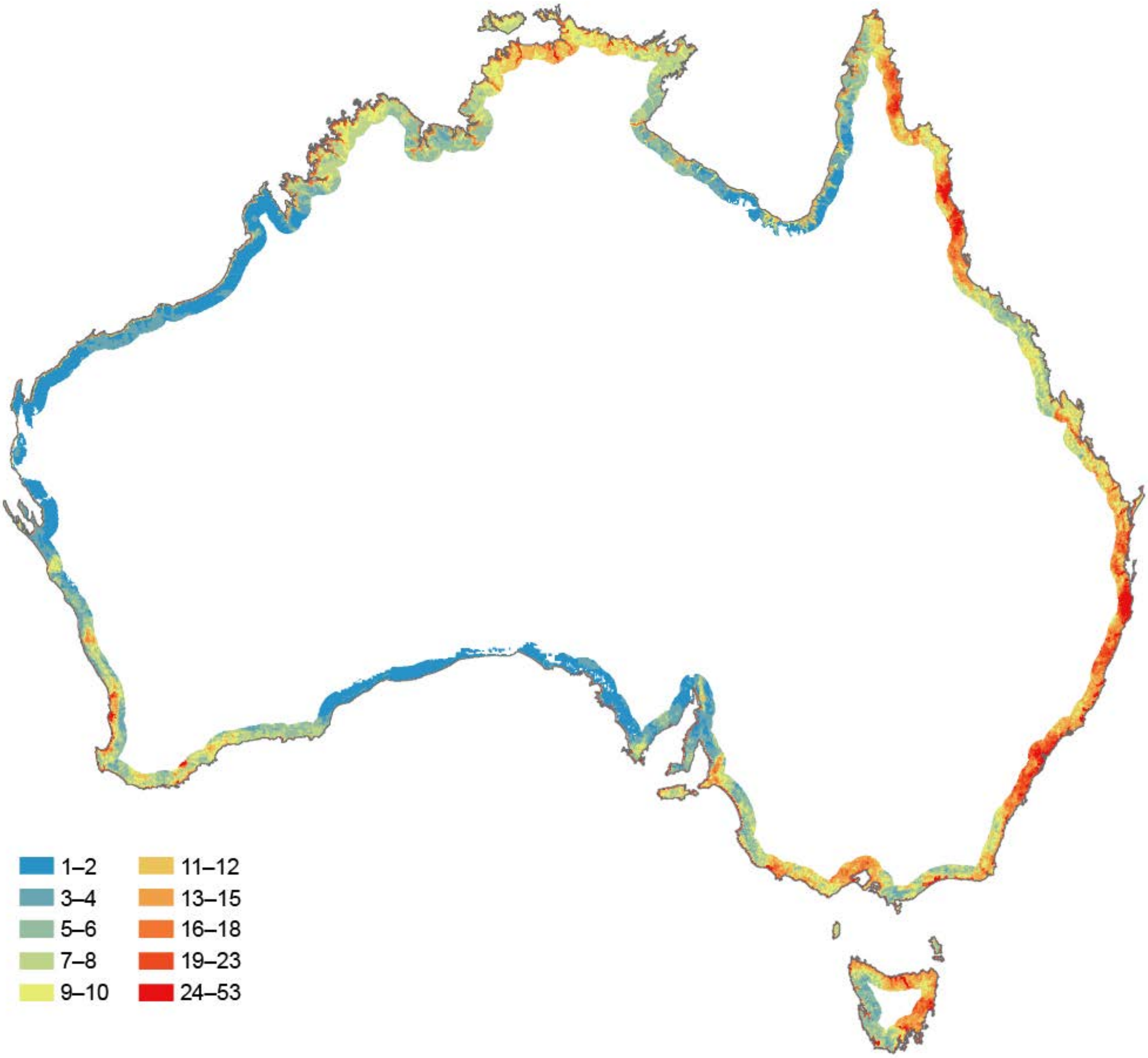
Shorebirds

Nationally, shorebird populations are in very poor condition and are rapidly deteriorating (Clemens et al. 2016). This is particularly true for species with a migration route passing through the Yellow Sea, where critical feeding areas have been lost (Murray et al. 2014). Four migratory shorebird species—the eastern curlew (*Numenius madagascariensis*), the curlew sandpiper (*Calidris ferruginea*), the great knot (*Calidris tenuirostris*) and the bar-tailed godwit (*Limosa lapponica menzbieri*)—are listed as critically endangered under the EPBC Act. There is broad agreement on the very poor state and trend of shorebirds, and consensus that the main causes are habitat loss and degradation, particularly in overseas areas on their migratory routes (Murray & Fuller 2015, Murray et al. 2015). Importantly, shorebird habitat can generally not be offset by other environmental compensation.

Pressures differ between resident and migratory shorebirds, and, consequently, so do their current states. Declines in resident shorebird abundances are attributed to coastal use and associated disturbance, with recreational pursuits, dogs, 4WDs and horses all adversely affecting shorebirds. The fitness and reproductive success of resident shorebirds are also reduced by introduced predators, and habitat loss and disturbance. There is evidence that degradation of inland wetlands in Australia, including from river regulation and abstraction (Silke et al. 2008), is affecting inland nonmigratory shorebirds, such as the red-necked avocet (*Recurvirostra novaehollandiae*), the black-winged stilt (*Himantopus himantopus*), the black-fronted dotterel (*Elseyornis melanops*) and the red-kneed dotterel (*Erythrogonys cinctus*) (Clemens et al. 2016). On a national scale, populations of nonmigratory coastal shorebirds are in better condition than those of migratory shorebirds (Clemens et al. 2016). However, there are cases where human activity on beaches is clearly placing pressure on individual shorebird populations, such as populations of the hooded plover (*Thinornis cucullatus*) across much of Victoria (Oldland et al. 2009), and the beach stone-curlew (*Esacus magnirostris*).

For migratory shorebirds, the dominant pressures are likely to be occurring overseas, and there is uncertainty about the degree to which human activities (e.g. urbanisation, water extraction) in Australia are contributing to their declines. However, nationally, feeding and roosting sites are deteriorating in extent and quality, limiting the ability of birds to make return flights to the Northern Hemisphere. Additionally, climate change, including sea level rise, threatens both coastal nonbreeding (Iwamura et al. 2013) and breeding (Wauchope et al. 2016) sites of shorebirds.

Shorebirds are declining in numbers, and threats are stable or increasing in most jurisdictions, although data on threats are limited, and it is difficult to distinguish between local and distant drivers of population decline. Many coastal areas in New South Wales are below the national average in retaining shorebird numbers, whereas, in Western Australia, most shorebirds occur in the relatively pristine north-west. Populations in Victoria show variable trends, although some large areas are losing many shorebirds. In Queensland, there are many areas with large numbers of shorebirds (GBRMPA 2014), although data are insufficient, particularly in the north, to fully assess their population trends. At least 1 area in Queensland with sufficient data, Moreton Bay, appears to be doing worse than the national average.



Note: This map uses the threatened (critically endangered, endangered or vulnerable) species listed as at January 2016 under the *Environment Protection and Biodiversity Conservation Act 1999*. Each species distribution was intersected with a 5 kilometre grid of the coastal region (50 kilometres inland), and a count for each grid cell was calculated.
Source: Environmental Resources Information Network, Australian Government Department of the Environment and Energy

Figure COA13 Number of threatened species that occur within 50 kilometres of the coast

In South Australia, the 2 largest shorebird areas—Gulf St Vincent and the Coorong—are rapidly losing shorebirds, with local pressures deteriorating the condition of the Coorong and amplifying more broadscale impacts (Aharon-Rotman et al. 2016). Following a recent wet period, trends for some shorebirds in the Coorong have stabilised; however, this region is entering another dry spell (Paton & Bailey 2012). Gulf St Vincent is threatened by sea level rise and coastal development, although this may be mitigated by proposed protected areas. Trends in Tasmania are largely consistent with the national average, but some species are under severe threat. The once-abundant eastern curlew is now facing the very real risk of local extinction. Some analyses suggest that shorebird numbers are not declining in the Northern Territory, although most areas in the Northern Territory have too little data to assess.

Conservation can only be achieved if the whole suite of nesting, feeding and migratory habitats used by shorebirds are protected, including in their flyway to breeding areas in the Northern Hemisphere. Severe declines, mainly driven from overseas, make it all the more important that we effectively manage the shorebirds while they are here in Australia (Szabo et al. 2016). State and community groups have increased resident shorebird conservation efforts in recent years, such as hooded plover population restoration efforts in Victoria (Dowling & Weston 1999). With the possible exception of hunting in parts of Asia, no threat to shorebirds has been effectively managed in that region.

The short-term and long-term outlook for shorebirds as a group is poor. Pressures in critical migratory staging sites in the Yellow Sea are increasing, along with habitat decline in some Australian areas, and sea level rise. Substantial conservation efforts are required to prevent further declines in resident shorebird populations. In the case of migratory shorebirds, these need to be coordinated with overseas programs.

Crocodiles

Two species of crocodile are found in Australian coastal waters: the freshwater crocodile (*Crocodylus johnstoni*) and the saltwater crocodile (*Crocodylus porosus*). They are most abundant in the Northern Territory, and northern parts of Western Australia and Queensland, although there are increasing reports of sightings further south. In the past 5 years, there has been no sign of declines in saltwater crocodile populations, and their numbers continue to increase towards carrying capacity. Saltwater crocodiles were protected in Western Australia in 1970, in the Northern Territory in 1971 and in Queensland in 1974. Whereas saltwater crocodile numbers are improving, freshwater populations have remained stable since 2011 because some populations have been affected by cane toads.

A high proportion of Australian saltwater crocodiles are found in the Northern Territory, which has a comprehensive monitoring program in place. Regular survey data collected since shortly after protection in 1971 indicate that saltwater crocodile populations in the Northern Territory have achieved full recovery. They have returned to levels of abundance that existed before intensive hunting started in 1945, and average size and biomass are still increasing (Fukuda et al. 2011).

Reasonably consistent data from Western Australia indicate that saltwater crocodile populations are steadily but slowly recovering, but at rates slower than in the Northern Territory because habitats are not naturally optimal. Long-term monitoring of saltwater crocodiles in Western Australia is restricted to regions of the Kimberley. Population increases occurred between 2000 and 2012 in the Ord River, and between 1999 and 2005 in West Arm, following harvesting from 1985 to 1998. The West Arm population was stable between 2006 and 2012. As of 2015, populations in the Prince Regent, Roe and Hunter rivers had tripled in size during the past 30 years. In both Western Australia and the Northern Territory, human impacts from habitat destruction are minor.

Saltwater crocodiles in Queensland have increased in abundance since protection in 1974; however, survey data in Queensland are patchy and inconsistent, and generally indicate slow recovery (Read et al. 2005). This is considered to be a result of a combination of the habitat being naturally unsuitable (insufficient breeding sites), extensive and ongoing habitat destruction because of coastal development and human population growth, and localised crocodile population depletion as a result of illegal shooting.

There is little concern for the outlook for saltwater crocodiles, in both the short and long terms, although increasing human–crocodile conflicts need to be addressed through appropriate management. Movement of saltwater crocodiles into upstream freshwater areas is an issue for both management and the displacement of freshwater crocodiles. Recently, calls have been made for culling of saltwater crocodiles to address growing public safety concerns. Saltwater crocodiles are increasingly used as a sustainable natural resource through tourism and farming in the Northern Territory and Western Australia, adding economic value to the species and assisting in their conservation. Similar commercial exploitation has been proposed in Queensland; however, there are questions about the science underpinning sustainable harvesting of these populations.

Monitoring of freshwater crocodiles is more limited than for saltwater crocodiles, but a few rivers in the Northern Territory have been closely monitored since the 1970s. The largest population in Australia occurs in the Daly River, Northern Territory, and data there show a serious decline in abundance during the past 15 years because of cane toads (Fukuda et al. 2015). Another large population is at Mary River, Northern Territory, where the population is showing a similar decline (Fukuda et al. 2015). Less is known about populations in Queensland, which may have been stable for the past decade. Harvesting of freshwater crocodiles is relatively minor, and the lack of economic value is reflected in the lower monitoring levels.

Dugongs

The dugong (*Dugong dugon*) is protected under the EPBC Act as a listed migratory and marine species. In Australia, dugongs occur in subtopical and tropical coastal and island waters from Shark Bay in Western Australia to Moreton Bay near Brisbane (Marsh et al. 2011). Small numbers of dugongs are found in New South Wales waters in summer, or when severe weather events strike southern Queensland (Allen et al. 2004).

Although dugongs are the most abundant marine mammal in the coastal waters of northern Australia (Marsh et al. 2011), their national status is unknown. Long-term monitoring has been limited throughout most of their range outside the east coast of Queensland and Torres Strait. Woinarksi et al. (2014) concluded that the status of dugongs in Australia is 'near threatened' using International Union for Conservation of Nature (IUCN) criteria. Based on several lines of evidence, Marsh et al. (2015) concluded that the Torres Strait subpopulation, the largest in the world, has been stable since the mid-1980s, despite significant levels of Indigenous harvest. However, concern exists about the status of the subpopulations along the east coast of Queensland, particularly in the southern Great Barrier Reef region south of Cooktown (Sobtzick et al. 2012), the region most affected by human development.

The main threats to dugong populations are gill-netting in Queensland, including in the Gulf of Carpentaria, and loss of seagrass habitat (see Seagrasses) to terrestrial run-off—the effect of which has been exacerbated by grazing, coastal development and extreme weather events, especially flooding and cyclones. A series of severe wet seasons culminating in the extreme weather events of the summer of 2010–11 had significant impacts on the dugong's seagrass habits in Queensland, with consequent impacts on the region's dugongs (Sobtzick et al. 2012, Meager & Limpus 2014, Fuentes et al. 2016). Vessel strikes are a localised threat to dugongs in populated areas. Native title holders are permitted to hunt dugongs in their sea Country. The local effects of such hunting are unknown outside Torres Strait, where the dugong subpopulation appears to be stable, as previously explained.

Most scientific data on the distribution and abundance of the dugong in Australia stem from aerial surveys, but the timeseries of information required for assessing trends does not exist outside the east coast of Queensland and Torres Strait. For much of the dugong's range, the information is based on only 1 or 2 surveys, or is out of date or non-existent. Surveys have recently been conducted along the Onslow and Kimberley coasts in Western Australia, and in the Northern Territory. However, in the absence of adequate timeseries, it is impossible to confirm the dugong's status in these areas.

Surveys have been limited by the availability of funding, compounded by complex logistics in remote regions, especially because of the need to limit surveys to restrictive weather conditions. Dugongs may be mistaken in aerial surveys for the co-occurring Australian snubfin dolphin (*Orcaella heinsohni*). Such misidentifications are most likely in the Northern Territory, as populations of snubfin dolphins are very small in most other parts of the dugong's range. Telemetry studies have been used to understand dugong movements and habitat use, and to develop locally relevant correction factors for animals that are unavailable to observers during aerial surveys. In Moreton Bay, vessel-based mark–recapture studies have also been used with a view to providing information on population size, trends, health genetics and movements. This technique has the potential to produce more accurate population estimates than aerial surveys, but will be logistically difficult, if not impossible, to use in remote areas because of the challenge in meeting the assumptions of mark–recapture studies.

In Queensland, the timeseries of aerial surveys since the 1980s has detected a decline in dugongs for the northern Great Barrier Reef region (where it is not yet statistically significant; Sobtzick et al. 2014, 2015) and in the southern Great Barrier Reef region (Sobtzick et al. 2012, 2015). In addition, the size of the subpopulations along the urban coast of Queensland south from Cairns are considered substantially reduced relative to the 1960s (Marsh et al. 2005), because of a combination of netting, habitat decline, boat strike and Indigenous hunting.

Dugong subpopulations in Western Australia and the Northern Territory are less exposed to anthropogenic activity than on the urban coast of Queensland. Dugong abundance along the entire Northern Territory coastline was estimated for the first time in 2015 (Groom et al. 2017), with approximately 60 per cent of animals occurring in the Gulf of Carpentaria. The impact of fishing in the Northern Territory, particularly by gill-netting, is difficult to determine, and the status and extent of the seagrass beds are largely unknown.

In Western Australia, the largest and most secure subpopulation is in Shark Bay (Hodgson et al. 2008, Marsh et al. 2011). Other important dugong areas are in Exmouth Gulf (Hodgson et al. 2008), in the Onslow region (Department of Parks and Wildlife, Western Australia, pers. comm., 2016) and in the Kimberley (Bayliss et al. 2015).

Protecting the quality of the coastal environment (e.g. further reducing terrestrial run-off and industry pollution)—in particular, seagrass communities—is crucial for ensuring the ongoing viability of the dugong in Australian waters. Dugongs have very slow reproductive cycles, such that even small reductions in survival are likely to have substantial impacts on population viability (Marsh et al. 2011). The National Dugong and Turtle Protection Plan 2014–17 has pledged $5.3 million to address the pressures on dugong and turtle populations, and may assist with recovery (DoE 2015).

The short-term and long-term outlook along the urban coast of Queensland is poor (i.e. this subpopulation will likely continue to deteriorate because of ongoing habitat loss unless terrestrial run-off is reduced). The outlook along the remainder of the dugong range is better in the short-term, but will likely deteriorate in the long term if there is further development in the remote north of Australia, or if seagrass meadows and dugong health are significantly affected by climate change.

Fishes in bays and estuaries

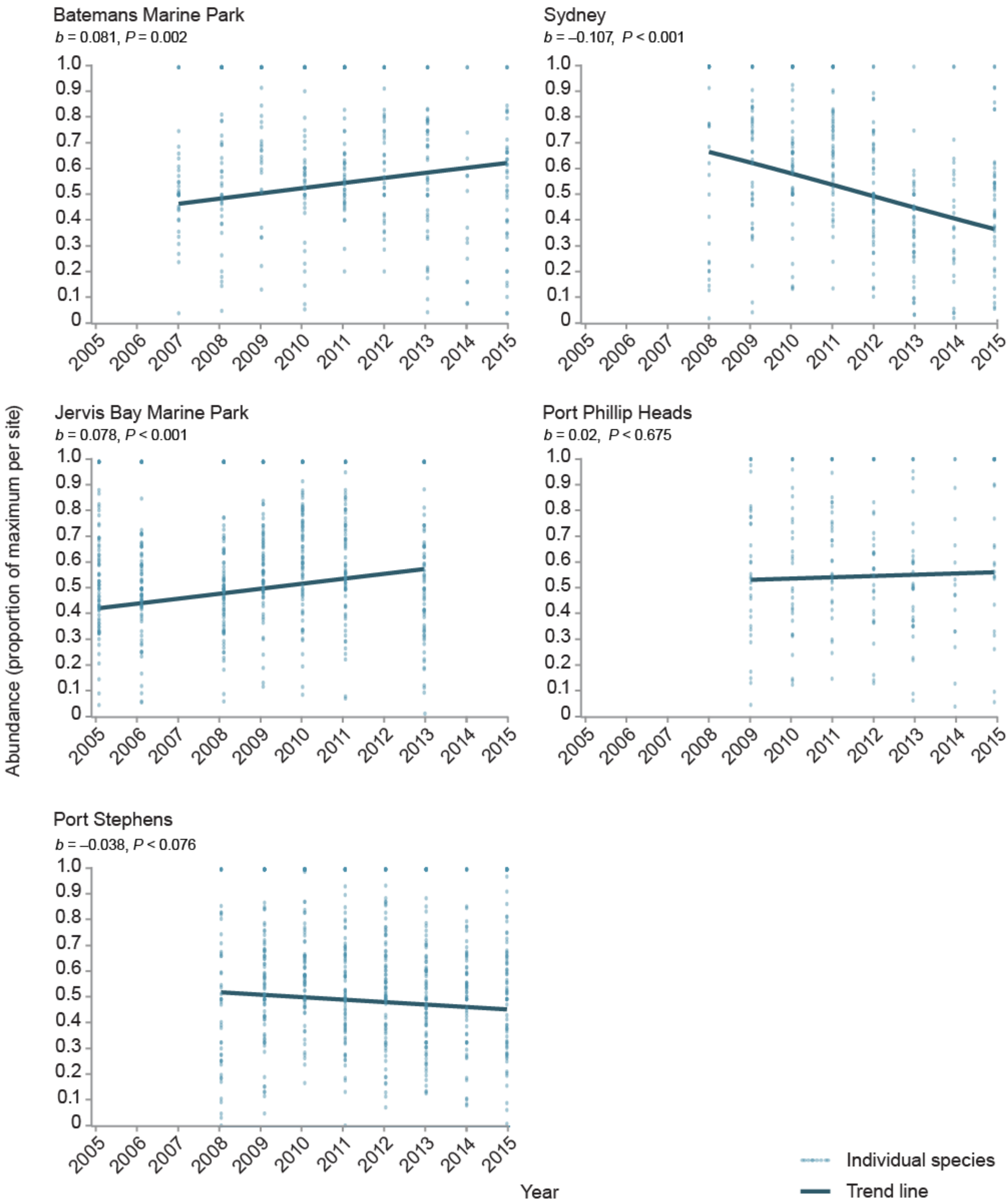
Many coastal fish species use bays and estuaries at the juvenile stage in their lifecycle (Potter et al. 2015). Most commercially important fish spawn in the coastal ocean and recruit to estuarine areas. Fish are an ecologically and economically important resource for commercial and recreational fishing. Most fish use rocky reef, seagrass and mangroves as nursery habitat (Blandon & zu Ermgassen 2014). For example, juvenile King George whiting (*Sillaginodes punctatus*; Moran et al. 2004) recruit to seagrass beds, whereas juvenile pink snapper (*Pagrus auratus*) recruit to deep, sandy regions (Hamer & Jenkins 2004). Therefore, some of the main threats to fish populations occur when these habitats are degraded by coastal development, urban run-off, dredging, trawling and activities that increase sedimentation. Recent studies show that some estuarine species (estuary perch, yellowfin bream, sand whiting) show remarkable fidelity to small areas, leading to the potential for local depletion (Gannon et al. 2015). Other areas of coasts and estuaries appear to be recruitment hotspots, characterised by a persistent abundance of juvenile fish (Ford et al. 2010), because of habitat or favourable currents. Such areas should especially be targeted for protection or rehabilitation.

As adults, fish that began their life within estuaries may be targeted by commercial and recreational fishers within those same estuaries or when they migrate offshore. Most commercial fisheries across Australia are regulated and monitored in some form; however, a substantial number of fish species stocks remain unassessed (Beeton et al. 2012). Moreover, information on the status of recreational targeted fish populations is often absent unless the fish species is also a commercially targeted fish. Detailed data on estuary-dependent fish in New South Wales are generally limited to commercially or recreationally important species, such as yellowfin bream (*Acanthopagrus australis*), sea mullet (*Mugil cephalus*) and mulloway (*Argyrosomus japonicus*). Fisheries-sourced data suffer from gear, effort and species biases, and fisheries-independent data are required for meaningful assessments.

Reef Life Survey has conducted fish counts in several bays around Australia since 2005 (Edgar & Stuart-Smith 2014). Two of these bays show increasing numbers of reef fish, 1 shows decreasing numbers, and 2 show no significant change (Figure COA14). New tropical fish species are an increasing occurrence off Sydney (Figueira & Booth 2010), as they are off Tasmania (Last et al. 2011), such as a large coral trout (*Plectropomus* sp.) captured off Sydney in 2015 (Australian Museum records), and tropical surgeon fishes (Basford et al. 2016). Increases in fish numbers at some sites may be partly because of protection measures such as marine sanctuaries, but may also be related to increased temperatures favouring warm-water species (Vergés et al. 2014).

Coastline of Ngaraloo Station near Carnarvon, Western Australia

Photo by Dragi Markovic, © Australian Government Department of the Environment and Energy, all rights reserved



b = value (regression coefficient) of slope of trend line; *P* = significance of t-test for the b value
Source: Reef Life Survey, used under CC BY NC

Figure COA14 Abundance of fishes and sharks visually recorded by Reef Life Survey at 5 estuaries, expressed as a proportion of the maximum abundance at each site, 2005–15

The primary issues of concern for fish populations in bays and estuaries vary among the states. Effects of warming coastal waters are particularly pronounced in New South Wales (Figueira & Booth 2010), where the southward spread of low-productivity tropical water combines with the pressures of urbanisation of Newcastle, Sydney and Wollongong. The strengthening East Australian Current has increased the temperature and salinity of coastal water, such that oceanographic conditions have shifted southwards by 350 kilometres (Ridgway 2007), and the ecological and economic impacts are just beginning to be realised around Australia (Johnson et al. 2011). Recreational fishing pressure in New South Wales is considered to be very high because of the high density of coastal population and the large number of residents with fishing licences; however, data on recreational fishing take are scarce (Beeton et al. 2012, Mayer-Pinto et al. 2015). Urbanisation also has the effect of greater chemical, light and noise pollution in the aquatic environment. Noise has recently been found to reduce foraging by mulloway (Payne et al. 2015a)—one of the main estuarine predators necessary for normal ecosystem function—and artificial light has been shown to increase fish predation on benthic invertebrates in Sydney Harbour (Bolton et al. 2017). Chemical pollution and habitat modification appeared to have substantial effects on larval fish in heavily modified estuaries of New South Wales (McKinley et al. 2011a), but effects on juvenile–adult communities surveyed by beach seine were not detectable (McKinley et al. 2011b).

Reduced freshwater flow is a key issue in southern Australia, affecting estuarine water quality, habitats and, consequently, fishes (Ferguson et al. 2013). Fisheries are also affected, such that drought-declared regions incur reduced catch per unit effort of 4 species across 7 New South Wales estuaries (Gillson 2011). Estuarine fisheries could qualify for drought relief support. Reduced freshwater flow increases marine influence, and pushes the salt wedge further inland, where it may miss areas of critical benthic habitat. Therefore, freshwater flow is important for normal functioning of estuaries and justifies the importance of environmental freshwater flows (e.g. for fish behaviour; Payne et al. 2015b). In the Peel–Harvey Estuary of Western Australia, salinity has risen because of a combination of climate-induced flow reduction and construction of an artificial channel to the sea, and this has increased the proportion of opportunistic marine fish in the estuary (Potter et al. 2016). The Peel–Harvey Estuary was artificially opened in response to eutrophication, which still plagues other estuaries and their fish populations in Western Australia (e.g. Hallett et al. 2016c). Some New South Wales estuaries are managed by increased opening frequency, but, therefore, may incur greater sand build-up and colonisation by mangroves.

In the south-west, species diversity is greater in permanently open estuaries (Valesini et al. 2013). Fishes are negatively affected by hypersalinity, habitat loss, and greater frequency and longevity of hypoxic events. Reduced freshwater flows, rising sea levels and increased storm surges may increase the periods for which ICOLLs are closed by sandbars, affecting the lifecycles of marine species and diadromous fish (species that migrate between marine and freshwater habitats, usually as part of their reproductive cycle) (Gillanders et al. 2011).

Invertebrates in bays and estuaries

Estuarine invertebrates are a diverse fauna that occupy hard substrates (e.g. sponges, gastropods, crabs, sea squirts, sea urchins) or soft substrates (e.g. nematodes, polychaetes), or form their own reefs (e.g. tube worms). They play critical roles in biogeochemical cycling and maintaining water quality by filtering particles from the sediment and water column (Gili & Coma 1998). Data on their diversity and abundance are limited, but patterns of habitat modification suggest that pressure on invertebrates is increasing, and their condition is likely worsening in developed areas.

Invertebrates in bays and estuaries are pressured by many processes related to coastal development and catchment modification. These include introduced species, disturbance and loss of critical habitats (e.g. seagrass, saltmarshes, shellfish reefs, soft sediments), contaminants, nutrients, sediment loads, and change in trophic structure because of unsustainable fishing pressure. Some pressures reduce invertebrate diversity and abundance, but others create imbalance in the other direction and cause invertebrates to proliferate and affect other ecosystem components. For example, overharvesting of fish can allow urchin populations to flourish, and overgraze kelp and create urchin barrens (Ling et al. 2015). Introduced species can boost overall abundance and diversity, but affect native species (Clark et al. 2015).

Some heavily modified estuaries show reductions in macroinvertebrate biodiversity (Stuart-Smith et al. 2015), whereas others have shown biodiversity and biomass gain (Dafforn et al. 2013, Clark et al. 2015). The latter can be attributed to nutrient enrichment, and occurs despite high concentrations of heavy metals (Dafforn et al. 2013; see Coastal river and estuary pollution). Variability in community response and lack of appropriate baseline data make it difficult to assess levels of impact without long-term monitoring.

The balance of freshwater and saltwater inputs is important for maintaining estuarine salinity, and this is influenced by climate, entrance modification and upstream water extraction (Robins et al. 2005). Freshwater inputs are vital for estuarine invertebrate populations, although large floods can cause mass mortality, particularly if fresh water is sustained for weeks across the substrate. Salinity in ICOLLs depends on the entrance state and can strongly affect invertebrates, but populations usually recover following the restoration of tidal regimes. In addition, productivity and food availability can be highly dependent on freshwater flows and the organic inputs associated with them.

Despite being some of the most abundant fauna in the most heavily used environments on the coast, invertebrate communities in estuaries and bays have limited data (Hutchings 1999). Knowledge of estuarine fauna tends to decrease with distance from major cities and research establishments, and varies between habitats and taxonomic groups. Natural population fluctuations in infauna make it difficult to attribute changes to anthropogenic or natural causes.

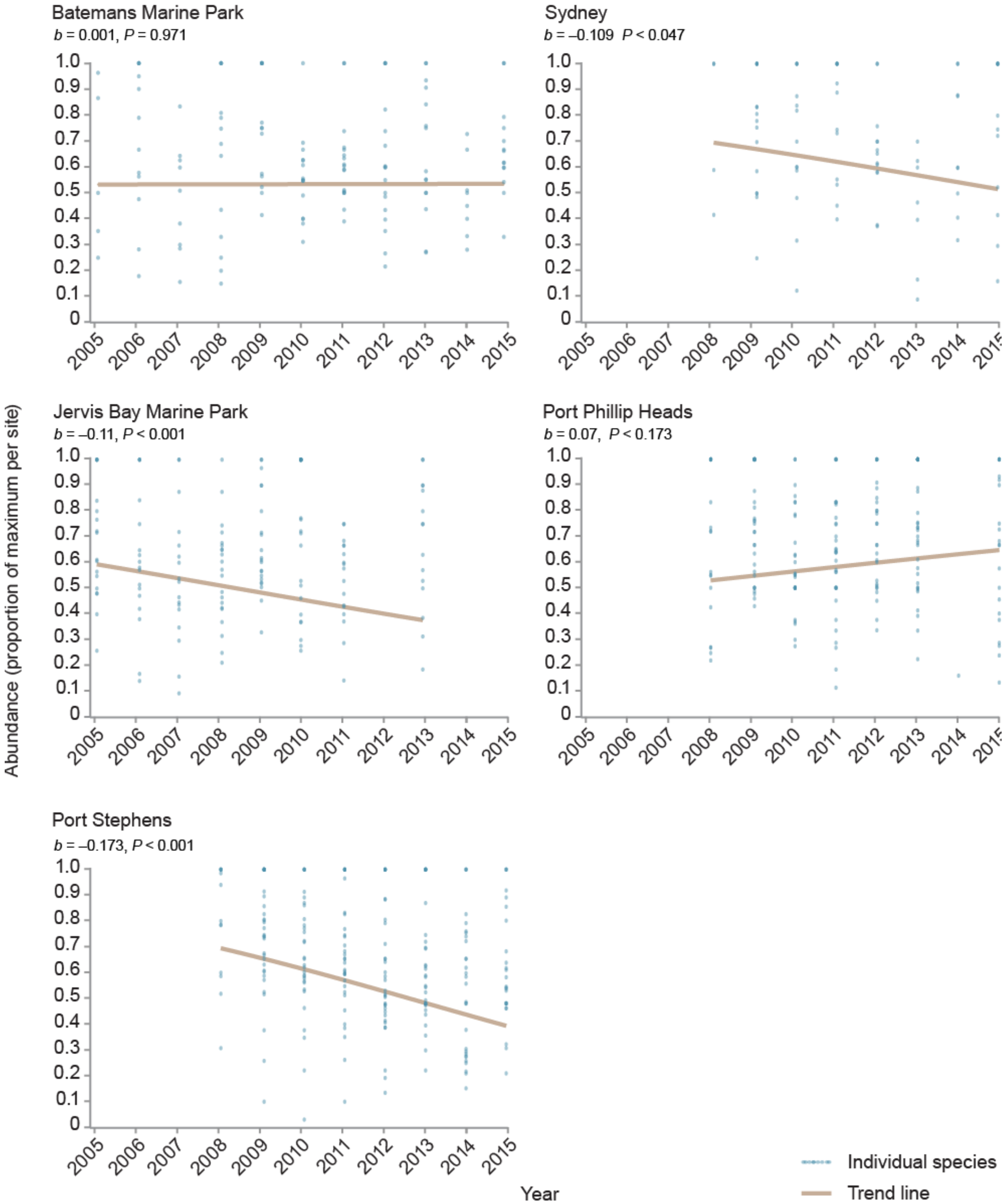
The state of estuary and bay invertebrates in New South Wales is highly variable and is related to the degree of urbanisation (Dafforn et al. 2013, Clark et al. 2015), although some remote coastal lagoons have poor water quality because of diffuse pollutant run-off. Legacy pollution continues to threaten invertebrate populations in estuaries such as Sydney Harbour, despite a reduction in commercial shipping and pollution in recent years. For example, the Sydney rock oyster shows signs of extreme cellular stress associated with high levels of sediment contamination in heavily modified estuaries (Edge et al. 2014).

Victorian and Queensland estuaries experience similar pressures related to urbanisation to those of New South Wales; however, there is less information on which to base assessments. It is likely that a higher proportion of estuaries in eastern Victoria and far north Queensland support invertebrate communities that are in good condition, although some nearshore waters of Queensland are affected by fertilisers from sugar cane plantations. In Port Phillip Bay, trends in mobile invertebrate abundance have recently been increasing or stable, but scallops were historically overfished and urchin barrens are likely expanding, with potential consequences for kelp-associated invertebrates. Flood patterns appear to be changing in Queensland, which will almost certainly affect invertebrate communities.

The Murray Mouth and Coorong of South Australia have lower invertebrate diversity than other southern temperate estuaries because of extensive periods of regulated flows, whereas much of the remaining coast of South Australia remains generally unmodified. Improvements were noted to the Murray Mouth and Coorong after the millennium drought and increased freshwater flows since 2011, although, recently, conditions have been deteriorating with decreased flows. In Port Davey, Tasmania, invertebrate populations appear stable, whereas in the D’entrecasteaux Channel, declines are evident, and the Derwent populations have been recently stable or have experienced small declines.

Data from Reef Life Survey show a declining trend in mobile macroinvertebrates in 3 of the 5 bays sampled (Figure COA15). This is suggested to be related to climate change, but there is, as yet, no strong link for causation.

The short-term and long-term outlook for native invertebrates is poor, as growing coastal populations continue to lower the quality of bay and estuarine habitats, and invasive species increasingly dominate communities. In the future, impacts of climate change are possible, including alteration of freshwater flows and saltwater intrusion, but predictions remain uncertain. Marine protected areas (MPAs) may promote the recovery of natural communities, but only if properly managed and enforced.



b = value (regression coefficient) of slope of trend line; P = significance of t-test for the b value
Source: Reef Life Survey, used under CC BY NC

Figure COA15 Abundance of invertebrates recorded by Reef Life Survey, expressed as a proportion of the maximum abundance at each site, 2005–15

Crab species

Australian marine and estuarine waters contain more than 1000 crab species, and this number continues to grow as new species are discovered. Most crab habitat is in relatively good condition, other than habitats located near developed areas. Pressures on crab populations associated with human developments include pollution, dredging, and the modification (e.g. alteration of drainage and run-off patterns) and destruction of habitat.

The Australian Faunal Directory contains the best information on crab taxonomy and broadscale distributions (Davie 2012), and detailed information exists in various taxonomic works. Specific species' distribution records and lists by locality, based on the combined records of the Australian museums, are available online through the Atlas of Living Australia. However, the taxonomic description of species found in Australia is incomplete, as is reliable information on their distribution and ecology. Quantitative data on crab diversity are poor, and are generally restricted to anecdotes, field collections and, to a limited extent, commercial catches. There is a lack of ongoing surveys of new areas, and little repeat monitoring of previous study sites.

In general, coastal crabs are relatively resilient and have good future prospects, given responsible management of coastal development and use. Climate change, particularly sea level rise, is likely to affect crab populations through direct habitat loss, erosion by intense storms, and flooding of habitats such as intertidal flats and mangroves.

Shellfish species

Shellfish is an encompassing term for marine invertebrate groups that share a characteristic exoskeleton morphology. Some shellfish, such as oysters and mussels, are vital coastal species that act as ecosystem engineers, detritivores and water clarifiers.

Despite improvements, the status of coastal native oyster beds remains in a critical state following largely historical losses, especially near urban centres, because the beds are particularly sensitive to changes in water quality and overharvesting. Many important infaunal bivalve species are also thought to have been lost to industrialisation, potentially because of sediment grain size changes or contaminants such as tributyltin. In 1994, Sydney rock oysters (*Saccostrea glomerata*) re-established in Sydney estuary, and, by 2002, densities were similar to nearby reference sites, likely linked to the partial banning of tributyltin in 1989 (Birch et al. 2014). Research is ongoing as to whether the invasive Pacific oyster (*Crassostrea gigas*) represents a serious threat to re-established Sydney rock oyster populations (Scanes et al. 2016).

Key mollusc industries (pearls, edible oysters and abalone) are threatened by disease, as are the wild populations of abalone (see Aquaculture and Diseases, infestations and fish kills). In the 1990s, invaders such as the European green crab (*Carcinus maenas*) and the northern Pacific starfish had large impacts on shellfish, although anecdotal evidence suggests these impacts have stabilised. A remaining threat is the potential for hybridisation between native and invasive mussels (e.g. *Mytilus* spp.), which are difficult to distinguish without molecular techniques.

The amount of information on shellfish does not reflect their importance to coastal ecosystem functioning. For example, there is limited information on the role of very high density mollusc populations in south-east temperate estuaries. Many of the historical shellfish reefs are thought to be functionally extinct because of early periods of overharvesting, and their existence has been largely lost to living memory (Alleway & Connell 2015). Catch data, the primary source of shellfish information, are of limited use for determining population trends up until collapse. Furthermore, production data from the aquaculture sector cannot always be obtained from small fisheries or industries. The research literature has good information on bivalves, although this needs to be updated with more studies on long-term temporal change and supply-side ecology. Key issues requiring greater attention are the impacts of current and emerging diseases; harmful algal blooms; anthropogenic pressures and urbanisation; harvesting; altered connectivity; interactions between aquaculture, wild species and ecosystems; and the effects of climate change.

The outlook for shellfish should be stable, except for possible improvement of the oysters *Saccostrea glomerata* and *Ostrea angasi*, which are the target of restoration trials (see Box COA13). As open populations, bivalves are likely to require regional-scale management to achieve conservation goals.

Coastal scenery at Smiths Point in the Cobourg Peninsula Aboriginal Land & Wildlife Sanctuary wetland area, Northern Territory

Habitat-forming species

Saltmarshes

Saltmarshes and mangroves (see Mangroves) are the dominant biological wetland types of the upper intertidal zone along the Australian coastline. Saltmarshes play a vital role in sequestering carbon, and function as habitat and nursery sites for diverse faunal communities, including birds, fish and insects (Laegdsgaard 2006). They are, however, among the most neglected type of wetland in Australia (Boon 2012), and are listed as a threatened ecological community under the New South Wales *Threatened Species Conservation Act 1995* and the EPBC Act.

The position of saltmarshes high on the shoreline and their arguably displeasing aesthetic has led to extensive historical losses and a suite of present-day pressures (Saintilan & Rogers 2013). At local or regional scales, total loss of saltmarsh has exceeded 50 per cent in some areas. For example, it is estimated that Sydney Harbour has lost 85 per cent of its original saltmarsh habitat (Mayer-Pinto et al. 2015). Tropical saltmarshes are extensive, but are much less studied.

The threats to saltmarshes are diverse and variable in spatial scale. There is a widespread issue of mangrove encroachment (Saintilan et al. 2014), where the expansion of mangroves squeezes saltmarshes into landward barriers. Invasive species are a problem in south-eastern Australia (Hurst & Boon 2016), and include common cordgrass (*Spartina anglica*), groundsel bush (*Baccharis halimifolia*), pampas grass (*Cortaderia selloana*) and spiny rush (*Juncus acutus*). There is a historical legacy of pollution in sediments that, if disturbed, has the potential for broad impacts. Oil spills are an unpredictable threat; however, few have occurred in Australia, and considerable contingency plans are in place.

A major threat to saltmarshes is clearing and drainage for mosquito control (Dale & Hulsman 1990). Saltmarshes are becoming increasingly fragmented, causing decreased biodiversity, resilience, sediment trapping and nutrient cycling; and altered food-web dynamics. Permitted and unpermitted tourist and recreational use, such as damaging 4WD activity or storage of tenders to access yachts, occurs in some locations. Other threats include tidal restriction, dredging, draining, eutrophication, acid sulfate soils, water pollution, saltwater inundation, grazing and erosion. In the future, climate change impacts are expected from sea level rise, rising carbon dioxide levels and temperature, increased frequency of extreme events, and acidification of floodwaters. Climate change processes may exacerbate to a ‘coastal squeeze’ on saltmarshes caught between land-based and sea-based pressures.

Historically, saltmarshes have been lost to land reclamation (including draining) and more recently to mangrove encroachment in New South Wales, Victoria, South Australia, southern Queensland and Western Australia. Approximately a decade ago, Victoria had approximately 192 square kilometres of saltmarsh and 32 square kilometres of estuarine wetland (Boon et al. 2011), but this is now greatly reduced. In South Australia, mapping in 2000 indicated that approximately 3.3 per cent of intertidal and 4.7 per cent of supratidal saltmarshes were degraded or displaying dieback; these proportions are likely to have remained largely unchanged, with losses occurring predominantly near urban centres.

Recent closure of salt fields north of Adelaide has provided an opportunity for saltmarsh restoration. However, 2 species of introduced seablite (*Suaeda baccifera* and *S. aegyptiaca*) are present and likely spreading in South Australia. Invasion of cordgrass (*Spartina* spp.) is also an increasing threat in Tasmania and Victoria, although management strategies are successfully implemented in Tasmania. In Queensland and Western Australia, salt production is a past and present cause of saltmarsh loss, but, in the tropical north, development pressure is low, and there are extensive saltmarsh and salt pan areas.

Saltmarshes are high-risk coastal habitats, and current management is insufficient (Rogers et al. 2016). Currently, saltmarsh management is largely a local and state-run operation, and variation between states in approaches can make it difficult to compare programs in terms of success and effectiveness. Development of recovery plans requires greater understanding of species of high functional importance, responses of saltmarshes to the plethora of threats, regulating factors such as nutrient inputs and herbivory, ecosystem function and services, and hydrology (relationship with tide, groundwater and fresh water; see Box COA8). Furthermore, recovery requires increased public recognition of the value of saltmarshes, and policy change to allow inland saltmarsh to respond to rising sea levels. Understanding of saltmarsh regeneration is still in its infancy, although early indications are of long restoration times and potential for mangrove encroachment into restored areas.

The short-term outlook for temperate saltmarshes has improved because of state and national conservation and planning in the past decade, along with growing public awareness. However, the longer-term outlook for temperate saltmarshes is poor, especially where site geology (e.g. incised valleys) or coastal development limits opportunities for inland retreat to accommodate rising sea levels and mangrove encroachment. The long-term outlook for tropical saltmarshes, where development is lower, is one of greater opportunity for inland retreat.

Box COA8 Saltmarsh restoration

The Mungalla wetlands east of Ingham, on the north Queensland coast, are typical of many tropical coastal wetlands that flow into the Great Barrier Reef lagoon. Historically, they have been used for many thousands of years by Indigenous Australians to provide food and fibre, and were sustainably managed by them for their spiritual and ecological values. The ecological functions of this important coastal zone include an interconnected habitat complex of tidal and freshwater wetlands, which provides critical nursery and feeding services for a range of aquatic and land flora and fauna.

The introduction of western agriculture to the Great Barrier Reef catchment around 100 years ago has led to the progressive loss and degradation of coastal wetlands through a combination of earth bunding (where retaining walls are used to keep water back) to reclaim land for pasture, and upstream agricultural use (grazing and sugar cane production), which leached ecologically damaging nutrients and sediments. As a result, most of the coastal wetlands (40–90 per cent) were lost, and those that remained were highly infested with weeds. This was the situation with the Mungalla coastal wetlands until the property was acquired in 1999 by the Nywaigi Aboriginal Land Corporation, providing an opportunity for Nywaigi people to re-establish links with their Country, and introduce their own form of land and wetland management. This began in 2001, after the formation of the Mungalla Aboriginal Corporation for Business (MACB), which operates a cattle-grazing enterprise, with a combination of agisted and owned stock. MACB also entered a partnership with scientific advisers from CSIRO, and Tropical Water and Aquatic Ecosystem Research, James Cook University, to monitor and restore the ecology of the Mungalla wetlands within the property.

Ecological conditions were extremely poor during the first decade, with massive weed infestations causing very low dissolved oxygen conditions that greatly degraded the wetland biodiversity. Initial attempts at weed control using chemical herbicides were expensive, ecologically undesirable and of limited success. Eventually, it was decided to investigate a more natural form of weed control using tidal ingress of seawater by removing an earth bund on the seaward side of the wetland. To give some confidence that this might work, CSIRO first carried out some simulation studies using sophisticated hydrodynamic modelling, which showed that, during large tides, sea water should penetrate well into the wetland.

The earth bund was removed at the beginning of October 2013, and subsequent monitoring of the depth and salinity in the wetland showed that sea water did indeed enter the wetland several times a year on the highest tides. The ecological response was remarkable, as the freshwater weeds were immediately reduced and became almost entirely absent within 2 years of removing the bund. Specifically, there was a 39 per cent decrease in olive hymenachne (*Hymenachne amplexicaulis*), a 76 per cent decrease in water hyacinth (*Eichhornia crassipes*) and a 37 per cent decrease in salvinia (*Salvinia molesta*). Two years following the bund removal, saltmarsh communities such as native sedges, primarily bulkuru (*Eleocharis dulcis*), dominated the site. Wetland biodiversity has greatly improved, with more aquatic species and increased bird numbers. The greatest reward for this approach is that it is ecologically sound and the tidal ingress will continue, cost free.

The other key lesson from the successful restoration of the Mungalla wetlands is that it relied on the combination of Indigenous ownership and management with scientific monitoring and modelling—an approach that could well be applied to many of the currently degraded coastal wetlands in northern Queensland.

Box COA8 (continued)

Photos taken in October 2012, 50 metres above the bund wall, that show the massive infestation of Weeds of National Significance, particularly water hyacinth, before the bund was removed, and the reduction in these weeds after the bund was removed (October 2014)

Photos by Mike Nicholas

Box COA8 (continued)

Two years following the bund removal, saltmarsh communities such as these native sedges, primarily bulkuru (*Eleocharis dulcis*), dominate the site

Photo by Carla Wegscheidl

Source: Jim Wallace and Ian McLeod, James Cook University

Mangroves

Australia is home to a diverse suite of mangrove species, including 1 endemic species, *Avicennia integra*. Mangroves are broadly distributed around the Australian coastline, excluding Tasmania. Mangroves form structurally complex and productive habitats that serve as critical nursery grounds for fish; habitat for sediment infauna; and habitat for a wide range of species that frequently use mangrove resources, including birds, terrestrial vertebrates and, in the north, crocodiles. Nationally, most mangroves occur in remote areas free of significant human development; however, in 2015–16, there was a large-scale dieback of mangroves in the Gulf of Carpentaria (around 10 per cent of Australia's cover) and other locations (e.g. Mangrove Bay, Ningaloo Marine Park, Western Australia), associated with prolonged drought.

Generally, a low proportion of mangrove species throughout Australia are threatened (Polidoro et al. 2010). Increasing growth and extent of mangroves in south-eastern Australia is attributed to favourable anthropogenic conditions, such as higher nutrients, sedimentation, sea level rise, atmospheric carbon dioxide and coastal development (Saintilan et al. 2014). Trends in the north of Australia are less predictable, with some locations experiencing increased extent, and others shrinking because of erosion (Asbridge et al. 2016).

Reforms in the 1970s and 1980s largely prevented further mangrove decline caused by development (Rogers et al. 2016). However, in some locations, particularly near developed areas, mangroves are severely affected by several pressures, including modified hydrology, exposure, burial, erosion, pollutants, clearing, land-use change, and limited potential for retreat in the face of rising sea levels.

In Victoria, mangroves cover approximately 52 square kilometres (Boon et al. 2011) and are in generally good condition. Mangroves remain pressured by local coastal developments, because they are not protected in Victoria beyond the approval pathways of relevant planning schemes or by the *Coastal Management Act 1995*. Mangroves in Queensland are facing direct and indirect threats, including agricultural run-off (e.g. locations in Torres Strait), intense cyclones, erosion, flooding and drought. Mangroves in Western Australia are subject to cyclones and sea level rise (Lovelock et al. 2015), although there is no large-scale evidence of reduced quality. Pollution and erosion have contributed to the degradation in some South Australian mangrove habitats, which are also vulnerable to sea level rise, and degradation in Darwin Harbour is linked to pollution and development pressures.

There is information on the extent of mangroves, but a lack of monitoring and evaluation of their function, productivity and condition. There is a pressing need to quantify carbon sequestration dynamics of mangroves (and saltmarshes) throughout Australia. State-level assessments are sometimes better, although they lack uniform methods and comparability, particularly for temporal trends. Further, few state or national mitigation or rehabilitation strategies exist. However, one example of implemented strategies is the successful restoration of mangrove habitat in some sections of the Hunter River, New South Wales.

The outlook for mangroves in the short term is good, as they are widely protected and are generally not cleared. In the longer term, mangroves are threatened by climate change and other anthropogenic pressures, but are well positioned to deal with these threats. Mangroves in north-western Australia are predicted to decline in response to changing salinity regimes associated with drought, but increase southwards in southern Australia because of increasing temperatures and atmospheric carbon dioxide (Alongi 2015). Predicted climate change–driven alteration of rainfall patterns around the nation is likely to alter mangrove productivity and growth, which decreases with lowered rainfall. In southern Australia, mangroves are threatened by coastal development, a process sometimes aided by public dislike for various features, including the aesthetics, of this habitat.

Seagrasses

Seagrasses are flowering plants that form meadows on intertidal and subtidal sandy and muddy sediments around Australia. The condition of seagrass meadows can be assessed by quantifying the area of cover, density, biomass and species composition, or measures of resilience such as genetic diversity, seed reserves and flowering frequency. Seagrasses play a vital role in carbon cycling (Forqurean et al. 2012), primary production and sediment stability, and provide habitat for a diverse range of fauna. Historical seagrass losses are extensive, and recovery times can range from months to centuries, depending on the species. It is likely that seagrass is in poor condition in more locations than are currently known (Waycott et al. 2009). Some populations are stable or have increased in cover, particularly in areas away from human habitation, where water quality has improved or where land reclamation rates have decreased.

Seagrass is threatened by numerous processes, including nutrient input and eutrophication, herbicides, toxicants, disease, reduced light, increased sedimentation loads and resuspension, dredging, algal blooms, boating (anchoring and mooring), and habitat loss to flooding and coastal development. Climate change and associated increases in extreme weather events are a long-term threat to these critical habitat-forming species (Short & Wyllie-Echeverria 1996).

In the north, seagrass habitat in Torres Strait appears to be in good condition. There are little data for the far northern Great Barrier Reef or the Gulf of Carpentaria, but these regions are likely to be in good to very good condition. In the Great Barrier Reef, monitoring of about 45 inshore seagrass meadows indicates that their overall abundance has declined along the northern, central and southern coasts (McKenzie et al. 2015b). Other indicators of the condition of seagrass meadows, such as reproductive effort and nutrient status, have also deteriorated (McKenzie et al. 2015b). These declines are a consequence of multiple years of above average rainfall, poor water quality, and climate-related impacts followed by extreme weather events (tropical cyclones *Larry* and *Yasi*) in early 2011 (GBRMPA 2014). Populations on the east coast of Queensland are recovering, but remain in a vulnerable condition (McKenzie et al. 2015b). Other examples of declining intertidal and subtidal meadows include Mourilyan Harbour, where seagrass meadows had been consistently present since 1993, but are now in very poor condition (Reason et al. 2016), as well as substantial reductions in the meadows adjacent to Cairns (McKenna et al. 2015), Townsville (Davies et al. 2013, McKenzie et al. 2015a) and Gladstone (Sankey & Rasheed 2011, Carter et al. 2015), although the meadows are recovering.

In New South Wales, some populations of the seagrass *Posidonia australis* are recognised as threatened communities. The condition of seagrass in Victoria is good near Melbourne and eastwards. In South Australia, recent losses have been observed at Kangaroo Island, whereas other areas (e.g. around Adelaide) have not fully recovered from historical losses. The relatively unmodified northern and western coasts of Australia likely support large areas of pristine seagrass habitat. In Western Australia, seagrass is in very good condition in the northern regions, such as the Kimberley, and some southern areas, such as Geographe Bay. However, seagrass is in poor condition in some southern parts of Western Australia, such as Cockburn Sound, Perth and Leschenault Inlet, and the more northern Shark Bay. Relatively little is known about seagrass populations in the Northern Territory.

Pressures on seagrass are set to continue in the short term, particularly near centres of coastal development (Waycott et al. 2009). Trends in seagrass decline could be minimised by appropriate management, the prospect of which improves when seagrasses are recognised as high-priority species for conservation. To achieve effective management of seagrasses, we must improve our understanding of not only their extent and distribution, but also the spatial and temporal distribution of pressures, impacts and seagrass tolerance to environmental change (Kilminster et al. 2015). The long-term outlook is uncertain, and will depend on how species can respond to changes in water temperature, sea level, storm activity, freshwater inputs and erosion.

Ecological processes

Connectivity

Connectivity among species, populations and habitats is important for their long-term persistence, contributing to gene flow and supporting adaptation to environmental change. Connectivity has been altered in most habitats to some degree, because of habitat loss or fragmentation, anthropogenic change to mechanisms of dispersal, or impacts on species' biology and lifecycles. There is high consensus that changes in connectivity are occurring, but direct evidence (e.g. from genetic studies) is limited because of the inherent difficulties in studying connectivity in nature, and the relatively recent availability of technologies to measure it. Understanding connectivity is important for conservation planning, particularly in the design and placement of marine reserves (Palumbi 2003).

On land and in nearshore waters, coastal urbanisation presents a barrier to species that are restricted to the coastal zone. For example, in New South Wales, there are known distributional gaps for species such as *Phyllospora comosa* (Coleman et al. 2008). This is particularly problematic for species that migrate or are reproductive seasonally or as part of their lifecycle, or for those attempting range extensions in response to changing climate. For example, disruption of connectivity through habitat loss on international flyways is considered the major threat to most shorebirds (see Nursing, roosting and nesting).

Of the jurisdictions, New South Wales, Western Australia and Queensland are the most likely to have altered marine connectivity because of their strong and rapidly changing boundary current systems (Cetina-Heredia et al. 2015). The ranges of tropical species (Vergés et al. 2014) are expanding, and temperate species are retreating polewards (Wernberg et al. 2011). A strengthening East Australian Current is facilitating expansion of the long-spined sea urchin (*Centrostephanus rodgersii*) into Tasmania. The importance of increased connectivity relative to other pressures for larval outbreaks of crown-of-thorns starfish (*Acanthaster planci*) along the Queensland coast is still uncertain (see the *Marine environment* report for further discussion of crown-of-thorns starfish). In Western Australia, connectivity of lobster populations is altered by climate change–driven heatwaves, and the loss of macroalgae from the north may have decreased connectivity.

In contrast, connectivity may be most stable in the Northern Territory, because of the largely unmodified coastline and lack of a rapidly changing boundary current.

Connectivity has changed, and will continue to change, in differing directions, particularly on larger temporal scales, but quantifying this requires long-term measurements using genetic tools at the least. On short temporal scales, changes to connectivity will likely be related more to short-term 'pulse' events that alter species distributions (e.g. pollution events, development) or episodic climatic events such as the 2012 marine heatwave in Western Australia (Wernberg et al. 2013).

Conservation strategies such as spatial closures and fisheries restrictions should aim to maintain connectivity of native species, and reduce connectivity for non-native species. How to integrate connectivity into conservation planning across species and habitats is uncertain, as is anticipating changes to vectors of dispersal. More temporal studies are needed, and generalities need to be explored (but see Durrant et al. 2013). One tool to assist is the Australian Connectivity Interface (currently known as Connie 2), which estimates the probability that any 2 regions of upper water column are connected through passive dispersal (Condie et al. 2005).

Nursing, roosting and nesting

Nursing, roosting and nesting sites are generally protective and productive habitats, such as mangroves, beaches, islands and wetlands. Several groups of animals, including shorebirds, seabirds and turtles, use these habitats to breed, and for juvenile development and rest.

The pressures on these sites vary between locations and species. Pressures on important beach sites include nourishment, armouring, grooming and seaweed harvesting (Schlacher et al. 2014). Seaweed harvesting is a growing industry in south-eastern South Australia, where a key ecosystem component is removed from coastal food webs. Other more general pressures include urbanisation, port developments, recreational disturbance, water abstraction and sea level rise. Rising sea levels threaten to move turtle nesting inland in the short term, and to remove suitable habitat in the longer term. Many turtle nesting sites are threatened by human settlement and associated light pollution (Kamrowski et al. 2012). Non-native predators such as dogs, foxes and rats also increase mortality at nursing, roosting and nesting sites. Predation by corvids, dogs and foxes threatens penguins and other ground-dwelling birds (Ekanayake et al. 2015), and foxes and pigs dig up the turtle nests and eat the eggs. The Queensland and Australian governments are contributing $7 million across 4 years to combat the threat of feral predators to turtle nests.

The outlook for coastal nursing, roosting and nesting sites is poor. Increasing sea levels, combined with coastal armouring, will modify habitats to the point that they will be unsuitable for many species, and nursing, roosting and nesting sites need to be explicitly considered when developing coastal management plans to accommodate these changes.

Trophic structures and relationships

The nature of trophic (feeding and predation) interactions among ecosystem members has implications for food-web diversity, stability and function (Rooney & McCann 2012). Human activities in the coastal environment disrupt trophic structure and relationships by removing larger species and predators, predominantly through overharvesting. Trophic structures may also be affected through bottom-up processes such as increased nutrient addition to local waters.

For estuaries, there are many uncertainties regarding the condition of trophic dynamics at the national scale, particularly for turbid estuaries in northern Australia. Good but patchy information on trophic relationships comes from stomach content analysis and stable isotope studies, and data on trophic structure come from fisheries data or diver-based surveys of outer estuaries and embayments (Edgar & Stuart-Smith 2014). In general, surveys have suggested that food webs are lacking in higher trophic level representatives that should be present and, in some cases, are extremely lacking in expected species and therefore particular functional groups.

Evidence for human impacts on trophic dynamics can be seen when management actions remove or reduce the activities that disrupt relationships. For example, data from green zones in the Great Barrier Reef show major changes in trophic structure in response to closure from fishing, demonstrating the effects that had previously been imposed by fishing. Other evidence has been found in Tasmania, where, outside the MPAs, removing lobsters decreases kelp resilience to invasive long-spined sea urchins (*Centrostephanus rodgersii*), increasing the potential for the creation of urchin barrens (Ling et al. 2009). Higher-level predators are also expected to increase in locations such as Jervis Bay, Port Stephens, Port Davey and Moreton Bay, where MPAs offer opportunities to restore more natural trophic structures.

The outlook for trophic structures in the future is uncertain. Trophic relationships will always exist, loss of species and trophic levels will reduce the range of relationships, and there will be an overabundance of biota that have been freed from their predators. In the short term, trends are likely to remain stable, with the potential to improve in the long term where human activities are well managed.

Filter feeding

Filter feeding (where animals such as sponges, bivalves and barnacles feed by straining suspended food particles from water) is a crucial ecological process that maintains water quality and biogeochemical cycling in coastal waters. Filter feeders can be particularly important in nutrient-poor environments. For example, because of their filter feeding and ability to recycle dissolved organic matter, sponges were recently found to facilitate coral reefs in nutrient-poor waters (de Goeij et al. 2013).

The state of coastal filter-feeding communities varies tremendously based on exposure to both local anthropogenic pressures (e.g. nutrients and point-source pollutants) and natural pressures (e.g. rainfall causing reduced salinity and increased run-off). Consequently, their state varies on small spatial scales (kilometres) and across relatively short time periods. For example, a filter-feeding community near a metropolitan river is likely to be in a different condition from a filter-feeding community in a remote area, although both will respond to recent changes in rainfall. Clark et al. (2015) found increased abundances of active filter feeders such as barnacles and sea squirts in highly developed estuaries, and this is a potential response to increased pelagic food availability in nutrient-enriched areas (Lawes et al. 2016).

There is no general source of information for filter feeding nationally. Online resources such as eReefs present a range of environmental variables and predictions relevant to Queensland coastal filter-feeding communities (e.g. catchment flow, water quality forecasting, sediment modelling); however, there is limited inclusion of fauna other than reef-forming corals.

To appropriately manage coastal filter-feeding processes, a focus is needed on measuring and modelling water quality parameters (e.g. nutrient and pollutant run-off, turbidity) and other pressures (e.g. temperature, salinity) (Fisher et al. 2015), and then linking these to the abundance of filter feeders and rates of feeding. A recent study compiling data from 3 dredging programs in tropical Australia summarised water quality parameters so that thresholds may be developed for filter-feeding organisms (Fisher et al. 2015). This form of research will facilitate best environmental practice and monitoring of filter-feeding communities in response to potential pressures.

The outlook for filter feeding as an ecological process is dependent on the spatial scale of interest. The likelihood of high rainfall because of extreme storm events associated with ENSO and climate change will increase the likelihood of extreme freshwater stress to estuarine populations of filter feeders. Other ecological communities (particularly those in intertidal and mudflat areas) may also be exposed to thermal stress because of warming waters and hotter days.

Microbial processes and nutrient cycling

Natural populations of endemic marine microorganisms form the base of the marine food web and provide a suite of valuable ecosystem services (Falkowski et al. 2008). Marine microbes transform elements in a series of processes that control biogeochemical cycling in coastal waters (Worden et al. 2015). These processes and elemental cycles in turn affect the availability of nutrients such as carbon and nitrogen to the food web, and the ocean's influence on global climate (Falkowski et al. 1998, Worden et al. 2015). Shifts in the productivity and composition of microbial populations can strongly influence food-web structure and even drive yields of commercial fisheries.

Microbial processes in the coastal zone are strongly influenced by the input of allochthonous nutrients (nutrients coming from outside the ecosystem), other contaminants (Doney 2010, Nogales et al. 2011) and organic matter. These inputs can lead to dramatic shifts in microbial community composition (Sun et al. 2012, 2013) that result in changes in function (e.g. elevated respiration leading to anoxia) or bloom events, which can be toxic. Eutrophication can also disrupt the balance of microbial interactions with marine plants and animals, leading to disease outbreaks.

Tasman Peninsula coastline, Tasmania
Photo by Megan Watson

In the short term, increased human population densities near the coast have the potential to increase the input of nutrients and contaminants (Kennish 2002), and exacerbate these impacts, although stricter environmental regulations and better awareness may buffer these effects. In the longer term, microbial diversity and functionality may be influenced by climate change processes (Doney et al. 2012). Microbial activity is strongly influenced by temperature, and there is evidence that rising seawater temperatures may cause significant shifts in the composition of marine microbial assemblages (Fan et al. 2013, Kroeker et al. 2013). This can ultimately lead to changes in the biogeochemical function of microbial assemblages, or increases in the occurrence and virulence of diseases (Campbell et al. 2011, Case et al. 2011), including potentially dangerous pathogens such as *Vibrio* spp. (Kelly 1982).

Microbial pathogens cause disease in marine animals and plants, including species of economic interest. Other marine microbes form transient noxious blooms, which can disrupt the function of entire coastal ecosystems. Microbe-related blooms are being observed more frequently, across larger areas and with more severity (Hallegraeff 1993). Introduced microbes, including enteric microbes (bacteria and viruses), enter marine environments through various pollution point sources (e.g. sewage overflows, storm water), and can threaten the health of human populations that use coastal environments for recreation and food supply (Nogales et al. 2011). Whether increased reporting of microbial-mediated disease reflects more incidences or greater awareness is unclear.

Because marine microbial populations are extremely sensitive to environmental change, the balance of these positive and negative effects can shift rapidly. This can have implications for ecosystem function (e.g. primary production) and, in some cases, can produce large-scale ecological impacts (e.g. noxious bloom events) (Hambright et al. 2014). Understanding the factors that control and alter the structure and function of marine microbial assemblages is critical from an ecosystem management perspective (Bodelier 2011), because even subtle shifts in the composition of microbial assemblages can affect ecosystem and human health.

Lack of data on microbial processes within marine systems makes it difficult to judge the state of microbial processes within the Australian coastal marine environment. Additionally, the complexity and spatiotemporal heterogeneity of microbial processes (Stocker 2012, Ladau et al. 2013) complicate our ability to understand microbial dynamics within Australian waters, or predict how microbial processes will change under different environmental conditions. Little is known about patterns of diversity (Ladau et al. 2013), specific responses of taxonomic units to stress and their contribution to ecosystem function (Evans-Illidge et al. 2013). We lack baseline information, such as the identity of natural communities of microbes living within specific habitats at a given time, and how the composition and function of natural marine microbial assemblages change temporally or spatially (Ottesen et al. 2012; see Box COA9). At a higher level, we also lack anything beyond a simple understanding of how microbial community structure and function respond to shifting environmental conditions and hydrodynamic processes.

To remedy this, we need sustained measurement of important microbial processes (e.g. nitrogen and carbon dioxide fixation, carbon turnover, host–microbe interactions), coupled with information on microbial diversity (Worden et al. 2015). This would enable us to link function to specific microorganisms, and hence develop a full model of the microbial process in the coastal environment. This information, combined with experimentation and ecosystem models (Coelho et al. 2013), would help to build a more complete picture of coastal ecosystem functioning in the face of environmental pressures.

Box COA9 Impacts of urbanisation on sediment microbial composition in New South Wales estuaries

In polluted estuaries, a significant proportion of excess nutrients and toxicants is stored in the sediments, which act like a sponge for contaminants. These same sediments also contain sediment microbes, which perform a diversity of crucial ecosystem processes. Although toxicants and microbes often co-occur, the impacts of pollution on the basic ecosystem processes provided by microbial communities are poorly understood.

To determine the impacts of pollutants on sediment microbes, sediments from both polluted and clean estuaries were collected to compare their microbial composition. This was done using DNA fingerprinting of the bacterial 16S-23S internal transcribed spacer gene. Changes in the relative abundance of 411 unique bacterial 'species' were measured in 58 sediment samples from 8 estuaries along the New South Wales coast. Water quality was measured at the time of sampling, as well as metal and organic pollutant concentrations in the sediment.

Researchers found that similarities in microbial community composition strongly reflected the spatial distribution of samples, with sediments from the same estuary having many common bacterial 'species'. However, the strongest influencing factor was found to be sediment silt content, because it determines the abundance of nutrients available for microbial growth. Sediment silt content explained about 9 per cent of community change. Metal toxicants, which come from anthropogenic sources such as pesticides, plastics and pharmaceuticals, also had a strong influence on bacterial community composition, explaining approximately 4 per cent of the variation.

Given the sensitivity of microbial communities to their surrounding environment, further research is looking to determine links between changes in community composition and the potential disruption of key ecosystem functions provided by microbes. This is being done by looking at gene expression levels of important biogeochemical pathways using next-generation sequencing techniques. Researchers performed a field experiment to test the impact of metal toxicants and fertilisers on sediment microbial processes. They have demonstrated not only shifts in the community structure with contamination, but also changes in microbial functions. Enrichment with fertilisers disrupted crucial biogeochemical pathways and led to the potential for increased production of greenhouse gases in affected sediments. The potential impacts on the global climate of these functional changes highlight the importance of understanding the impact of contaminants on microbial processes.

Currently, temporal observations of both reference and human-affected microbial communities are contributing to building a database of Australia's microbial potential. Surveys on impacts of storm water on microbial processes will further our understanding of functional changes in affected coastal ecosystems.

Source: Dr Melanie Sun, University of New South Wales

Knowledge of coastal microbial processes is improving on the back of technological advances and greater research interest (Stocker 2012). Modern approaches have enabled researchers to gather valuable information in the past 5 years, with a limited body of recent work demonstrating human impacts on microbial communities. Currently, our knowledge of microbial processes within Australian marine ecosystems is derived from 2 main sources:

- Research and monitoring conducted by universities, CSIRO and the Australian Institute for Marine Science.

  Australia has a strong research community in marine microbial ecology, and research is conducted in a range of habitats, spanning the coasts to the open ocean, and from the water column to sediments, and in animal and plant hosts (Marzinelli et al. 2015). A recent development that will advance this research is the Bioplatforms Australia Marine Microbiology Project, which involves members of several universities, as well as CSIRO, the Australian Institute for Marine Science and the Integrated Marine Observing System (IMOS). The project will sequence microbial assemblages from 7 oceanographic IMOS National Reference Stations and 3 coastal monitoring sites around Australia, and will describe the monthly, seasonal and interannual dynamics of microbial taxonomic and metabolic capacity in waters ranging from the tropics to the Southern Ocean.

- Monitoring of coastal environments for microbial contaminants from pollution (sewage and storm water).

  Monitoring by various state and Australian government agencies provides data on the occurrence of enteric indicator microbes (e.g. enterococci counts), to gain an insight into the occurrence of potentially dangerous human pathogens within coastal habitats. One example of this basic data source in New South Wales is provided by Beachwatch, which uses *Escherichia coli* counts to consider the water quality of beaches along the New South Wales coastline. Given the advanced technology available to detect a huge range of more sensitive indicators of pathogenic potential, basic cell counts of cultivated microbes such as this are likely to be rapidly replaced.

Coastal heritage

The section should be read in conjunction with the *Heritage* report. Much of the data in the *Heritage* report include the coastal zone, so it is summarised here, and readers are directed to the *Heritage* report for detail.

Coastal heritage includes places, items, practices, observations, customs and lores important to the historical, natural and cultural values of the coast. Heritage is intrinsically dependent on knowledge, as this is required to attach significance to an item or place. Collating and maintaining appropriate documentation for all facets of heritage is a major challenge in solidifying the value of coastal heritage through time.

We describe 2 important case studies relating to the documentation of coastal heritage since 2011:

- improved understanding and recognition of Indigenous coastal heritage in New South Wales
- incorporation of heritage values into Great Barrier Reef reporting and planning.

Coastal Indigenous heritage in New South Wales

In the past, documentation on coastal heritage in New South Wales has been largely eurocentric, focusing on shipwrecks, buildings and sites of significance to early European colonisation. There has been some inclusion of Indigenous middens and sites with Indigenous art, but documentation has seldom been representative of the nature, depth and richness of Indigenous heritage. This is in contrast to northern parts of Australia, where Indigenous heritage has received more attention.

Recent efforts have sought to improve this, with a report commissioned by the New South Wales Marine Estate Management Authority to examine Indigenous heritage in relation to the coast and sea (Feary 2015). The report found that the main benefits of the New South Wales marine estate to Indigenous people are cultural connection and cultural identity associated with resource use. Marine resources are not only a food source for Indigenous people, they are a mechanism through which a range of socio-cultural behaviours and protocols shape modern Indigenous society. In particular, community harvesting of resources is an integral part of maintaining cultural identity, as it encourages people to congregate on the coast, and pass on traditional knowledge within and between generations.

In 2013, the New South Wales Government released a model for standalone Indigenous cultural heritage legislation (NSW OEH 2013). This was delivered after extensive consultation with stakeholders and the community, and advice from the independent Aboriginal Culture and Heritage Reform Working Party. The proposed new model aims to improve the identification of important objects, provide more effective protection for cultural assets and higher penalties for breaches of the proposed Aboriginal Cultural Heritage Act, and achieve better integration of cultural heritage in planning processes.

Other recent advances in New South Wales include:

- Indigenous cultural heritage, including legal recognition of 'cultural fishing'
- special zoning in marine parks
- greater participation in decision-making.

Heritage of the Great Barrier Reef

The *Great Barrier Reef outlook report 2014* was the first in the series to include a chapter on heritage values. This was in response to the 2008 amendment of the *Great Barrier Reef Marine Park Act 1975*, and recommendations by the World Heritage Committee in 2012.

The report organised heritage values into 6 groups, and captures the following components:

- Indigenous heritage values—cultural practices, observations, customs, lores, sacred sites, sites of significance, places of cultural tradition, stories, songlines, totems, languages, Indigenous structures, technology, tools and archaeology
- historic heritage values—historic voyages, shipwrecks, historic lighthouses, World War 2 features and sites, other places of historical significance
- other heritage values—places of social, aesthetic and scientific significance
- World Heritage values—natural beauty and natural phenomena, places reflecting major stages of Earth's evolutionary history, ecological and biological processes, and habitats for conservation of biodiversity
- Commonwealth heritage values—military training areas, lighthouses and islands
- natural heritage values—biodiversity and ecosystem function.

The report found that, in general, heritage values of the Great Barrier Reef were poorly documented and understood. This is likely to improve with increased inclusion of heritage in planning and outlook reporting.

The Traditional Use of Marine Resource Agreements outline management practices relating to traditional use of included regions. These agreements are formed by Great Barrier Reef traditional owner groups in partnership with the Great Barrier Reef Marine Park Authority, the Queensland Government and the Australian Government.

Pressures

Pressures on coastal heritage include the pressures outlined for the coastal environment. Coastal development is threatening to remove or degrade sites of natural heritage, although protection is generally increasing. Effects of climate change will accelerate the degradation of any historic artefacts and change the character of natural heritage values. In particular, predicted sea level rise would see many sites of coastal heritage inundated, often with no options for relocation. In addition to pressures on the environment, coastal heritage is pressured by activities or policies that reduce the capacity of Indigenous coastal communities to continue their cultural practices, including their observations, customs, lores, stories, songlines, totems and languages.

Assessment summary 2

State and trends of quality of habitats

Component	Summary	Assessment grade (Very poor, Poor, Good, Very good)	Confidence (In grade, In trend)	Comparability (To 2011 assessment)
Rocky shoreline	Data are poor, but it is clear that rocky shorelines are stressed by heatwaves, pollution, groundwater discharge, harvesting, trampling, sea level rise and foreshore development			
Beaches and sand dunes	Most beaches are in good condition but are threatened by debris, mechanical cleaning and compaction by 4WD vehicles. Sand dunes are heavily affected by foreshore development, invasive species and historical practices of 'stabilisation'			
Mudflats and sandbars	Data are poor, but the majority are in good condition when they are at a distance from population centres			
Lagoons	Recent trends are unclear, but their condition is affected by coastal development, organic enrichment, recreational fishing and entrance modification			
Estuaries	Approximately half are significantly affected by historical and contemporary developments. Pressures include pollution, hydrological modifications, the addition of artificial structures, dredging, shipping, invasive species, and recreational and commercial fishing			
Bays	Heavily used bays suffer from contamination issues, introduced species, increased physical disturbance, fishing and the addition of artificial structures			

Assessment summary 2 (continued)

Recent trends	Grades	Confidence	Comparability
Improving	**Very good:** Human activities or declining environmental conditions have had no or only minor impacts on habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes	**Adequate:** Adequate high-quality evidence **and** high level of consensus	**Comparable:** Grade and trend are comparable to the previous assessment
Deteriorating	**Good:** Human activities or declining environmental conditions have had some significant impacts on habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes, but effects are not persistent or substantial on overall habitats, species/taxa groups or processes	**Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus	**Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
Stable	**Poor:** Human activities or declining environmental conditions have caused substantial changes to habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes, resulting in persistent and substantial effects on habitats, species/taxa groups or processes	**Limited:** Limited evidence **or** limited consensus	**Not comparable:** Grade and trend are not comparable to the previous assessment
Unclear	**Very poor:** Human activities or declining environmental conditions have caused widespread changes to habitats, species/taxa groups or processes, resulting in loss of habitat, species/taxa groups and ecosystem functioning	**Very limited:** Limited evidence **and** limited consensus	X **Not previously assessed**
		Low: Evidence and consensus too low to make an assessment	

Assessment summary 3

State and trends of quality of habitat-forming species

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Saltmarshes	Historically decimated near urban areas in the south-east, with loss due to channelling of rivers, concretisation and drainage. Currently under threat from mangrove encroachment, invasive species and insect control activities	Poor ↙	◕	◕	⬙
Mangroves	Approximately 10% of Australia's mangroves were lost in 2016 because of climate pressures in northern Australia. Affected by coastal development in some areas, but increasing in extent elsewhere	Poor ↙	◕	◔	⬙
Seagrass	Pressured by nutrient and sediment addition, habitat loss and severe weather events (e.g. tropical cyclones), particularly in Queensland and New South Wales	Poor ↙	◒	◒	⬙

Recent trends

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

Grades

- **Very good:** Human activities or declining environmental conditions have had no or only minor impacts on habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes
- **Good:** Human activities or declining environmental conditions have had some significant impacts on habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes, but effects are not persistent or substantial on overall habitats, species/taxa groups or processes
- **Poor:** Human activities or declining environmental conditions have caused substantial changes to habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes, resulting in persistent and substantial effects on habitats, species/taxa groups or processes
- **Very poor:** Human activities or declining environmental conditions have caused widespread changes to habitats, species/taxa groups or processes, resulting in loss of habitat, species/taxa groups and ecosystem functioning

Confidence

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

Comparability

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

Assessment summary 4

State and trends of species populations and groups

Component	Summary	Assessment grade				Confidence		Comparability
		Very poor	Poor	Good	Very good	In grade	In trend	To 2011 assessment
Shorebird species	In severe decline because of loss of critical habitat in Australia and overseas							
Crocodiles—saltwater	Populations are healthy and growing under protection from hunting, particularly in the Northern Territory							
Crocodiles—freshwater	Major populations in the Northern Territory are declining because of the impacts of cane toads							
Dugongs	Good in Torres Strait, and likely good in most of the remote regions of northern Australia, with the likely exception of the northern Great Barrier Reef. Poor and deteriorating in the southern Great Barrier Reef region (south of Cooktown). Stable in south-east Queensland. Declines because of habitat loss, gill-netting and extreme weather events in the past 5 years							
Estuarine fish species	Species composition and abundance are altered in some estuaries because of fishing, nutrient addition (leading to eutrophication), reduced freshwater input and increased marine influence							
Estuarine invertebrate species	Modified by human activities including invasive species, contamination and disease, although the direction of change is variable							
Crab species	Data are poor, but believed to be in good and stable condition in areas away from major human settlements							

Assessment summary 4 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Shellfish species	Suffered from historical overexploitation, but are currently stable, and restoration trials are under way. At threat from disease in some regions	Poor, Stable	Limited	Limited	Somewhat comparable

Recent trends

- Improving
- Deteriorating
- Stable
- Unclear

Grades

- **Very good:** Human activities or declining environmental conditions have had no or only minor impacts on habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes
- **Good:** Human activities or declining environmental conditions have had some significant impacts on habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes, but effects are not persistent or substantial on overall habitats, species/taxa groups or processes
- **Poor:** Human activities or declining environmental conditions have caused substantial changes to habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes, resulting in persistent and substantial effects on habitats, species/taxa groups or processes
- **Very poor:** Human activities or declining environmental conditions have caused widespread changes to habitats, species/taxa groups or processes, resulting in loss of habitat, species/taxa groups and ecosystem functioning

Confidence

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

Comparability

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

Assessment summary 5

State and trends of ecological processes

Component	Summary	Assessment grade				Confidence		Comparability
		Very poor	Poor	Good	Very good	In grade	In trend	To 2011 assessment
Connectivity	Data are poor, but believed to be worsening because of habitat fragmentation and anthropogenic change to mechanisms of dispersal. Connectivity has increased for those species that can use ships and other vessels as a vector		↙					
Nesting, roosting and nursing sites	Under increasing threat from a range of human activities and climate-related pressures		↙					
Trophic structures and relationships	Modified by overharvesting and nutrient enrichment. Improving where fishing activity and urban/ agricultural inputs are well managed		—					
Filter feeding	Data are poor; baseline and current condition are largely unquantified but are believed to be stable			—				
Microbial processes and nutrient cycling	Data are poor. Sensitive to human impacts, particularly nutrient and contaminant inputs. May be useful indicators for biomonitoring		↙					

Assessment summary 5 (continued)

Recent trends

- Improving
- Deteriorating
- Stable
- Unclear

Grades

- **Very good:** Human activities or declining environmental conditions have had no or only minor impacts on habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes
- **Good:** Human activities or declining environmental conditions have had some significant impacts on habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes, but effects are not persistent or substantial on overall habitats, species/taxa groups or processes
- **Poor:** Human activities or declining environmental conditions have caused substantial changes to habitats; species/taxa groups; or physical, biogeochemical, biological or ecological processes, resulting in persistent and substantial effects on habitats, species/taxa groups or processes
- **Very poor:** Human activities or declining environmental conditions have caused widespread changes to habitats, species/taxa groups or processes, resulting in loss of habitat, species/taxa groups and ecosystem functioning

Confidence

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

Comparability

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

Effectiveness
of coastal management

At a glance

Qualities that make Australia's coast remarkable—its vastness and diversity—also make it challenging to manage. The coast is important to a wide range of stakeholders, and is often subject to competing interests that require effective management. All tiers of government (local, state, national) have roles in decisions related to coastal management, but insufficient coordination between these tiers has long been a concern. Many aspects of coastal management in Australia are conducted at the scale of local council, yet there are ongoing calls for better integration with higher levels of government.

The challenge for coastal managers is to balance multiple competing uses of the coast, while minimising the environmental, economic and social impacts of those uses. Increasingly, coastal managers must also integrate climate adaptation and mitigation into their management plans. Cumulative impact management would assist in achieving this goal, by acknowledging the combined and synergistic impacts of multiple activities. Other promising avenues in coastal management are ecosystem-based management, risk-based methods for prioritising management, emerging analytics (e.g. remote sensing, molecular biomonitoring), and frameworks for conservation at multiple levels of biodiversity.

Coastal governance and management

As was emphasised in previous SoE reports (e.g. SoE 2011), coastal management in Australia is carried out using a range of approaches by multiple levels of government. Most management is done by local councils, and state and territory governments, and, for most issues, levels of government are not coordinated (see Integrated coastal management frameworks). Ideally, the scale of management should match the scales at which pressures and processes operate. Many of the pressures affecting the coast are national in scale, and national management frameworks are therefore desirable.

The EPBC Act provides national protection for coastal biodiversity. Coastal environments receive national protection under the EPBC Act if classified as Ramsar wetlands[1] (Australia has 28 coastal wetlands), or if they contain nationally threatened species (see Threatened species), ecological communities or migratory species. Of the 23 Conservation Management Zones outlined by the Australian Government, 18 include a coastal component.

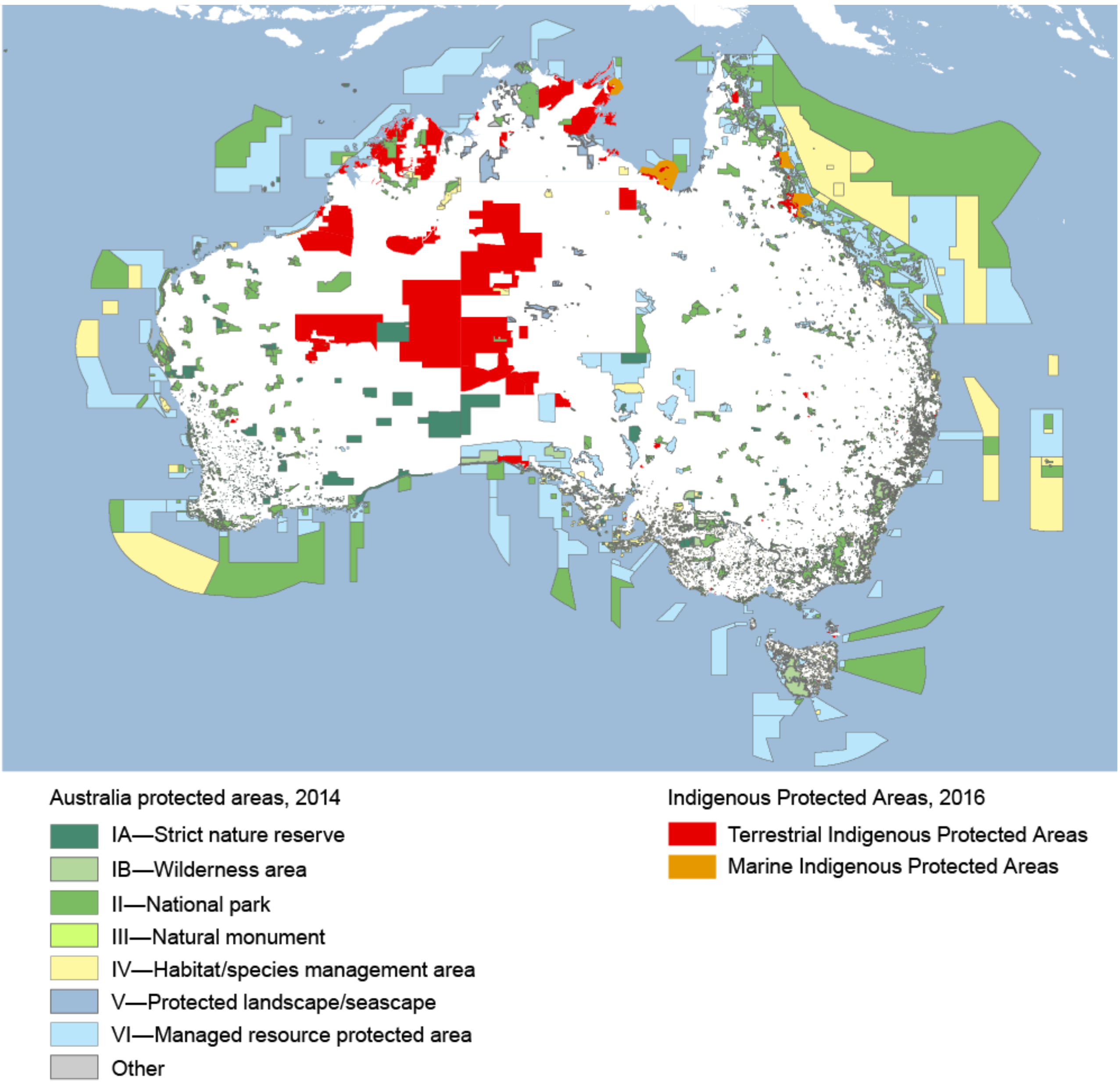
An overview of protected areas across Australia is provided by the Collaborative Australian Protected Area Database, which compiles information on protected areas, including those in the coastal zone (Figure COA16). Levels of protection range from 1 to 6, corresponding to the 6 IUCN protected area categories. The highest level of protection is 1, and 6 is the lowest. In addition to these are Indigenous Protected Areas, which are identified land and sea Country dedicated for protection by Aboriginal and Torres Strait Islander people.

Coastal communities often hold mixed values and opinions about how to manage the land, the sea and natural resources. Coastal planners have the difficult task of considering different points of view, solving conflicts and creating a management plan that is widely acknowledged (Domínguez-Tejo et al. 2016). To achieve this, coastal planners follow planning frameworks.

1 The Convention on Wetlands of International Importance (Ramsar, Iran, 1971) is an intergovernmental treaty whose mission is 'the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world'. As of January 2013, 163 nations had joined the convention as contracting parties, and more than 2060 wetlands around the world had been designated for inclusion in the Ramsar List of Wetlands of International Importance.

Frameworks are like building blueprints that help planners and the community work together on what they want to achieve. They provide guidelines, or step-by-step instructions, to lead the planning process.

Marine spatial planning (MSP) is one of the frameworks used worldwide. Through MSP, multiple stakeholders collaborate in a public process, analysing human activities in their planning area. They assess the known and potential impacts of the activities on



Source: Collaborative Australian Protected Area Database, Australian Government Department of the Environment and Energy, 2014

Figure COA16 Australian protected areas, 2014, and Indigenous Protected Areas, 2016 the environment, and, ultimately, a plan is drafted supporting a balanced set of ecological, economic and social objectives. MSP has been undertaken in places such as the Great Barrier Reef (see Box COA10) and the New South Wales coast. Similarly, the ecosystem-based approach (EBA) to marine planning tries to find a balance between development needs and protecting the environment, and is the backbone of the United Nation's Convention on Biological Diversity. When these frameworks are coupled together, the MSP–EBA paradigm has shown great potential to help us understand social values attached to the marine environment.

Coastal management is also promoted by nongovernment organisations, such as the Australian Coastal Councils Association. Known as the National Sea Change Taskforce until July 2015, the association is a national body representing the interests of coastal councils and their communities. It commissions research on a range of coastal issues and advocates for the interests of coastal councils to various levels of government.

The *Marine nation 2025: marine science to support Australia's blue economy* (2013) position paper outlined Australia's 'blue economy' prospects. This document was preceded by the National Marine Science Plan (NMSP; 2015), which identified the creation of sustainable urban coastal development as a key challenge in supporting Australia's blue economy attempts to deliver 'economical, cultural and social benefits that are efficient, equitable and sustainable'.

The NMSP made the following recommendations for better management of urban coastal areas, some of which are also applicable to unmodified areas of coast:

- Provide targeted projections of sea level rise, including changes in extreme flood events.
- Better characterise catchment contaminant pathways, coastal morphologies and environmental processes, and define envelopes of natural variability and thresholds of concern.
- Understand pressure interactions and resource use, including the cumulative impacts of sea level rise; loss and continual degradation of coastal and estuarine habitats; and loss of productivity, ecosystem services and population connectivity.
- Develop innovative sensing technologies, including those based on new molecular tools, to provide cost-effective monitoring in the coastal zone.
- Improve data coordination and discoverability of coastal data from multiple sources.
- Develop, test and apply methods to mitigate the impact of coastal hazards, including eco-engineering and restoration approaches.

The National Climate Change Adaptation Research Facility is developing its CoastAdapt tool, which will address some of these recommendations. Australia's 'blue economy' plans are discussed in further detail in the *Marine environment* report.

The *Plan for a cleaner environment* (DoE 2016) outlines Australia's efforts towards achieving clean air, clean land, clean water and heritage protection.

A measure of the effectiveness of land management is the status of conservation of major vegetation groups. Figure COA17 shows the extent of each remaining vegetation group relative to the percentage protected under IUCN protected levels 1 to 4 (see Figure COA11 for information about their change in coverage). It shows the current state in 2014 and the change since 2010 in the percentage reserved. Coastal vegetation groups that are both low in extent and poorly protected (and therefore vulnerable) are Acacia Open Woodlands, and Acacia Forests and Woodlands (Figure COA17). Reduced protection has occurred for Chenopod Shrublands, and Samphire Shrublands and Forblands, which have had their protected areas reduced by more than 15 per cent since 2010.

Three current issues in coastal management are frameworks for integrated management, cumulative impact management and risk-based methods for prioritising management. These are discussed in the following sections, followed by a discussion of recent developments in approach and methods for coastal management.

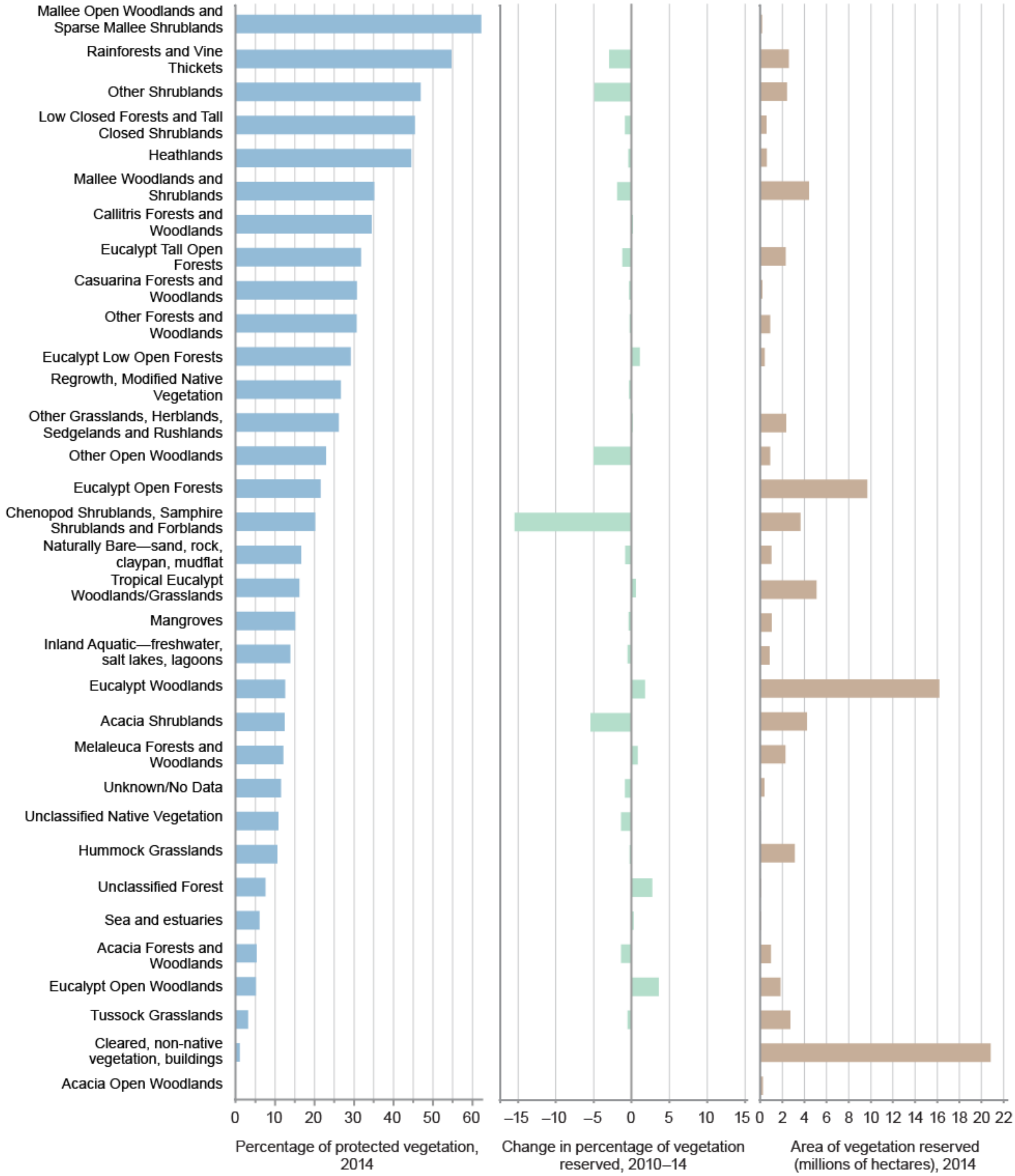
Box COA10 Management of the Great Barrier Reef

A topical area of coastal management is the Great Barrier Reef. The Reef is in poor and declining condition as a result of catchment activities, in combination with pressures associated with climate change (see the *Marine environment* report). Future governance is facing the difficult prospect of balancing economic growth with environmental sustainability, while simultaneously managing the effects of a changing climate. Focus is placed on improving water quality and restoring critical ecosystems, but there is often disagreement among interested parties (e.g. agriculture versus tourism industries) regarding the effectiveness of current and proposed management frameworks.

Several recent reports outline management practices for the Great Barrier Reef, including *Great Barrier Reef outlook report 2014*, *Great Barrier Reef Water Science Taskforce final report 2016*, the Reef 2050 Long-Term Sustainability Plan (2015) and the Reef 2050 Plan—Implementation Strategy.

Diver among numerous fish off the coast of the World Heritage–listed Lord Howe Island

Photo by Paradise Ink



Note: Of most concern are vegetation groups that have both low extent, and low percentage reserved and/or high decrease in percentage reserved.
Source: Environmental Resources Information Network, Australian Government Department of the Environment and Energy, 2016

Figure COA17 Percentage reserved and change in percentage reserved of major vegetation groups within 50 kilometres of the shore, 2010 to 2014

Integrated coastal management frameworks

Integrated coastal zone management (ICZM) is the process for managing all coastal issues in a framework integrated across biota and habitats, time and space, and levels of government. It attempts to consider and streamline cooperation among a range of stakeholders and government agencies. The overarching aim of ICZM is sustainability, while achieving the best possible outcomes for both large-scale and local-scale issues concerning society, the environment and the economy.

ICZM is a dynamic, multidisciplinary and iterative process to promote sustainable management of coastal zones. It covers the full cycle of information collection, planning (in its broadest sense), decision-making, management and monitoring of implementation. ICZM uses the informed participation and cooperation of all stakeholders to assess the societal goals in a coastal area, and to take actions towards meeting these objectives. ICZM seeks, during the long term, to balance environmental, economic, social, cultural and recreational objectives, all within the limits set by natural dynamics.

The principles of ICZM are for it to be:

- transparent
- based on risk assessment
- inclusive of a social aspect
- appropriate to the scale of the issues being addressed
- underpinned by sound ecological understanding
- able to provide clear structures among agencies to streamline the entire process.

Currently, ICZM is only implemented in some areas of Australian coastal management, and to varying extents. Although the national ICZM framework has been formally outlined (NRMMC 2006), no body of information contains the various management policies and strategies found around Australia. Additionally, the current framework among government departments for dealing with coastal issues is largely defunct, with each state having separate management practices and legislation concerning development of the coast.

In most regions, current decision-making processes can, in theory, lead to improvements in the state of coastal environments, but there is little integration between coastal and marine planning. The management landscape is further complicated by the presence of catchment councils, port authorities and regional management authorities, and the role of these agencies in advising or decision-making varies. Population growth in coastal regions is adding substantial financial strain to local councils.

ICZM requires ecological evidence on which to base risk assessments and other components of the framework. Effective ecological assessment requires quantification of multiple components of ecological health, using transparent and reproducible methods for comparable coasts in a given region (Borja et al. 2016). Effective ecological assessments are not available for most of Australia's coastal waterways. In addition, those involved with environmental management of coastal and marine ecosystems may consider economic valuation of ecosystem services to be useful in decision-making; however, rarely has this approach been put into practice (Marre et al. 2016).

Coastal management policy and its coordination lack clarity, especially concerning sea level rise (Bell et al. 2014). Invasive species management and certain fisheries frameworks are also state specific, and integration among and within states and territories is variable. Assessment of planned projects may also fail to consider cumulative impacts (see Cumulative impacts and management of multiple uses), and 23 per cent of coastal organisations do not monitor and evaluate the effectiveness of management actions (Jacobson et al. 2014).

Major challenges in ICZM include better understanding of:

- cumulative socio-ecological vulnerability
- the effectiveness of institutions and behaviour change mechanisms
- spatiotemporal scales of impacts and responses
- the science–knowledge interface and the influence of other agendas (e.g. economic and regional development) on ICZM
- the effectiveness of the social and institutional aspects of progressing management strategies
- mechanisms to minimise regulatory capture by developers.

In 2012, the New South Wales Government removed planning benchmarks for sea level rise, and a large proportion of rural local governments in New South Wales do not consider climate change within their planning frameworks (Struys 2015). New South Wales state-level coastal management operates according to the *Marine Estate Management Act 2014*, although it is too early to judge its success. The Coastal Management Bill 2016 and the proposed Coastal Management State Environmental Planning Policy intend to facilitate integrated management of the coastal environment of New South Wales.

The Victorian Coastal Council recently delivered a 5-year strategy (2014) on integrated management of the coast, dealing with population growth, climate change, land and infrastructure, the environment, and marine planning. In 2013, the Queensland Government ceased its Queensland Coastal Plan 2012 state planning policy system (Bell & Morrison 2015), which was replaced by the Coastal Management Plan in 2014 and the recent 2016 implementation of the complementary State Planning Policy. The *Tasmanian coastal works manual 2010* outlines coastal management guidelines in Tasmania, and includes reference to integrated approaches. South Australia's Coastal Protection Board policy includes integrated management objectives; however, it has been unable to provide adequate funding to regional councils to achieve their integrated management independently.

The outlook for ICZM in the short term is poor, because important issues have not been prioritised by recent governments. There has been some progress with recent legislation, such as the establishment of the New South Wales Marine Estate Management Authority (see Box COA11), and attempts by the Great Barrier Reef Marine Park Authority to develop cumulative impact assessment processes (see Cumulative impacts and management of multiple uses). The success of such initiatives may guide future progress in this regard. In the long term, the outlook may improve following positive changes in the social, economic and political landscape, much of it by necessity (Turner et al. 2016). International initiatives may also catalyse change, as will the CoastAdapt toolkit soon to be released by the National Climate Change Adaptation Research Facility (see Resilience of the coastal environment).

Cumulative impacts and management of multiple uses

Cumulative impact management is the process of determining the desired future state of an ecosystem, and how this will be achieved through control of developments that may have direct, indirect or interactive impacts on that ecosystem (Cuddington et al. 2013). Impacts may interact in additive, synergistic or antagonistic ways, and understanding the nature of potential interactions is crucial in determining optimal management strategies (Anthony et al. 2013). An example of cumulative impact management is the situation where multiple threats to seagrass in the Great Barrier Reef were assessed in a spatial framework, to determine hotspots of anthropogenic risk (Grech et al. 2011).

At the national level and within most states, the landscape for cumulative impact management is poor in terms of articulation and development of legislation, policies and plans. Cumulative impacts are acknowledged in management plans, but pressures are still treated individually, with little effort to develop frameworks for analysing or managing interacting pressures within or among industries. Efforts have been further developed through the development of a framework for understanding cumulative impacts to inform decision-making in the Great Barrier Reef World Heritage Area (Anthony et al. 2013). The EPBC Act also allows for strategic assessments that consider large-scale cumulative impacts in coastal regions.

At lower levels of management, the treatment of cumulative impacts is less well developed. In many states, few agencies are working to assess and manage cumulative impacts, or to assist local governments in this regard. Cumulative impacts are largely ignored by legislation for development and planning, and are rarely assessed when new developments take place. Insufficient funding, expertise and community support is limiting the progress of local councils towards implementing adaptive planning strategies (Gurran et al. 2013).

Current cumulative impact management frameworks are often provided as guides, and therefore lack structure, incentives and resources for appropriate long-term management. Ideally, under a framework of cumulative impact management, a proposed development would be considered in the context of previous impacts, other potential developments in the broad surrounds and broadscale impacts of the activity itself. In theory, this could be achieved through models of environmental impacts of multiple pressures.

Greater understanding of cumulative impacts is required from management agencies, including understanding of the practical limitations of cumulative impact management at local and regional scales. Local and regional bodies are increasingly having to deal with cumulative impacts and pressures that are larger in scope than the areas for which they are responsible. Typically, management remains local in scale, and there are few examples of management at larger scales. When allocated limited resources, management should identify sites where achievable reductions of local pressure will achieve the greatest results in the context of global pressures (Brown et al. 2014).

Challenges are not only administrative, but also scientific. The impact of multiple interacting pressures is an inherently difficult field of research, and recent studies have led to only incremental understanding of cumulative impacts on ecosystems or species. Obtaining controlled field samples to quantify cumulative impacts is difficult, particularly because cumulative impacts are often highly variable through space and time, and require extensive data to attribute impacts to different pressures.

The outlook for cumulative impact management in the short and long terms is poor, unless all levels of government adopt effective frameworks backed by strong incentives and regulations. Effective cumulative impact management requires the development of approaches to facilitate realistic and respectful interactions between managers, researchers, government advisers, stakeholders and communities.

Risk-based methods for prioritising management

Authorities charged with managing the coast are increasingly adopting risk-based methods to inform decision-making. In risk-based frameworks, the benefits derived from environmental assets are matched to the threats imposed by human use, and, from this, the risks associated with various management decisions are deduced (Van den Brink et al. 2016). Such an approach has recently been taken by the Marine Estate Management Authority of New South Wales (Jordan et al. 2016) and the Queensland Government (Brodie et al. 2013). If successful, it is expected to become a common model for coastal management.

Advantages of risk-based methods are that:

- environmental assets, benefits and pressures are clearly defined by the process
- interests of all stakeholders can be used in decision-making; there are nearly always competing demands for coastal resources, and assessing benefits and threats to each stakeholder better enables appropriate consideration of each of these
- risks can be minimised and benefits maximised.

Box COA11 Threat management in the New South Wales marine estate

The New South Wales Marine Estate Management Authority (MEMA), established in 2013, has taken a new approach to coastal management. The approach uses a threat and risk assessment framework, and aims to prioritise risks and maximise benefits to all sectors of the community.

Community surveys

People were surveyed to determine the benefits of, and threats to, the marine estate, as perceived by a broad cross-section of the community. The methods included:

- a statewide community survey, including 36 in-depth interviews with marine estate interest and user groups, including peak recreational groups; the fishing, boating and tourism industries; local councils; 5 Indigenous coastal community representatives; and 7 regional focus groups (6 coastal, 1 central), with a representative sample of the community
- a quantitative survey that involved more than 1000 residents (using an online survey), and more than 700 coastal residents and visitors (using field intercept surveys at 7 coastal locations)
- targeted stakeholder workshops and an interactive web portal
- targeted engagement with the Indigenous community in the Hawkesbury bioregion.

Benefits and threats

Table COA2 lists the main benefits and threats identified by the surveys.

Table COA2 Benefits of, and threats to, the coast identified by community surveys

Type	Benefits	Threats
Environmental	• Clean waters supporting a variety of habitats and marine life • Abundance of marine life • Uniqueness of marine life • A way to observe and interact with a variety of marine life	• Littering/dumping of rubbish/marine debris • Oil and chemical spills • Water pollution from sediment or run-off
Social	• Enjoyment of natural beauty • Safe space for social activities • Opportunity for healthy and active lifestyle • Heritage and intrinsic values • Role in Indigenous culture, identity and traditions, especially in relation to resource use	• Antisocial behaviour • Potential loss of appeal because of pollution/littering or overcrowding • Danger to swimmers from recreational activities such as boating and jetskiing • Lack of public access • Insufficient restrictions on commercial fishing • Gaps in management
Economic	• Income provision • Iconic images that promote tourism • Variety of seafood to catch and eat	• Water pollution affecting the viability of tourism • Loss of natural areas reserved for tourism • Increasing costs to access

Box COA11 (continued)

MEMA agencies determined environmental assets by classifying habitat types within the marine estate, such as estuaries, coastal waters and rocky shores. They also determined a list of activities (e.g. shipping) that threaten these assets, and classified activities as driven by resource use, land use or climate change.

Risk assessment

Risk ratings for each ecosystem component were determined by MEMA agencies and independent experts. Risk considered relative impact and likelihood, in the context of environmental, social and economic benefit across a 20-year timeframe, assuming current management controls.

The main findings included the following:

- Estuarine areas had a higher proportion of moderate and high risks than the continental shelf.
- Risks to estuaries encompassed a broader range of threats than to the continental shelf; these included sediment and water contamination, dredging, recreational fishing and boating, and related infrastructure and shipping.
- Many risks to social and economic benefit reflected conflict between uses of the marine estate (e.g. between recreational and commercial fishing), rather than being an overall threat.
- The highest cumulative threats were access availability, climate change, effect of regulation, water pollution and sediment contamination, recreational and commercial fishing, recreation and tourism, foreshore and urban development, reduction in fish abundance, and habitat disturbance.

Summary

The threat and risk assessment framework, together with extensive surveys and consultation, provided an effective means of determining risk to the benefits the community derives from the New South Wales marine estate. Such an approach will continue to develop as it is applied at different spatial scales (e.g. marine parks) and to different management issues (e.g. pollution in estuaries). Improved integration of threats across social, economic and environmental areas will allow more transparency around the trade-offs that are often required in management decisions in marine and coastal areas.

Coastal hills near Gadget Gully, Macquarie Island

Photo by Melinda Brouwer

Recent developments

There have been some recent developments in the approach and tools for coastal management, including emerging analytical methods for decision-making, and conservation at multiple levels of biodiversity.

Emerging analytical methods for decision-making

Technologies are emerging that provide new ways of collecting and analysing environmental data at large scales. The most significant of these during the past 5 years have been in the fields of metagenomics, remote sensing and crowdsourced data.

Rapidly reducing prices for molecular sequencing have allowed researchers to collect large amounts of genetic data relatively cheaply. This is core to studying microbial processes, but there are also successful examples of using molecular tools to survey macroorganisms (Dafforn et al. 2015). Molecular biomonitoring tools have the potential to provide the rapid, sensitive and reliable biodiversity sampling that is currently missing from regular ecosystem monitoring in coastal waterways. One of the main challenges now is to speed up the processing, analysis and interpretation of the vast quantities of data produced, and new techniques in bioinformatics are being developed to achieve this.

Remote sensing has been in place since the beginning of the satellite era in 1979, but techniques and products are emerging to extract more ecological information from sensed data. One major project is the Data Cube being produced by Geoscience Australia and CSIRO. The Data Cube is a 3D presentation of Landsat data collected since 1984 across the whole of Australia, and georectified for use. Infrastructure is now being established to allow researchers to interrogate these data easily and efficiently, for analysis such as the National Water Quality and Fractional Cover analyses in this report. SoE 2016 is the first to use the Data Cube to provide such national assessments of water quality and coastal vegetation change.

Citizen science is another means of collecting large quantities of data. It does so by accepting data from nonspecialists or those with only basic training. The advantage of this is the sheer quantity of data gathered, despite some loss in data quality. An example of this is Redmap, which is a compilation of fish occurrence records around Australia, submitted by interested citizens.

Conservation at multiple levels of biodiversity

Biodiversity is important for the maintenance of ecological processes and, consequently, the ecological services and goods that are valued by humans (Mace et al. 2012). Historically, biodiversity conservation has been species-centric, because this is the level at which biodiversity is most easily quantified and interpreted. Recently, appreciation has increased of the importance of conserving both higher (communities, ecosystems) and lower (genes, microbes) levels of biodiversity for healthy ecosystem function, and moves to incorporate ‘functional’ diversity (i.e. diversity of traits) into conservation frameworks (Cadotte et al. 2011). With these levels of diversity, conservation should aim to maintain diversity both within and between areas.

Identification of priority targets and locations for management is critical to best distribute the limited funds allocated to conservation. Australia recently ranked 38th on a list of countries that were underfunding biodiversity conservation (Waldron et al. 2013). One strategy for the use of limited funds is to use charismatic fauna as ‘umbrella’ species for conservation of communities and ecosystems, whereby efforts to protect a single species cover multiple groups and levels of biodiversity.

Maintaining adequately diverse representation within and between components (genes, species, communities, ecosystems) of diversity should be a priority, along with preservation of disproportionately important components (e.g. ‘foundation’ species occupying a central role in specific communities). Microbes are often neglected in conservation frameworks but perform important ecosystem functions, and microbial diversity is important to preserve ecological redundancy and maintain function (see Microbial processes and nutrient recycling).

View of the Tasman Coast from Cape Huoy, Tasmania
Photo by Megan Watson

Assessment summary 6
Effectiveness of coastal management

Summary	Assessment grade: Ineffective	Partially effective	Effective	Very effective	Confidence: In grade	In trend	Comparability: To 2011 assessment
Coastal governance and integrated management							
Understanding of context: The development of frameworks has improved understanding in some areas of management. Uncertainty remains about how to best allocate responsibility across levels of government		↗					
Planning: Coordination in planning across levels of government is generally lacking, although this varies between areas of management		↗					
Inputs: There are insufficient data for many pressures, which hinders effective management. However, promising avenues are emerging, such as remote sensing and molecular techniques		↗					
Processes: Most governance is carried out by local councils, and less by state and territory and Australian governments. Integrated management needs to be strengthened in some areas and implemented for the first time in others		↗					
Outputs and outcomes: Coastal governance is slowly improving through better coordination and use of risk management frameworks		↗					
Cumulative impacts management							
Understanding of context: There is limited scientific understanding of the impacts of multiple pressures, particularly their interactions		↗					
Planning: Cumulative impacts management has been used in some recent planning frameworks, but only in a small proportion of managed areas		↗					
Inputs: Data on the direct effects of many pressures, and their interactions, are sparse in some areas		↗					
Processes: Seldom implemented because of knowledge gaps and lack of resources		↗					
Outputs and outcomes: Implemented in the Great Barrier Reef Marine Park zone management, although the Reef remains in a poor state and is deteriorating		↗					

Assessment summary 6 (continued)

Recent trends	Confidence	Comparability
↗ Improving	● **Adequate:** Adequate high-quality evidence **and** high level of consensus	◆ **Comparable:** Grade and trend are comparable to the previous assessment
↙ Deteriorating	◕ **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus	⬙ **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
— Stable	◒ **Limited:** Limited evidence **or** limited consensus	◇ **Not comparable:** Grade and trend are not comparable to the previous assessment
? Unclear	◔ **Very limited:** Limited evidence **and** limited consensus	**X** **Not previously assessed**
	○ **Low:** Evidence and consensus too low to make an assessment	

Assessment summary 6 (continued)

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

Assessment summary 6 (continued)

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

Resilience
of the coastal environment

At a glance

Resilience of the coastal environment includes its resistance to change and its ability to recover once disturbed. Resistance to change is linked to the maintenance of high biodiversity, which is expected to provide greater redundancy in ecological functions. Resistance can also be increased by improving the tolerance of important keystone or habitat-forming species to pressures. Furthermore, resistance to additional pressures can be improved by minimising the impacts of other pressures.

Recovery from change can be facilitated through active restoration or by limiting human use to allow natural recovery. Defining appropriate baselines and quantifying the success of recovery are key challenges for restoration ecology. Protection from some degree of human use is the most common method of ecosystem recovery in coastal Australia, and the extent of protected coastal environments in Australia has increased during 2010–14. There have also been several recent efforts in active restoration, where human intervention aims to restore an ecosystem to a predefined state.

Resilience is defined as the capacity for a system to experience shocks while retaining essentially the same function, structure and feedbacks, and therefore identity. This report considers 2 components of coastal resilience: the extent to which the coast can resist change in the face of pressures, and how well it can recover from change once disturbed.

Resistance to change

For ecological habitats, species and processes, strong resistance to change is often related to high biodiversity and healthy ecosystem function. High biodiversity leads to ecological redundancy, which is when multiple ecological components play a similar role in maintaining the ecosystem. This means that when one component fails, another can compensate, and the system is maintained. Because of the complexity of most ecosystems, it is often not practical to manage redundancy directly, and it is more common to manage biodiversity with the knowledge that this will act to maintain ecological redundancy and therefore resilience.

Resistance can also result from keystone or habitat-forming species that have a high tolerance for disturbances, harsh environmental conditions or diseases. Resistance can be increased through breeding programs that bolster tolerant genotypes, or by maximising genetic diversity to allow adaptation to the widest range of environmental conditions (see Box COA12). Ecological community-level and species-level resistance to one pressure can also be increased if other pressures are moderated. For example, temperature tolerance may be higher if an organism is in good health.

Box COA12 Engineering climate-proof oyster reefs

The eastern seaboard of Australia is experiencing among the highest rates of climate warming on the planet. This is threatening the loss of endemic species, which comprise 80 per cent of temperate Australian coastal biodiversity. Intertidal plants and animals are particularly susceptible to climate warming because many already live close to their thermal limits. On rocky shores, these organisms may experience temperatures exceeding 50 °C when low tides coincide with maximum midday air temperatures. The ability of these animals and plants to adapt to warming conditions will be contingent on the availability of natural refuges that provide cooler conditions.

Sydney rock oysters (*Saccostrea glomerata*) could provide natural refuges for intertidal biodiversity from the effects of climate warming by providing shade and trapping moisture at low tide. On New South Wales rocky shores, maximum temperatures are, on average, 4.5 °C cooler inside oyster beds than on bare rock. Consequently, oyster beds contain species that are unable to tolerate temperature extremes on bare rock. Oysters once formed extensive reefs in estuaries of eastern Australia, but perhaps as few as 1 per cent of these remain because of historical overharvest. Rebuilding oyster reefs that are resilient to climate warming may help to curb the loss of Australia's coastal biodiversity.

On the hot black tiles, more wild (left) than selectively bred (right) oysters survived to form habitat. In the right panel, only shells of dead selectively bred oysters remain

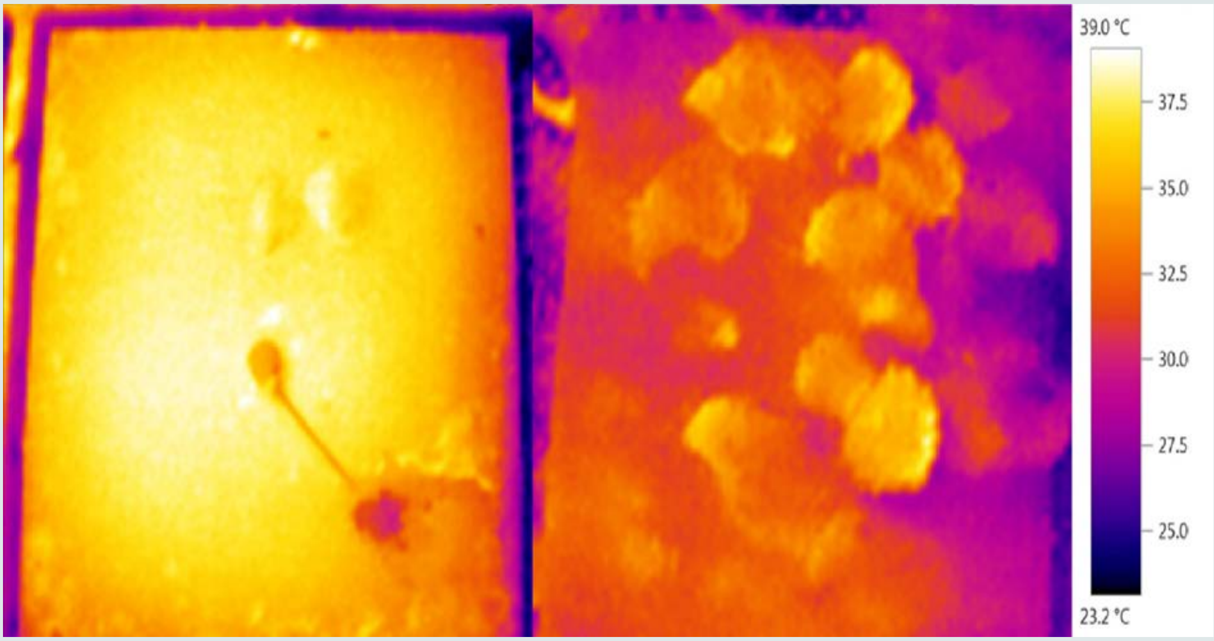
Photo by Dominic McAfee

Box COA12 (continued)

Sydney rock oysters are the focus of a sizeable aquaculture industry in New South Wales and southern Queensland. The management strategy of the industry includes a selective breeding program to produce fast-growing and disease-resistant oysters. Researchers at Macquarie University are assessing the ability of Sydney rock oysters to persist and form habitat under warmer conditions, and whether there are particular oyster breeding lines that display greater thermal tolerance and could therefore benefit restoration projects targeting climate change adaptation of coastal ecosystems.

The researchers manipulated temperature conditions in the field by growing oysters on tiles that are white, grey or black in colour and differ in their thermal properties. The white tiles, which reflect heat, reach 36 °C; the grey tiles reach 47 °C; and the black tiles, which absorb heat, reach 60 °C. The experiments show that there are large differences in the ability of oyster breeding lines to continue to grow and form habitat on the hotter tiles. Whereas oysters selectively bred for fast growth and disease resistance grew faster than wild oysters on the cooler white plates, on the hotter grey and black plates they lost this growth advantage, and instead experienced higher mortality than the wild oysters. The net effect was that, on the hot black tiles, wild oysters provided more habitat and facilitated cooler temperatures and greater biodiversity than the selectively bred oysters. Nevertheless, the presence of either type of oyster on tiles reduced temperature, and increased biodiversity.

The results suggest that shading provided by the complex 3D structure of oysters will enhance the adaptive capacity of intertidal biodiversity to climate warming. The magnitude of this effect will, however, vary between oyster breeding lines.



Temperatures are higher in the absence (left) than the presence (right) of oysters

Photo by Dominic McAfee

Source: Associate Professor Melanie Bishop, Macquarie University

Resistance of the physical environment to change is largely dependent on engineering coasts to withstand changes such as rising sea level, or conserving natural ecosystem components that are able to buffer change. Mangroves, for example, accrete soil and can grow vertically in response to rising sea level (Krauss et al. 2014), although there may still be issues with the environment immediately landwards of the mangroves. So far, the need for coastal engineering to counter the effects of climate change has been patchy, but will increase and become widespread in the coming decades.

In 2015, the Australian Government released a National Climate Resilience and Adaptation Strategy, which outlines how Australia is building resilience against future climate risks. It identified principles to guide effective adaptation practices and management, much of which applies to the coastal zone. The strategy recognised the primary role of climate in shaping the coast, both historically and in the future. It outlined the risks to the coastal zone associated with changing climate, how Australia is preparing and what we need to do in the future.

Some recent initiatives relating to coastal resilience include:

- the Reef 2050 Plan, which aims to build the resilience of the Great Barrier Reef
- coastal management reforms in New South Wales
- managing climate risks to Defence land and property holdings.

In another initiative, the National Climate Change Adaptation Research Facility is working with stakeholders around Australia to create an online coastal risk management framework, CoastAdapt. Due in 2017, this will help users to understand and manage the risks associated with sea level rise, storm surges and other hazards. It will be a practical, hands-on tool and information guide to help governments, businesses and communities manage climate risks in the coastal zone. CoastAdapt will make use of national datasets and research outputs developed during the past 5 years by Australian research organisations. Informed by extensive consultation with potential users, CoastAdapt aims to provide guidance on all aspects of adaptation planning in the coastal zone, including community engagement, risk assessment and adaptation options.

Recovery from change

Recovery from change can be observed in systems that have been heavily degraded, and then either actively restored or allowed to recover by natural processes. Challenges in restoration ecology are the setting of appropriate goals, and the ability to detect when goals are reached. The problem of shifting baselines complicates restoration, since some habitats have been so heavily degraded since European colonisation that restoring them to a recent state (e.g. to a 1950s baseline) is insufficient to recover their predisturbed biodiversity or function.

The most common method of achieving recovery is through protection from human use. Approximately 22 million hectares of major vegetation types in the coastal zone of Australia (from the shore to 50 kilometres inland) receive some level of protection, and 14 million hectares receive the higher levels of protection (IUCN levels 1 to 4, which include strict nature reserves or wilderness areas, national parks, natural monuments or features, and habitat/species management areas). The trend in extent of area receiving protection is positive—from 2010 to 2014, an additional 3.7 million hectares received protection, almost 800,000 hectares of which were at protection levels 1 to 4.

Active restoration is when humans actively intervene to restore an ecosystem to its former state, rather than simply managing or protecting it from negative impacts of human use. Examples of this in the coastal zone are the restoration of seagrasses in the Coorong (the Ruppia Translocation Project), and restoration of shellfish reefs that were once far more abundant than they are at present (see Box COA13).

Box COA13 Shellfish reef restoration—recovering a lost marine habitat for environmental, social and economic benefit

What are shellfish reefs and where have they gone?

Shellfish reefs are complex, 3D living structures, made up of high densities of oysters, mussels and other shellfish. They play a similar ecological role to coral reefs, providing food, shelter and protection for a range of invertebrate and fish species, as well as helping to reduce coastal erosion and improve water clarity. Shellfish reefs occur in enclosed and nearshore coastal waters in both tropical and temperate regions across every state in Australia. Before the 20th century, shellfish reefs were common features of coastal systems and were an important food source for Indigenous Australians. Early maritime explorers, such as Cook, Flinders, Eyre and Vancouver, regularly referred to extensive shellfish reefs in voyage reports and journals. From early European settlement of Australia, vast quantities of oysters and mussels were harvested for food to support the growing colonies, and as a source of lime for the construction of early roads and buildings. It is estimated that shellfish reefs were commercially harvested during the 1800s and early 1900s in more than 150 locations across Australia, but are now considered functionally extinct habitats, with only a handful of reefs remaining (Gillies et al. 2015).

Towards the recovery of shellfish reef habitats

The loss of shellfish reef habitat, in addition to the loss and degradation of other important marine habitats, greatly inhibits our ability to manage the health of coastal environments and to ensure they remain environmentally, economically and socially productive. Healthy habitats enable the processing of nutrients and sediments into cleaner waters and abundant fish, while also sequestering carbon and helping to mitigate coastal risks such as sea level rise. Rebuilding native shellfish reefs and other marine habitats is considered a job-intensive industry, with more than 17 full-time and part-time jobs created per $1 million spent (Edwards et al. 2013). Types of jobs generated from restoration include marine engineering, construction, science, recreational fishing, tourism and ecotourism. Shellfish reefs are also considered ‘fish factories’, supporting the growth and augmentation of recreationally and commercially important fish species, such as snapper (*Pagrus auratus*), yellowfin bream (*Acanthopagrus australis*) and King George whiting (*Sillaginodes punctatus*).

In 2014, Australia’s first shellfish reef restoration project was initiated in Port Phillip Bay, Victoria. Since then, several new shellfish reef restoration projects have been established across Australia, demonstrating the momentum and interest in recovering shellfish reef habitat. These include Oyster Harbour in Western Australia, Pumicestone Passage and Noosa River in Queensland, Georges River in New South Wales, and Gulf St Vincent in South Australia. Much of this early work has leveraged the success of large-scale, long-term shellfish reef restoration projects in the United States, such as in Chesapeake Bay. Efforts to recover shellfish reefs can be strengthened by forming partnerships and collaborations with groups that have complementary knowledge and experiences that can support restoration efforts and long-term community stewardship. Partnerships among the shellfish aquaculture industry, recreational fishers, Indigenous groups, government and not-for-profit groups are particularly well suited to providing the resources, knowledge and community ownership required to sustain large-scale restoration efforts.

Box COA13 (continued)

Native flat oyster (*Ostrea angasi*) reef, Georges Bay, Tasmania
Photo by Chris Gillies

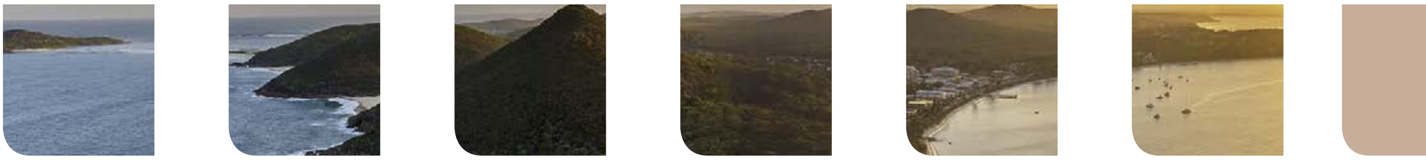
Sydney rock oyster (*Saccostrea glomerata*) reef, Richmond River, New South Wales
Photo by Patrick Dwyer

Box COA13 (continued)

Hundreds of volunteers repairing oyster reef for shoreline protection work in the United States. Similar large-scale projects are possible in Australia

Photo by Erika Nortemann, © The Nature Conservancy

Source: Dr Chris Gillies, The Nature Conservancy



Risks
to the coastal environment

At a glance

Despite concerted efforts to manage pressures on the coast, there remains residual risk that impacts will still occur. Here we categorise each of the pressures identified in this report in terms of their likelihood to cause impact and the severity of that impact, once current management has taken effect.

Risks to the coast related to climate change (sea level rise, change in climate and weather) are of most concern, because they are almost certain, their impacts would be catastrophic, and they are currently relatively unmanaged. Also of great concern are risks from invasive species, because these can have ecologically dire consequences but are very difficult to safeguard against. Microplastics are a significant unknown risk, as their introduction to, and spread through, the coastal environment is growing far more rapidly than research and understanding of their impact.

Risks associated with managed pressures generally represent inadequacies of current management to fully eliminate their impacts, which is expected given limited resources and acceptance of minor impacts. Some managed pressures are still considered to have major or moderate impacts because of their large extent and diffuse nature; examples are estuarine and coastal pollution, and recreational fishing.

In this section, risk refers to residual risk, or the risk that a pressure will still result in an impact after management actions are applied. Pressures in the assessment summary are partitioned into those that are managed, and those that are unmanaged or for which impacts cannot be predicted. This assessment is qualitative rather than quantitative, and assumes that current management practices continue. Quantitative risk assessments are best practice and are increasingly implemented in coastal management at local and regional scales, such as the threat and risk assessment framework for the New South Wales marine estate (MEMA 2015), but are beyond the scope of this report.

The most significant risks are those associated with climate change. Sea level rise, and changes in climate and weather fall within the critical zone of the risk matrix, as both are almost certain and will have catastrophic impacts. Moreover, Australia has relatively little means to manage these risks, because of the global scale of both the driver and consequent pressures. Sea level rise will not only cause inundation of low-lying coast, it will also lead to extensive erosion inland and the destruction of coastal habitats. Increased storm activity will have a similar effect in exacerbating loss of coastal land and habitats.

Invasion by exotic species is another risk that is almost certain to occur in the future, given ongoing shipping between Australia and other regions. Invader establishment and spread are highly unpredictable, because they are determined by the combination of invader traits and density, and the recipient biotic and abiotic environment. Most exotic organisms that enter Australia do not become invaders, but those that do can be environmentally and economically devastating. Globally, the annual cost of introduced species exceeds US$1.4 trillion—5 per cent of GDP (Pimentel et al. 2001), and in Australia alone the cost is more than $7 billion per year (CSIRO 2011). Australia has a national ballast water management system in place, but currently there is no enforced national system for managing biofouling. Some states, such as Western Australia, have implemented biofouling regulations, and extending these nationally would go some way towards reducing risk. Domestic ballast water regulations are another measure that would reduce spread, but are currently only implemented in Victoria.

Most risks from managed pressures are considered to have high likelihood (i.e. are likely or almost certain to occur), but vary in the severity of their impact. Of these, coastal river and estuary pollution are predicted to have the most severe impacts, and both are almost certain to continue as coastal population grows. Current management is only partly effective in reducing their impact, particularly for diffuse sources.

Pressures considered low risk include tourism and recreation, desalination, and artificial structures. Although almost certain to occur, they are generally well managed and/or small in extent. Desalination plants and artificial structures are both growing in number around Australia, but have highly localised effects. A 5-year study of the impacts of the Sydney Desalination Plant found that effects on marine invertebrate recruitment were limited to the vicinity of the outlet, and were undetectable within months of plant shutdown. Some species of fishes even appeared to benefit from the effluent, likely because of increased turbulence and food availability. Similarly, artificial structures benefit some fishes, but have severe but localised impacts on other taxa (e.g. burial of soft-sediment infaunal communities).

Risks associated with fishing differ between the commercial and recreational sectors because of differences in monitoring and management. Impacts from both activities are considered moderate, but better data for commercial fishing allow the risk to be considered likely, whereas a lack of data for recreational fishing means it must be considered possible. Unlike most other countries with coastal fishing waters, it is widely believed that impacts of recreational fishing in Australia exceed those of commercial fishing, but more data are needed to test this.

Microplastics are a major unknown risk, as their use and introduction to the coastal environment has far outpaced research into their potential impacts. Microscopic plastic fibres are embedded into many clothing and consumer products, and are introduced into waterways when these items are washed and fibres enter waste water. Nanoparticles are a similar issue, where research and environmental legislation have not kept up with emergence of novel pollutants.

Roach Island, Lord Howe Island Group
Photo by Ian Hutton

Assessment summary for risk

Managed pressures

	Catastrophic	Major	Moderate	Minor	Insignificant	Unknown
Almost certain		Coastal river and estuary pollution Nutrient pollution	Aquaculture Vessel activity and infrastructure	Tourism and recreation (excluding fishing) Desalination Artificial reefs		
Likely			Oil, gas and mining impacts Toxins, pesticides and herbicides Water turbidity, transparency and colour Fishing (commercial and recreational)			
Possible						
Unlikely						

Not considered

Assessment summary for risk

Unmanaged pressures or impacts unable to be predicted

	Catastrophic	Major	Moderate	Minor	Insignificant	Unknown
Almost certain	Sea level rise Climate and weather	Invasive species (aquatic)	Algal blooms Low-oxygen dead zones			
Likely				Jellyfish blooms		Marine debris (microplastics)
Possible						
Unlikely						

Not considered

Outlook
for the coastal environment

At a glance

The current pressures associated with human population, catchment land use, agriculture and resource extraction are growing and will be exacerbated by the increasing pressures of climate change. The most significant climate change pressures for the coast include sea level rise, and increased frequency of cyclones and severe rainfall events. Consequences of climate-related pressures include habitat loss, disruption of ecological processes, potential species extinctions, range expansions and risk of damage to the built environment.

It is critical that Australia prepares for the coming changes as best we can, to mitigate impacts. The success of our management will ultimately determine how pressures and changes will affect the Australian coast.

In the short term (i.e. the next 5 years), the outlook for coastal issues covered in this report is mixed. The state of most biological components is stable or worsening in response to ongoing local or regional pressures, which themselves are either stable or increasing.

Growth in coastal pressures around urban centres is strongly correlated with human population growth, which shows little sign of curbing. The short-term outlook for this urban pressure will depend on whether effective ICZM can be achieved, and the success of recent risk-based approaches. Apart from the increasing evidence of a range of climate change pressures, there have been few significant new pressures on urbanised coasts in the past 5 years—most are historical or ongoing pressures that are awaiting effective management.

Exceptions to this are emerging contaminants, such as microplastics and nanoparticles. These have only recently received public attention, and are poorly understood in terms of their extent, impacts and options for management. They currently lack appropriate legislation and regulation. Given the rate at which new classes of contaminants are developed and released into the environment, it is uncertain whether ecological research can assemble sufficient knowledge in time for the development of legislation to prevent serious and lasting consequences. In these cases, a precautionary approach may be most pragmatic, until such time that research can properly assess risk.

In contrast to urban areas, many remote stretches of coast are facing pressures new to the area. These pressures are related to resource extraction and processing, particularly in the north-west of Australia where significant new developments are occurring or planned. Although most extraction occurs inland or offshore, port infrastructure is required to service processing and export. Much of this infrastructure has been recently built during the mining boom, but future impacts are likely from its operation and potential expansion. There are formal, funded plans for major development of northern Australia, including agriculture, dams, mining and roads, and concern for the environment in these plans appears to be lacking. In these regions, the outlook will depend on the extent to which government and regulatory authorities manage developments and control potential environmental impacts. To some extent, these pressures will be driven by global economics, and the demand for raw materials and food, but governance will ultimately determine how such pressures can affect the coast.

Coastal growth on the shoreline of Barilla Bay, Tasmania
Photo by Nick Rains

Species of most concern are migratory shorebirds, which, despite protection in Australia, are severely threatened by impacts on overseas habitat areas. To achieve a positive outlook, these species will require multilateral management strategies that span international boundaries—something that can be difficult to establish and even more difficult to enforce.

For other species harmed by historical or contemporary pressures, restoration of former ecosystem structure and function may be possible. This is currently being attempted for shellfish (see Box COA13) and saltmarshes (see Box COA8), and the success of these projects will be evident in coming years. Care should be taken, however, to ensure that restoration projects achieve appropriate aims for all levels of diversity, including genetic and microbial diversity, and do not have untoward outcomes by establishing overly simple (low-diversity) ecosystems.

In the longer term, the outlook for the coast could be grim, depending on mitigation and adaptation actions taken. Sustainable management of natural systems requires strategies that increase resilience and are adaptive to future rates of environmental change (Scharin et al. 2016). Effects of climate change, particularly sea level rise, will permeate the entire coast and, except for coastal engineering and global reductions in emissions, the scope for mitigation is limited. Seas are predicted to rise 0.8 metres by the end of the 21st century, inundating vast areas of coastal land and eroding even greater areas inland. Options for human settlement include managed retreat or coastal armouring, both of which come at exorbitant economic cost. In some remote areas of the coast, there may be space for coastal communities to move landwards with rising sea levels; however, this will not prevent the loss of many invaluable environmental and heritage assets.

Acronyms and abbreviations

Acronym or abbreviation	Definition
4WD	four-wheel drive
ENSO	El Niño–Southern Oscillation
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
GDP	gross domestic product
GPS	global positioning system
ICOLLs	intermittently closed and open lakes and lagoons
ICZM	integrated coastal zone management
IUCN	International Union for Conservation of Nature
LNG	liquefied natural gas
mm/y	millimetres per year
MPA	marine protected area
POMS	Pacific oyster mortality syndrome
SoE	state of the environment

Glossary

Term	Definition
abstraction	Withdrawal of water from the environment for human use.
acidification	The process of becoming more acidic (i.e. lowering the pH). Soils tend to become acidic through natural leaching and weathering, and because of some agricultural practices such as loss of organic material and overuse of nitrogenous fertilisers. The ocean is becoming more acidic as atmospheric carbon dioxide (CO_2) levels rise and the concentration of dissolved CO_2 in sea water increases, forming carbonic acid.
adaptation	Shifts (e.g. in behaviour, management practices, biology) in response to change that support survival; responses that decrease the negative effects of change and capitalise on opportunities.
adaptive management	A systematic process for continually improving policies and practices by learning from the outcome of previously used policies and practices.
Allee effects	A correlation between the size of a population and the individuals' fitness.
algal bloom	A sudden proliferation of algae (microscopic plants) that occurs near the surface of a body of water. Blooms can occur because of natural nutrient cycles, or can be in response to eutrophication or climate variations. *See also* eutrophication.
anthropogenic	Caused by human factors or actions.
aquaculture	Cultivation of aquatic and marine species such as fish, crustaceans, shellfish and algae, predominantly for use as human or animal food.
asset	Parts or features of the natural environment that provide environmental functions or services.
bioaccumulation	The accumulation of contaminants in organisms.
bioavailability	The degree to which a contaminant can move into or onto an organism.
biodiversity	The variety of all life forms. There are 3 levels of biodiversity: • species diversity—the variety of species • genetic diversity—the variety of genetic information contained in individual plants, animals and microorganisms • ecosystem diversity—the variety of habitats, ecological communities and ecological processes.
biogenic	Produced by living organisms or biological processes.

Term	Definition
biomass	The quantity of living biological organisms in a given area or ecosystem at a given time (usually expressed as a weight per unit area or volume).
bioregion	A large geographically distinct area that has a similar climate, geology, landform, and vegetation and animal communities. The Australian land mass is divided into 89 bioregions under the Interim Biogeographic Regionalisation for Australia. Australia's marine area is divided into 41 provincial bioregions under the Interim Marine and Coastal Regionalisation for Australia.
biosecurity	Processes, programs and structures in place to prevent entry by, or to protect people and animals from, the adverse impacts of invasive species and pathogens.
biota	Living organisms in a given area; the combination of flora, fauna, fungi and microorganisms.
Bruun's rule	The theory that shoreline erosion (from sea level rise) is a function of the slope of the shore.
carbon sequestration	Processes to remove carbon from the atmosphere, involving capturing and storing carbon in vegetation, soil, oceans or another storage facility.
catchment	An area of land determined by topographic features, within which rainfall will contribute to run-off at a particular point. The catchment for a major river and its tributaries is usually referred to as a river basin.
climate change	A change of climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and is additional to natural climate variability observed over comparable time periods (under the terms of the United Nations Framework Convention on Climate Change).
community	A naturally occurring group of species inhabiting a particular area and interacting with each other, especially through food relationships, relatively independently of other communities. Also, a group of people associated with a particular place.
condition	The 'health' of a species or community, which includes factors such as the level of disturbance from a natural state, population size, genetic diversity, and interaction with invasive species and diseases.
connectivity	Linkages between habitat areas; the extent to which particular ecosystems are joined with others; the ease with which organisms can move across the landscape.
connectivity conservation	Conserving or re-establishing interconnected areas and corridors of vegetation to protect linked ecosystems and the species within them.
conservation	Protection and management of living species, communities, ecosystems or heritage places; protection of a site to allow ongoing ecosystem function or to retain natural or cultural significance (or both) and to maximise resilience to threatening processes.
coral bleaching	When the coral host expels its zooxanthellae (marine algae living in symbiosis with the coral) in response to increased water temperatures, often resulting in the death of the coral.

Term	Definition
corridor	A linear landscape structure that links habitats and helps movement of, and genetic exchange among, organisms between these habitats.
critically endangered (species or community)	At extreme risk of extinction in the wild; the highest category for listing of a threatened species or community under the criteria established by the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth).
crustaceans	A class of mainly aquatic arthropods including prawns, lobsters and crabs.
decline	When the condition of an ecosystem, species or community has decreased to a point where its long-term viability is in question. It usually represents more than just a decrease in numbers of individuals, and describes the result of several interacting factors (e.g. decreasing numbers, decreasing quality or extent of habitat, increasing pressures). In this report, the use of the term is generally prompted by reports that a substantial number of species within a group or community are classified as threatened and there is a high likelihood that more species are likely to qualify for a threatened classification if trends continue. Where 'decline' is applied to elements of environments (e.g. condition of vegetation as habitat), it means that changes have been sufficient to potentially affect the viability of species relying on those elements.
detritivore	An organism that feeds on dead or decomposing matter.
disturbance	A temporary change in average environmental conditions that disrupts an ecosystem, community or population, causing short-term or long-term effects. Disturbances include naturally occurring events such as fires and floods, as well as anthropogenic disturbances such as land clearing and the introduction of invasive species.
drivers	Overarching causes that can drive change in the environment; this report identifies climate change, population growth and economic growth as the main drivers of environmental change.
ecological processes	The interrelationships among organisms, their environment(s) and each other; the ways in which organisms interact ,and the processes that determine the cycling of energy and nutrients through natural systems.
ecology	*See* ecological processes.
ecosystem	An interrelated biological system comprising living organisms in a particular area, together with physical components of the environment such as air, water and sunlight.
ecosystem services	Actions or attributes of the environment of benefit to humans, including regulation of the atmosphere, maintenance of soil fertility, food production, regulation of water flows, filtration of water, pest control and waste disposal. It also includes social and cultural services, such as the opportunity for people to experience nature.
El Niño	A periodic extensive warming of the central and eastern Pacific Ocean that leads to a major shift in weather patterns across the Pacific. In Australia (particularly eastern Australia), El Niño events are associated with an increased probability of drier conditions. *See also* La Niña.
emissions	Output or discharge, as in the introduction of chemicals or particles into the atmosphere.

Term	Definition
endangered (species or community)	At very high risk of extinction in the wild; in danger of extinction throughout all or a portion of its range; criteria are established by the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth).
endemic	Unique to a spatially defined area; in this report, used mainly to refer to large bioregions of the continent and marine environment.
endemism	The degree to which species and genes are found nowhere else; the number of endemic species in a taxonomic group or bioregion.
Environment Protection and Biodiversity Conservation Act 1999 (Cwlth)	The Australian Government's main environmental legislation; it provides the legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places.
environmental flows	Managed freshwater flow to natural water systems designed to maintain aquatic ecosystems.
epifauna	Organisms living on the surface of the seabed, or attached to submerged objects or aquatic animals or plants.
eutrophication	Excessive nutrients in a body of water, often leading to algal blooms or other adverse effects. *See also* algal bloom.
extent	Areal coverage—for example, of vegetation or sea ice.
extinct (species)	When there is no reasonable doubt that the last individual has died.
feedback	Where the outputs of a process affect the process itself.
food web	Interconnected food chains; a system of feeding connections in an ecosystem.
fragmentation	Isolation and reduction of areas of habitat, and associated ecosystems and species, often because of land clearing.
general resilience	Resilience to unknown or unidentified pressures, disturbances or shocks.
geographic range	Geographical area within which a species can be found.
geomorphology	Scientific study of landforms and the processes that shape them.
greenhouse gases	Gases that contribute to the greenhouse effect, the most important of which are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), short-lived tropospheric ozone (O_3), water vapour, chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6).
groyne	A wall or barrier built along a beach.
habitat	The environment where a plant or animal normally lives and reproduces.
Interim Biogeographic Regionalisation for Australia	A set of 85 bioregions within the Australian landmass, used as the basis for the National Reserve System's planning framework to identify land for conservation.
infauna	Animals that live in seabed sediments.

Term	Definition
invasive species	Non-native plants or animals that have adverse environmental or economic effects on the regions they invade; species that dominate a region as a result of loss of natural predators or controls.
jurisdiction	An Australian state or territory, or under the control of the Australian Government.
lagoon	A shallow body of water, especially one separated from a sea by sandbars or coral reefs.
landscape	An area of land comprising land forms and interacting ecosystems; an expanse of land, usually extensive, that can be seen from a single viewpoint.
landscape processes	Processes that affect the physical aspects of the landscape (e.g. weathering of rock formations, erosion, water flow).
La Niña	A periodic extensive cooling of the central and eastern Pacific Ocean. In Australia (particularly eastern Australia), La Niña events are associated with increased probability of wetter conditions in eastern Australia. *See also* El Niño.
major vegetation groups	Aggregation of vegetation into distinct categories; Australia's native vegetation has been classified into 23 major vegetation groups.
microplastics	Small pieces of plastic, generally less than 1 millimetre in size, which can be found in the environment.
millennium drought	The recent drought in southern Australian that lasted from 2000 to 2010 (although in some areas it began as early as 1997).
mitigation	Actions intended to reduce the likelihood of change or to reduce the impacts of change.
nanoparticle	Very small particles; generally between 1 and 100 nanometres in size.
National Reserve System	Australia's network of protected areas that conserve examples of natural landscapes, and native plants and animals. The system has more than 9300 protected areas, including national, state and territory reserves, Indigenous lands, and protected areas run by conservation organisations or individuals.
natural resource management	The management of natural resources such as land, water, soil, plants and animals, with a focus on sustainable practices.
nutrient cycling	Movement and exchange of organic and inorganic materials through the production and decomposition of living matter.
pathogen	A microorganism that causes harm to its living host.
peri-urban	A region between the outer suburbs and the countryside.
pH	A measure of acidity or alkalinity on a log scale from 0 (extremely acidic) through 7 (neutral) to 14 (extremely alkaline, or basic).
photochemical	Referring to a chemical reaction that is triggered by the effect of light on molecules.
pressures	Events, conditions or processes that result in degradation of the environment.
primary production	The production of organic compounds from atmospheric or aquatic carbon dioxide, principally through photosynthesis.

Term	Definition
radiative forcing	A measure of the influence a factor (such as greenhouse gases) has on altering the balance of incoming and outgoing energy in the Earth–atmosphere system. Warming of climate is a response to positive radiative forcing, while cooling is a response to negative radiative forcing.
recruitment	Influx of new members into a population or habitat by reproduction, immigration or settlement. In fisheries management, recruitment represents influx into the fishable part of the stock of a target species.
resilience	Capacity of a system to experience shocks while retaining essentially the same function, structure and feedbacks, and therefore identity.
run-off	Movement of water from the land into streams.
salinisation	The process of becoming more salty; the accumulation of soluble salts (e.g. sodium chloride) in soil or water. Many Australian soils and landscapes contain naturally high levels of sodium salts held deep in the soil profile.
salinity	*See* salinisation.
species	A group of organisms capable of interbreeding and producing fertile offspring.
specific resilience	Resilience to identified pressures, disturbances or shocks.
surface phytoplankton bloom	A sudden bloom of phytoplankton (microscopic plants) that occurs near the surface of a body of water. *See also* algal bloom.
sustainability, sustainable	Using 'natural resources within their capacity to sustain natural processes while maintaining the life-support systems of nature and ensuring that the benefit of the use to the present generation does not diminish the potential to meet the needs and aspirations of future generations' (*Environment Protection and Biodiversity Conservation Act 1999*, p. 815). 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (United Nations Brundtland Commission).
taxa	A group of one or more organisms classified as a unit. Taxonomic categories include class, order, family, genus, species and subspecies.
taxon	One member of a group; singular of taxa.
taxonomic	Related to the classification and naming of species (taxonomy).
threatened (species or community)	Likely to become endangered in the near future.
threatening process	A process or activity that 'threatens … the survival, abundance or evolutionary development of a native species or ecological community' (*Environment Protection and Biodiversity Conservation Act 1999*, p. 273) and that also may threaten the sustainability of resource use.
threshold	A boundary between 2 relatively stable states; a point where a system can go rapidly into another state, usually because of positive feedback(s).

Term	Definition
trigger values	Criteria levels within guidelines that trigger action; specifically, those that indicate a risk to the environment and a need to investigate or fix the cause.
trophic	Related to an organism's place in a food chain. Low trophic levels are at the base of the chain (microorganisms, plankton); high trophic levels are at the top of the chain (dingoes, sharks).
turbidity	A measure of water clarity or murkiness; an optical property that expresses the degree to which light is scattered and absorbed by molecules and particles in the water. Turbidity results from soluble coloured organic compounds and suspended particulate matter.
value	The worth of environmental assets. Categories of environmental values include: • indirect-use values—indirect benefits arising from ecological systems (e.g. climate regulation) • direct-use values—goods and services directly consumed by users (e.g. food or medicinal products) • non-use values (e.g. benevolence) • intrinsic value (i.e. environmental assets have a worth of their own regardless of usefulness to humans).
vulnerable (species)	At high risk of extinction in the wild; likely to become endangered unless the circumstances threatening its survival and reproduction improve.
watertable	The level below which the ground is saturated with water; the division between the subsurface region in which the pores of soil and rocks are effectively filled only with water, and the subsurface region in which the pores are filled with air and usually some water.
Weeds of National Significance	Weeds identified as a threat to Australian environments based on their invasiveness, potential for spread, and socio-economic and environmental impacts; 20 plant species are currently listed as Weeds of National Significance.

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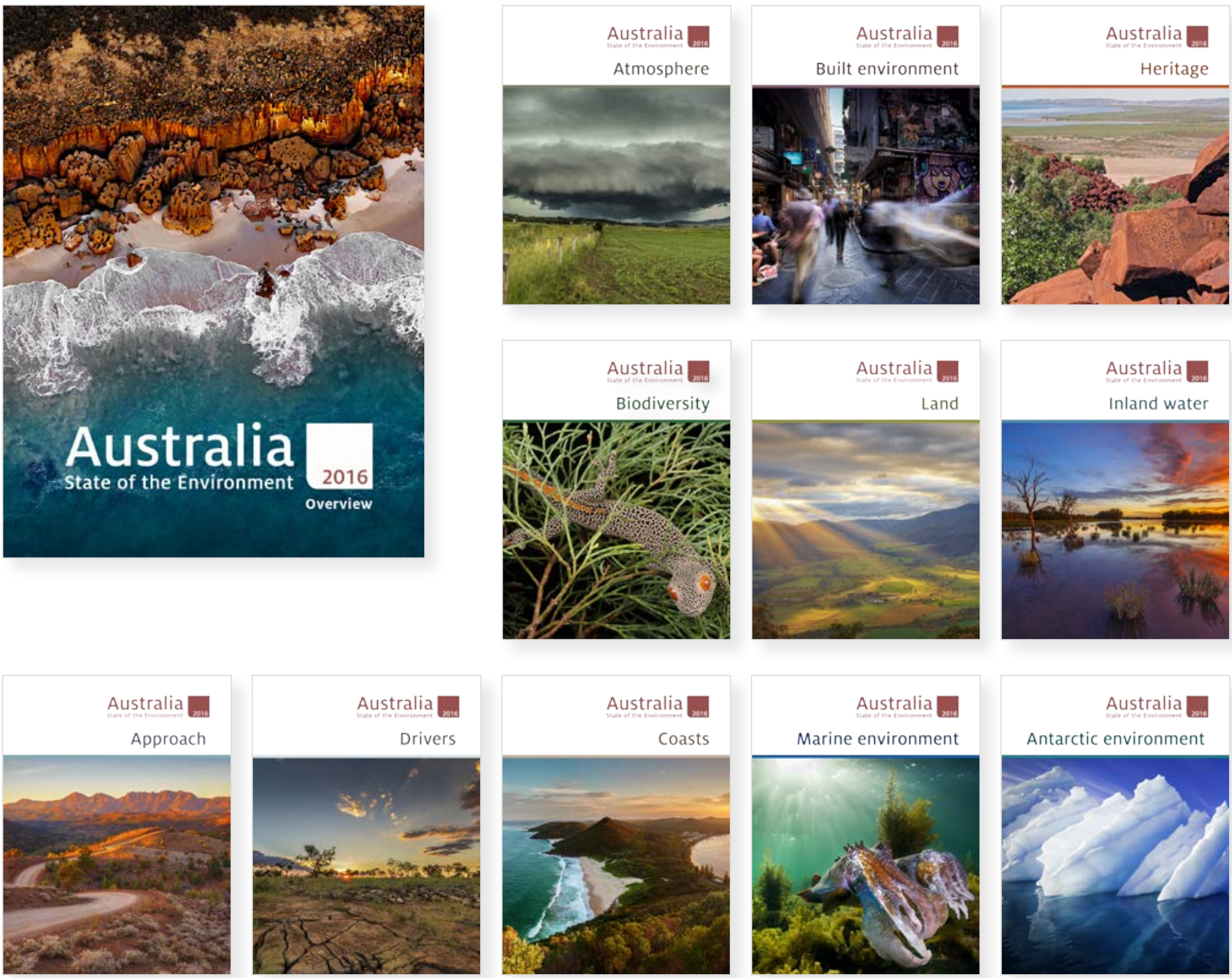

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