Australia
State of the Environment 2016

Marine environment

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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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This report may contain images, names of or references to deceased Aboriginal or Torres Strait Islander people.

Credits

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Executive summary

Australia's marine environment is the world's third largest marine jurisdiction, at 13.86 million square kilometres. It is home to a diverse array of marine species, many of which occur nowhere else in the world. Our oceans also contribute to the lifestyle of many Australians, 85 per cent of whom live within 100 kilometres of the ocean. Oceans are an important and essential component of sea and land cultural practice for Indigenous communities. Our ocean species directly and indirectly support commercial fisheries and aquaculture, worth $2.5 billion in 2013–14. The economic value of resources extracted from our oceans is expected to more than double by 2029–30; by 2025, marine industries are expected to contribute around $100 billion each year to Australia's overall economy. Australian species and our natural marine treasures—such as the Great Barrier Reef in Queensland, Lord Howe Island in New South Wales, the Great Australian Bight in South Australia and Ningaloo Reef in Western Australia—stand as icons of Australia's national identity and support important revenue from marine tourism. Importantly, our oceans and coasts provide a further $25 billion worth of essential ecosystem services, such as carbon dioxide absorption, nutrient cycling and coastal protection.

Our oceans are subject to many varied pressures driven by increasing use of ocean resources and human-driven environmental change. Several pressures that, historically, have had substantial impacts on the marine environment, such as commercial fishing, and oil and gas exploration, are now decreasing because of economic pressures and management frameworks put in place to ensure future sustainability and environmental protection. Management frameworks for the traditional use of marine resources and recreational fishing are also improving, but from a lower base. Several pressures, such as those associated with climate change and marine debris, continue to increase, largely in association with limited management. Climate extremes since the last state of the environment (SoE) report in 2011 have led to widespread coral bleaching, loss of kelp forests, habitat destruction and invertebrate mortalities in both western and eastern waters of Australia. Although the overall status of habitats, communities and species groups may be good, there are individual species and habitats that remain in poor condition or are declining. Trends in many marine habitats, communities, species groups, processes and listed species remain unclear, thereby limiting the power of assessments conducted by successive SoE reports.

The outlook for the marine environment, given the current pressures and management frameworks in place to mitigate these pressures, is clearly mixed. Many improvements to management frameworks across Australian Government and state and territory jurisdictions, including the implementation of new national regulators, have provided beneficial outcomes for the marine environment. However, efforts continue to be poorly coordinated across sectors and jurisdictions. The lack of recognition of multiple pressures on marine resources and coordinated approaches to managing these pressures has the potential to result in gradual declines, despite appropriate management of the individual pressure, sector or jurisdiction. Thus, many management plans do not currently support building the resilience of marine ecosystems. Improved monitoring and reporting of marine ecosystems that build on current observing programs, such as the Integrated Marine Observing System, the Long-term Temperate Marine Protected Area Monitoring Program and the Australian Institute of Marine Science Long-term Monitoring Program, will be required to satisfy future stakeholder and public expectations, and support future assessments made under the SoE reporting framework. Further development and implementation of management options that are robust to future changes in marine ecosystems would minimise risks to our existing natural assets and human uses, and maximise new opportunities, especially across climate-sensitive industries such as fisheries and energy. Addressing challenges for the marine environment as we look to the future will require a coordinated, collaborative and dedicated effort involving researchers, government, industry and the Australian community. Key gaps in current capacity to undertake national assessments of the marine environment are outlined, and potential solutions are provided that may substantially improve future SoE reporting.

Spangled emperor (*Lethrinus nebulosus*), Houtman Abrolhos Islands, Western Australia
Photo by Institute for Marine and Antarctic Studies

Key findings

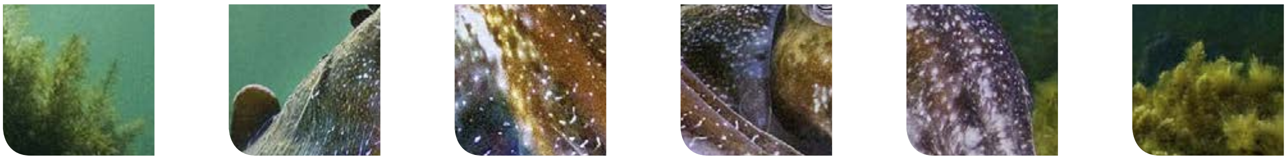
Key finding	Explanatory text
Australia's marine environment currently contributes approximately $50 billion per year to Australia's overall economy; this contribution is expected to double by 2025	Our oceans directly and indirectly support commercial industries such as fisheries, shipping and resource extraction, and provide important revenue from recreational activities, including tourism. The economic value of resources provided by our marine environment is expected to contribute around $100 billion each year to Australia's overall economy by 2025. Importantly, our oceans and coasts also provide an estimated $25 billion worth of essential ecosystem services, such as carbon dioxide absorption, nutrient cycling and coastal protection.
Australia's marine environment is influenced by the cycles of several natural climate phenomena, including the El Niño–Southern Oscillation, the Indian Ocean Dipole and the Southern Annular Mode	Variability in the phases of these climate phenomena change rainfall patterns, sea surface temperatures, surface winds and oceanic currents. These changes can influence the degree of vertical mixing through the water column and the relative location of cyclone events. Simultaneous fluctuations in the phases of these climatic phenomena, or particularly strong phases of each, can result in extreme changes in ocean processes and substantive impacts on the marine environment.
Climate extremes have resulted in widespread coral bleaching, habitat destruction and species mortalities in the past 5 years	One of the strongest recorded La Niña events (2010–12), superimposed on overall increasing water temperatures, led to widespread bleaching of corals, loss of kelp forests, fish and invertebrate deaths, and changes in species distribution in western Australian marine environments. Also associated with that La Niña event, cyclone *Yasi*, the strongest cyclone to make landfall in Queensland since at least 1918, caused widespread direct damage to central portions of the Great Barrier Reef in 2011. In 2015–16, the strongest El Niño event since 1998, superimposed on overall increasing water temperatures, affected northern and eastern environments, and also resulted in widespread bleaching of corals.
Anthropogenic ocean warming and ocean acidification, superimposed on natural climate variations, pose risks to Australia's marine ecosystems and their habitats, communities and species groups	Sea surface temperatures are continuing to increase, with surface ocean warming during the 21st century occurring at approximately 7 times the rate observed during the 20th century. The frequency of extreme sea surface temperature events has increased. Rising summer ocean temperatures are increasing the extent of coral bleaching. Climate change is also resulting in ocean acidification and changes to ocean currents. In response to changes in the marine environment associated with climate change, there have been significant shifts in the ranges of various invertebrates and fish.

Key finding	Explanatory text
Some historical pressures on the marine environment are decreasing because of the implementation of sustainable management measures and new regulatory schemes	Management measures aimed at the sustainable development of commercial fisheries implemented during the past decade have decreased the number of fish stocks classified as overfished. Of 53 countries (making up 95 per cent of global commercial fisheries catches) assessed on the basis of 14 indicators of resource management, Australia's commercial fisheries management was ranked equal fourth overall and second in terms of sustainability. Regulatory reform of the oil and gas industry, and implementation of the National Offshore Petroleum Safety and Environmental Management Authority have increased the level of scrutiny of the sector, resulting in a better understanding of impacts of activities, greater levels of industry compliance and increased levels of preparedness for unplanned events.
Some pressures are increasing, with uncertain impacts on the marine environment	Since 2011, there has been an increase in most forms of vessel activity in marine waters. As a result, risks associated with grounding of vessels, anchor scouring, accidents at sea in ecologically sensitive areas, vessel strike of marine animals, and introduction of foreign marine species to the Australian marine environment through the exchange of ballast water and biofouling are also likely to have risen, particularly those that are not currently managed across all forms of vessels. Improvements in the management of commercial vessels are resulting in mitigation and minimisation of some of the associated risks, but the outcomes of other risks remain unclear. High, but variable, concentrations of land-sourced and ocean-sourced marine debris are found in all marine environments, with significant quantities of plastics reported in the digestive tracts of several species of marine vertebrates. Continued growth in plastics production and use is expected, despite initiatives banning the use of some plastic products and improved waste management processes. Thus, marine debris will continue to be a ubiquitous problem affecting marine animals and their environment. Sources of high point-source anthropogenic noise are spatially variable, but generally regarded as either stable or decreasing. Increasing use of the marine environment is shifting anthropogenic contributions to marine soundscapes towards ongoing low-level noise, with uncertain long-term chronic impacts on the Australian marine environment.

Key finding	Explanatory text
Reporting on the current state and recent trends of Australia's marine environment is highly variable and often inadequate for robust assessment	The extent of information available on marine habitats, communities and species groups differs across marine regions. There are few coordinated, sustained biological monitoring programs at both the regional and the national level for the marine environment, and most monitoring is restricted to fisheries assessments and short-term programs in localised regions. Reporting varies in its spatial and temporal coverage, parameters measured, methods used and key indicators monitored. A good understanding of what ecosystems may have looked like before being modified by human impacts is lacking. As a result, empirical information about the status and trends for many habitats, communities and species groups is unclear; for some, there is insufficient understanding for assessment.
Overall, habitats, communities and species groups assessed in the 2016 state of the environment report are in good condition, with stable or improving trends	Of those habitats, communities and species groups for which timeseries are available, many are in good condition or improving following historical impacts. Key indicators of marine health, such as primary productivity, trophic processes and algal blooms, are also mostly considered to be in good condition. Several habitats, communities and species groups are highly spatially and temporally variable, and determination of trends in these is difficult, particularly where timeseries are short.
Generally, habitats, communities and species groups in the Temperate East and South-east marine regions have been affected by historical pressures to a greater degree than those in other regions	These marine regions have been subject to higher historical impacts than other marine regions. Thus, declining conditions and, in some areas, a lack of recovery of habitats, communities and species groups have been observed. The relatively lower use of the marine environment and the remoteness of much of the North, North-west and Coral Sea marine regions mean that habitats, communities and species groups across these regions are assumed to be in good condition, although few data exist from these marine regions to confirm their condition.
No marine species have been removed from the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) threatened species list since 2011; 8 species and 1 ecological community have been added	Since 2011, 2 sea snakes, 2 seabirds, 2 sharks, 1 sawfish and 1 fish have been listed, and 2 fish have been reclassified as critically endangered. Giant kelp forests across south-eastern Australia were the first marine community to be listed as a threatened ecological community. Australian populations of humpback whales have increased to the point that their current listing could now be reconsidered.

Key finding	Explanatory text
Activities to manage and mitigate threats identified in species recovery plans and threat abatement plans have been limited	There is a clear gap between the identification of pressures and issues associated with threats in recovery plans under the EPBC Act, and the implementation of activities that might mitigate pressures and assist the recovery of species or communities that are the focus of plans. A recent review of the threat abatement plan for the entanglement and ingestion of marine debris found that the plan had not met its objectives, and should be extended or revised.
Management frameworks continue to be poorly coordinated across sectors and jurisdictions, despite high spatial overlap. In association with this, understanding and management of cumulative impacts of all pressures are lacking	Efforts continue to be poorly coordinated across jurisdictions, although improvements have occurred in some sectors, such as fisheries and shipping. Coordination between sectors sharing common resources or using common regions remains lacking, resulting in inadequate accounting for all pressures and, in particular, cumulative pressures on the marine environment. As a result, many management plans do not currently support the development of resilience within marine ecosystems.
There has been steady development in the National Representative System of Marine Protected Areas since 2011, especially in the Commonwealth marine area	In 2012, 40 Commonwealth marine reserves were added to those already proclaimed in the South-east Marine Region. Management plans for the marine reserves in the South-east Marine Region have been implemented, and those developed for the remainder of the marine reserve network have recently been reviewed and are currently under redevelopment by the Australian Government. National coordination of management and monitoring of the network, however, is lacking. Marine reserves have also been implemented across some states and the Northern Territory.
Application of formal ecological risk assessment frameworks within the Australian marine environment has been limited	The use of formal risk assessments for managing marine resource use is patchy, resulting in variability in the prioritisation of limited resources and actions, associated processes in implementation, and addressing of cumulative impacts.
Residual risks to the marine environment associated with pressures vary in their likelihood and impacts, depending on the effectiveness of management frameworks	The likelihood and impacts of residual risks associated with pressures have been reduced because of management frameworks in some areas (e.g. commercial fishing impacts on habitats, planned oil and gas exploration and production activities). Pressures considered to have residual risks and the highest likely impacts on the marine environment are those associated with climate change and marine debris, because of a lack of effective management.

Key finding	Explanatory text
The outlook for the marine environment is clearly mixed	Although the overall status of the marine environment is good, some individual species and species groups remain in poor condition. Despite improving management in several sectors, trends in many marine environmental resources and, in particular, many listed species are uncertain, and some populations continue to decrease in size. The lack of coordinated monitoring and management across sectors reduces Australia's capacity to respond to new and increasing pressures and cumulative impacts.
Improved monitoring, reporting and implementation of decision-making support tools will be required to address the increasing complexity of managing marine resources facing increasing pressures, and to ensure that management frameworks can be adaptive and satisfy community expectations	The increasing complexity and mixture of local and remote pressures will require increasingly sophisticated information and tools for managers to choose the most cost-effective and enduring interventions that satisfy individual sectors, while ameliorating cumulative impacts. Improved, sustained monitoring can provide the indicators against which resources can be managed and management effectiveness reviewed. Prioritising what, when and how components of the marine ecosystem are monitored is essential if scientific data are to support marine managers in the changing and increasingly complicated environment in which they find themselves. Addressing challenges for the marine environment as we look to the future will require a coordinated, collaborative and dedicated effort, involving researchers, government, industry and the Australian community.



Approach

This report identifies the key pressures affecting the marine environment as a result of the social and economic drivers associated with population growth, energy production and consumption, food production, and recreation. Current understanding of the state and recent trends in key components of the marine environment, and the possible impacts on these components are discussed. Management frameworks addressing key pressures on the marine environment and their effectiveness are evaluated, and the resilience of the environment in light of current management frameworks is discussed (see Resilience of the marine environment for the definition of resilience used in this report). Further risks to the marine environment are identified, and an outlook for the marine environment is provided, taking all these factors into account.

This report builds on the 2011 state of the environment (SoE) report. Components of the marine environment identified for assessment were set in SoE 2011, and SoE 2016 is required to provide updates on these assessments.

In SoE 2011, the marine environment chapter covered many coastal topics. In SoE 2016, many of these topics can now be found in the expanded *Coasts* report; users of SoE 2016 are encouraged to read both reports. Careful and considered coordination between the authors of the marine environment and coasts reports has ensured that the 2 reports provide a comprehensive assessment of both environments, and there is clear reference to cross-cutting issues across the 2 environments.

Although most of the assessments included in SoE 2011 are updated here, the framework under which the assessments are presented has been modified slightly from that presented in 2011. It now distinguishes clearly anthropogenic pressures from pressures that were identified in SoE 2011 as natural processes. For example, assessments associated with dumped wastes and toxins, pesticides and herbicides, which were identified as physical or chemical processes in SoE 2011, are presented as pressures in SoE 2016. Many components identified as physical and chemical processes in SoE 2011 are collectively presented as impacts associated with the pressure of climate change in SoE 2016. This is because many of the changes observed in these components during the SoE reporting period are the direct result of changes occurring as a result of climate change. This avoids repetition of content between sections of the SoE report.

Reporting in 2011 presented commercial and recreational fishing collectively. Because of the considerable differences in the pressures associated with each and the means by which these are managed, it was regarded as more appropriate to present these in separate assessments in SoE 2016. Assessments dividing habitats according to a depth component have been revised and standardised to reflect recognised categorisation of the marine environment by the scientific community, and to avoid repetition of content between assessments.

Assessments in 2011 were the output of general regional workshops, with decisions on grade and trend based on general consensus between workshop attendees, rather than incorporating formal analyses. In 2016, the rigour and reproducibility of assessments have been increased by tasking specific experts to develop assessments using identified data sources and clearly stated methods. Each assessment was guided by a standardised reporting template and then independently reviewed. Around 150 experts were involved in the assessments and reviews, which frequently included new analyses of available data carried out specifically for SoE 2016. Metadata records of sources and methods used in assessments have been made publicly available through the Australian Ocean Data Network, and the metadata records provide direct links to individual assessments. The authors used these assessments, and additional published data and information to develop a national overview of the marine environment for SoE 2016.

Because of the lack of direct analysis of datasets, and the ambiguity associated with approaches to, and justification for, many of the assessments in SoE 2011, direct comparisons between the assessments in 2011 and 2016, and identification of changes in either grades or trends for many assessments were not possible between the 2 reporting periods. As a result, many assessments are identified in their summaries as being either only somewhat comparable or not comparable; only 3 assessments were considered to be comparable. It is hoped that, by providing clear information on the approach to each assessment, and the supporting data and information via metadata records housed on the Australian Ocean Data Network, datasets, methods and analyses can be built on and reproduced in future SoE reports, allowing directly comparable assessments of grade and trend.

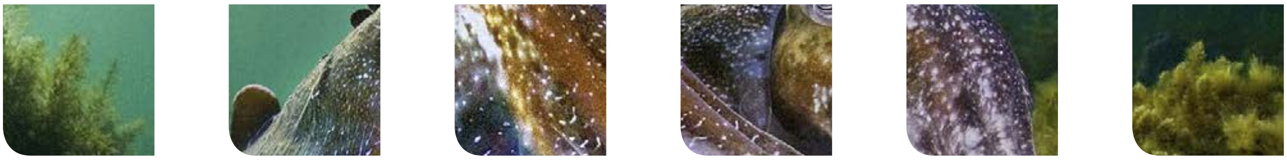
The SoE *Approach* report (Jackson et al. 2016) sets out the structure of the assessment summary tables and the associated categorisation of grades, trends and comparability with SoE 2011; the residual risk table; and the likelihood and impact categories, and associated definitions for each. Assessments provided are therefore the sum of the available data, the analyses conducted, expert knowledge and best judgement on the use of the categories set out for each of the assessment tables by each of the contributors to the marine environment report. The text and the assessment summaries, although based on the results of analyses carried out for SoE 2016 and the latest scientific research, management and policy publications, are presented for a general audience.

Data and information available for assessments vary across the components presented in this report. Those aspects of the marine environment for which data are lacking or limited are identified. Long-term datasets available for determining trends over time are often spatially limited, and datasets from different locations often vary in the variables measured and the time periods across which data are collected. It is difficult to scale grades and trends from a small number of variables measured at a small number of locations to whole habitats, communities or species groups at a national scale. Many assessments therefore incorporate considerable variability and uncertainty. Where assessments span a range of grades (e.g. good to very poor) or trends (e.g. improving to deteriorating)—because of variable data; spatial variability in grade or trend; or variability in grade or trend across species within a habitat, community or species group—the authors indicate a median value in the assessment summaries. For such assessments, the text associated with each assessment summary identifies that the grade or trend varies for that component of the marine environment. A consequence is that many grades or trends may appear to be overly simplistic and more narrative in nature than quantitative. Records for each assessment provided on the Australian Ocean Data Network should be referred to for further detail on each assessment.

The marine environment report of SoE 2011 was based on the marine regions identified under marine bioregional planning conducted in support of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The 2016 report also follows this framework for comparative reasons, recognising that the area of the Great Barrier Reef Marine Park lies outside the identified marine regions and therefore is not included in discussions of these regions.

Under s. 54 of the *Great Barrier Reef Marine Park Act 1975*, a report is compiled every 5 years detailing the Reef's biodiversity, ecosystem health, heritage values, and commercial and noncommercial use; factors influencing the Reef's values; existing protection and management; resilience; risks; and the long-term outlook for both the ecosystem and heritage values. In discussing the marine environment associated with the Great Barrier Reef Marine Park area, rather than repeating the work published in the most recent Great Barrier Reef outlook report (GBRMPA 2014a), SoE 2016 refers extensively to that report. Where relevant, updates on the state of the environment within the Great Barrier Reef Marine Park since publication of the outlook report are included in SoE 2016, to ensure that reporting on the marine environment is as spatially comprehensive as possible.

Southern blue devil fish (*Paraplesiops meleagris*), Port Phillip Bay, Victoria
Photo by Andrew Newton



Introduction

At 13.86 million square kilometres, Australia's marine environment is the third largest marine jurisdiction in the world (Symonds et al. 2009). It is home to a diverse array of marine species, including marine mammals and reptiles; more than 4000 species of fish; and tens of thousands of species of invertebrates, plants and microorganisms. Many of Australia's marine species occur nowhere else in the world; others use Australian waters as part of extensive migrations or movements. Our oceans also contribute to the lifestyle of many Australians, 85 per cent of whom live within 100 kilometres of the ocean (NMSC 2015). The oceans are also an essential part of Aboriginal and Torres Strait Islander people's cultures, customs and traditions.

Australia's vast ocean territory is a valuable asset. It makes a substantial contribution to the national economy, and this contribution is expected to increase as part of the emerging 'blue' economy.[1] Our ocean species support commercial fisheries and aquaculture that were worth $2.5 billion in 2013–14 (Savage & Hobsbawn 2015). The economic value of resources extracted from our oceans is expected to more than double from $32 billion in 2012–13 to $67 billion by 2029–30 (APPEA 2015). By 2025, Australia's marine industries are expected to contribute around $100 billion each year to our economy (OPSAG 2013, NMSC 2015). Australian species and our natural marine treasures—such as the Great Barrier Reef in Queensland, Lord Howe Island in New South Wales, the Great Australian Bight in South Australia and Ningaloo Reef in Western Australia—stand as icons of Australia's national identity and support important revenue from marine tourism. Importantly, our oceans and coasts provide a further $25 billion worth of essential ecosystem services, such as carbon dioxide absorption, nutrient cycling and coastal protection (Eadie & Hoisington 2011, NMSC 2015). Benefiting from the value of our oceans requires effective management, including conservation, and the sustainable use of the environment and living resources.

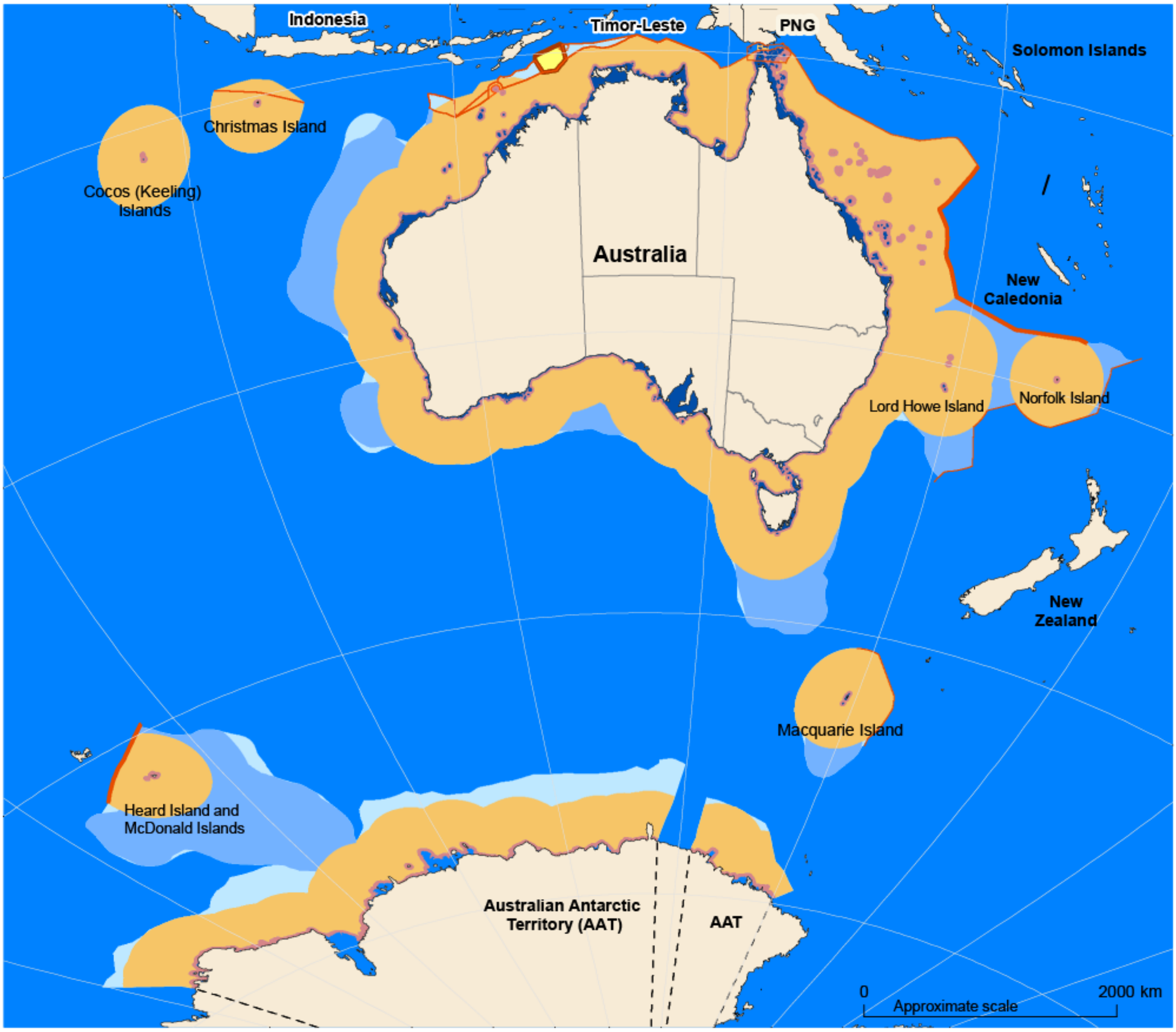
1 A blue economy is one that strikes a balance between maximising the economic potential of our oceans and safeguarding their longer-term health. A blue economy is one in which our ocean ecosystems bring economic and social benefits that are efficient, equitable and sustainable (DFAT 2015).

Jurisdictions covered

Australia's marine environment is part of the Indian Ocean, the Pacific Ocean and the Southern Ocean. It covers a diversity of seascapes and unique biodiversity values associated with tropical and Antarctic waters, from the shoreline to the abyss. The outer boundary of Australia's marine jurisdiction adjoins international waters, as well as the boundaries of several other countries and territories, predominantly in subtropical and tropical waters, including Indonesia, New Zealand, Papua New Guinea, the Solomon Islands, Timor-Leste and the French territory of New Caledonia (Figure MAR1).

For the purposes of managing the marine environment, in broad terms, Australia's marine territory can be divided into 3 jurisdictions (Figure MAR1), which reflect the role of the state, Northern Territory and Australian governments, and the terms of international agreements and conventions:

- coastal waters extending 3 nautical miles from the adjusted low-water line and managed by the state and Northern Territory governments
- the territorial sea, extending to 12 nautical miles, and the exclusive economic zone (EEZ), extending 200 nautical miles from the adjusted low-water line; the waters outside coastal waters are managed by the Australian Government
- the extended continental shelf beyond 200 nautical miles, proclaimed by Australia in 2012 following the recommendations of the United Nations Commission on the Limits of the Continental Shelf; the seabed and



3 nautical mile limit: coastal waters
12 nautical mile limit: territorial sea
200 nautical mile limit: exclusive economic zone
Treaty boundary with opposite or adjacent state
Joint petroleum development area
Extended continental shelf
Extended continental shelf (yet to be resolved)

PNG = Papua New Guinea
Source: Australia's maritime zones, Geoscience Australia

Figure MAR1 Zones that comprise Australia's marine jurisdiction the nonliving resources of the shelf, but not the water column and its resources, are under the jurisdiction of the Australian Government.

The outer limit of Australia's full marine jurisdiction is now largely in place. The exceptions are 2 small areas associated with the Joey Rise on the Exmouth Plateau and Williams Ridge on the Kerguelen Plateau, which are subject to a potential new or revised submission, and a small area of potential continental-shelf delimitation with France to the north-east of Norfolk Island. Further, a permanent maritime boundary delimitation between Australia and Timor-Leste has been set aside for up to 50 years under the 2006 Treaty between Australia and the Democratic Republic of Timor-Leste on Certain Maritime Arrangements in the Timor Sea (Symonds et al. 2009).

Boundaries and jurisdictions within the area managed by the Great Barrier Reef Marine Park Authority are slightly different from those described above, and are described in the Great Barrier Reef outlook report (GBRMPA 2014a).

In this report, we focus on the marine environment within Australia's EEZ adjacent to the continental land mass and associated islands north of the Subtropical Front (Orsi et al. 1995, Rintoul 2000). Australia's subantarctic and Antarctic marine environments are discussed in the *Antarctic environment* report. The direct interfaces between the land and the ocean, estuarine and enclosed embayments and habitats, and communities and species groups predominantly associated with these regions are discussed in the *Coasts* report.

Marine regions

Six discrete marine regions have been identified under marine bioregional planning conducted in support of the EPBC Act: North, Coral Sea, Temperate East, South-east, South-west and North-west (Figure MAR2). Marine bioregional plans have been developed for 4 of the regions (North, Temperate East, South-west and North-west), and a marine regional profile has been developed for the South-east Marine Region. The plans and profile aim to improve decision-making processes under the EPBC Act, and to protect marine biodiversity and heritage values, while supporting the sustainable use of ocean resources by marine-based industries.

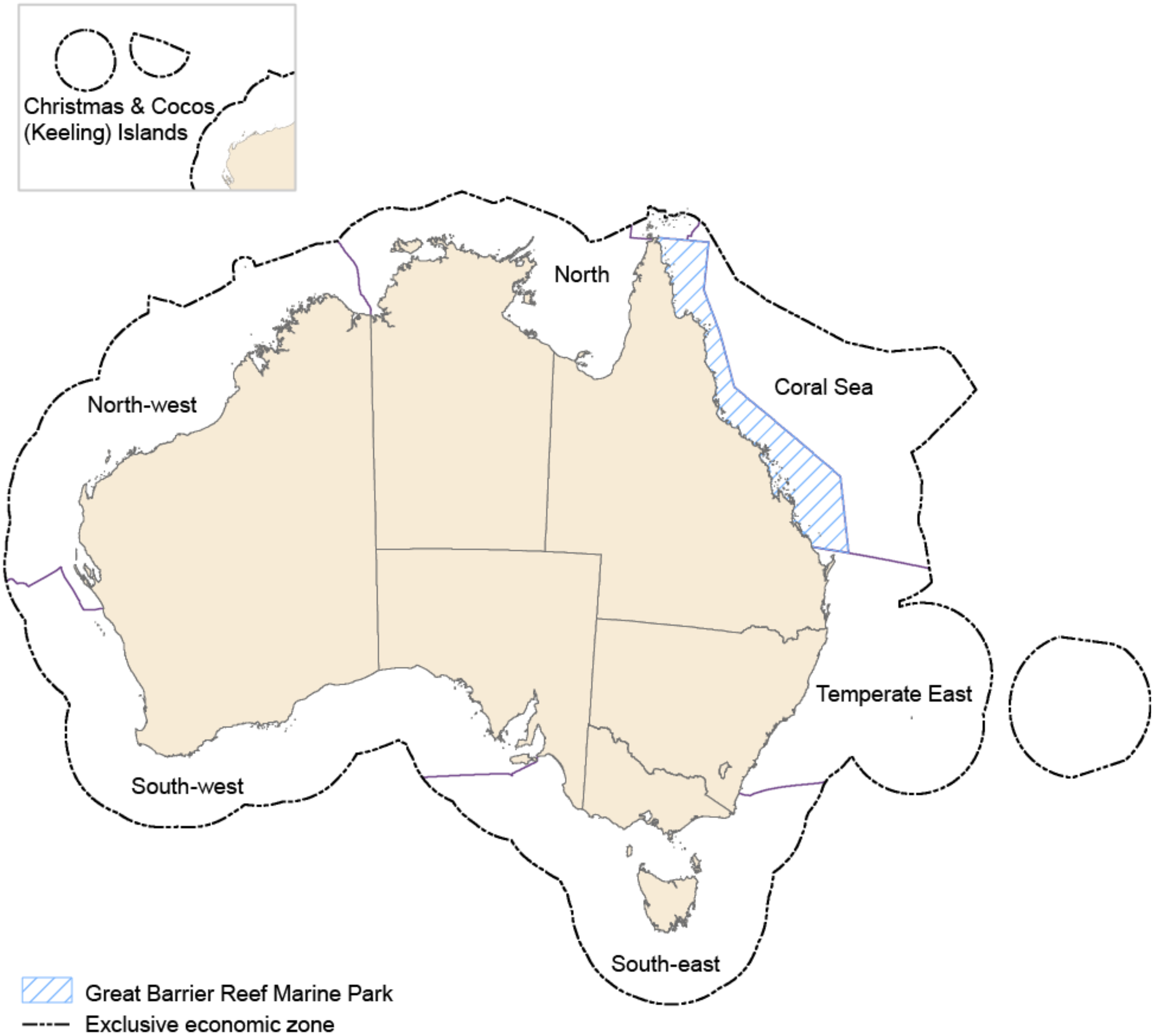
Designation of the 6 marine regions was informed by the provincial bioregions identified as part of the Integrated Marine and Coastal Regionalisation of Australia (IMCRA 4.0). The marine regions form the framework for the Commonwealth Marine Reserve Network (see also Effectiveness of marine management).

Assessments in this report consider each of the 6 recognised marine regions within the framework of a national overview of the marine environment, as well as relevant components within the area of the Great Barrier Reef Marine Park (Figure MAR2). Here, we provide an overview of the marine environment associated with each of the 6 regions. An overview of the marine environment within the Great Barrier Reef Marine Park can be found in GBRMPA (2014a) and will not be repeated here.

North Marine Region

The North Marine Region covers Australian waters from west of Cape York Peninsula to the Northern Territory – Western Australia border. The shelf west of Cape York Peninsula is overlain by mostly shallow, tropical waters of less than 70 metres depth, modified by complex tidal regimes and high cyclonic activity. A clockwise gyre in the Gulf of Carpentaria occurs during the summer monsoon and results from the net flow of the tides (Forbes & Church 1983). As a result of the gyre, the sea-floor basin in the centre of the Gulf receives low levels of sediment relative to sea-floor areas closer to shore. It tends to be flatter and less biologically diverse than nearshore environments (Long & Poiner 1994, Heap et al. 2004).

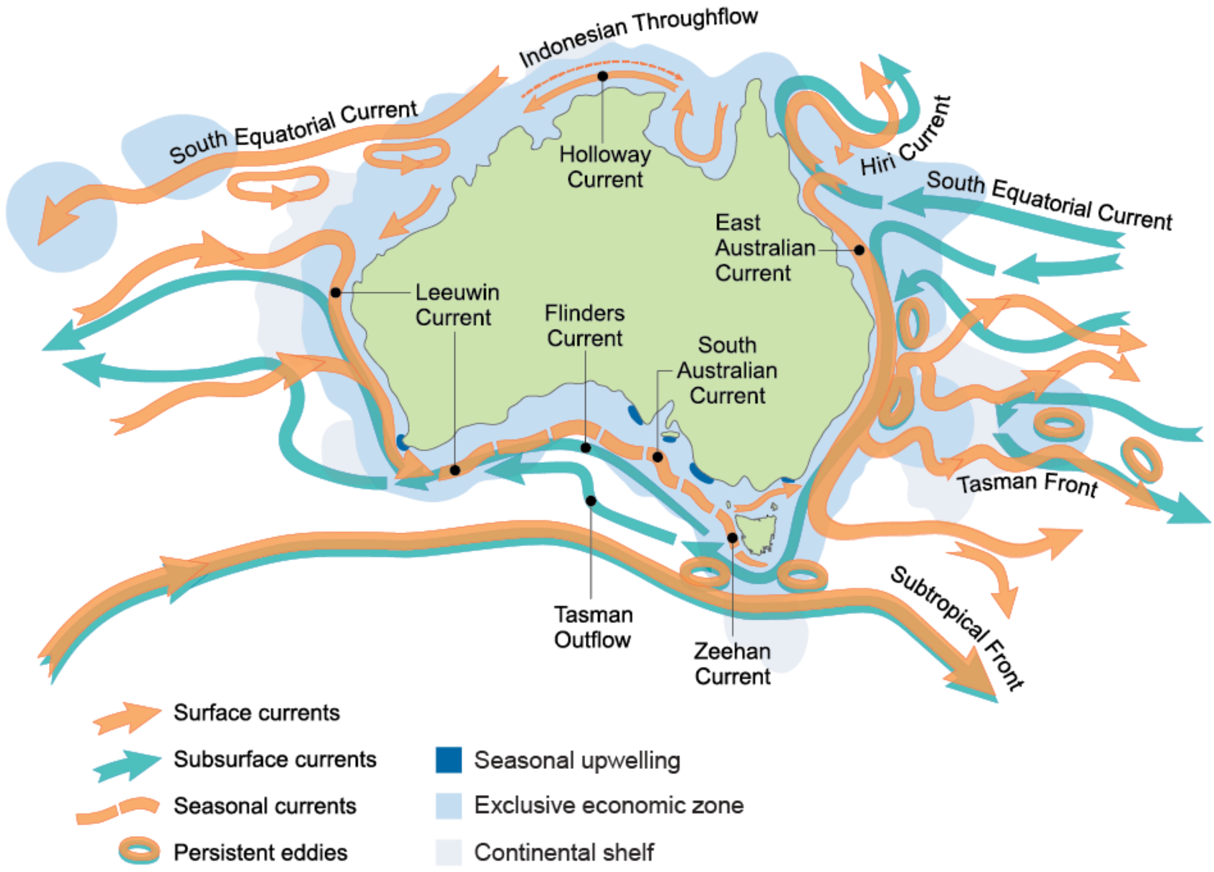
Further west, the Van Diemen Rise and Arafura Shelf contain complex sea-floor features such as canyons, shoals, banks, terraces and valleys. Oceanic currents across the marine region are driven largely by strong winds and tides, with minor influence from the Indonesian Throughflow and the South Equatorial Current to the north (Figure MAR3), which transfer water from the Pacific Ocean to the Indian Ocean. This seasonal circulation pattern broadly follows the contours of the Australian coastline and is known as the Holloway Current (Schiller 2011). The marine region is also one of the sources of the polewards-flowing Leeuwin Current, which flows along the west coast of Australia (Feng et al. 2003). Features such as the Arafura Sill and Torres Strait restrict water movement through the North Marine Region.



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

Figure MAR2 Australia's marine regions, including the Great Barrier Reef Marine Park

The North Marine Region borders the Coral Triangle, a marine biodiversity hotspot, which is known for its high biodiversity of tropical species, although endemism (species unique to the area and found nowhere else) is relatively low. One of the reasons for this low endemism is that there are no physical barriers to species dispersal, thereby facilitating species exchange with neighbouring regions. Food webs throughout the marine region are predominantly based on the large diatoms and zooplankton species that tend to be typical of warm, shallow coastal waters. Several protected, rare and endangered marine animals use the marine region for breeding and/or feeding, including marine turtles, sea snakes and marine mammals.



Source: CSIRO/National Environmental Science Programme Marine Biodiversity Hub

Figure MAR3 Major ocean currents and features influencing Australia's marine environment

The marine region contains 4 provincial bioregions under IMCRA 4.0. Eight key ecological features have been identified across the region (DSEWPaC 2012a; see also Box MAR10):

- pinnacles of the Bonaparte Basin
- carbonate bank and terrace system of the Van Diemen Rise
- shelf break and slope of the Arafura Shelf
- tributary canyons of the Arafura Depression
- Gulf of Carpentaria Basin
- plateaus and saddle north-west of the Wellesley Islands
- submerged coral reefs of the Gulf of Carpentaria
- Gulf of Carpentaria coastal zone.

The North Marine Region supports several industries, including commercial fisheries managed by the Australian and Northern Territory governments, oil and gas exploration and production, commercial and recreational vessel activity, recreational fishing, Indigenous activities, and defence operations.

Coral Sea Marine Region

The Coral Sea Marine Region covers Australian waters east of Cape York Peninsula, south to 24°29′S. It is adjacent to, but does not include, the Great Barrier Reef Marine Park. The Coral Sea Marine Region and the Temperate East Marine Region previously comprised the East Marine Region. The Coral Sea Marine Region encompasses tropical to subtropical environments, and incorporates atoll reefs, reef complexes, coral cays, offshore islands, terraces, deepwater valleys and troughs, offshore plateaus, abyssal plains, and seamounts. High seasonal cyclonic activity is typical of the marine region.

Oceanic currents reflect the bifurcation of the several currents and jets of the South Equatorial Current, and formation of the resulting northwards-flowing Hiri Current and the southwards-flowing East Australian Current (EAC; Figure MAR3). Surface currents associated with the Hiri Current form the quasi-stationary Coral Sea gyre in the Queensland Plateau area (Burrage 1993, Schiller et al. 2008), and the EAC forms a slow-moving clockwise eddy in the Marion Plateau area (Griffin et al. 1987).

Waters within the Coral Sea are influenced by the Western Pacific Warm Pool water mass. The warm pool is a water mass with a monsoonal and trade wind influence, and high interannual variability associated with the El Niño–Southern Oscillation (ENSO) (McPhaden & Picault 1990). Although Coral Sea waters are considered nutrient poor at the surface, a deep chlorophyll maximum layer, resulting from a nutricline at about 60–140 metres, has been observed, with chlorophyll levels (and primary production) peaking from June to August. This feature may be attributable to the increase in south-east trade winds at this time (Lyne & Hayes 2005).

Biological communities are poorly known, but are thought to reflect the high diversity of geomorphic features and habitats throughout the marine region. Food webs throughout the region are predominantly based on large diatoms, cyanobacteria and dinoflagellates, with the region supporting aggregations of prey species for apex predators, such as aggregations of lantern fish (*Diaphus* spp.; McPherson 1991). Several protected and migratory species use the marine region for breeding and/or feeding, including marine turtles, sea snakes and marine mammals. The marine region supports transient populations of highly mobile and migratory pelagic species (notably pelagic predators such as billfish, tuna and sharks), and is the only known spawning site for black marlin (*Istiompax indica*; Young et al. 2012).

Six IMCRA 4.0 provincial bioregions are contained within the region, and 3 key ecological features have been identified: the Tasmantid seamount chain; reefs, cays and herbivorous fish of the Queensland Plateau; and reefs, cays and herbivorous fish of the Marion Plateau (DSEWPaC 2011).

Flinders Commonwealth Marine Reserve community, Tasmania, showing a mix of sponges and bryozoans and some butterfly perch
Photo by Institute for Marine and Antarctic Studies

The marine region supports several industries, including commercial fisheries managed by the Australian Government, offshore tourism, commercial and recreational vessel activity, recreational fishing, Indigenous activities, and defence operations.

Temperate East Marine Region

The Temperate East Marine Region covers Australian waters from the southern boundary of the Great Barrier Reef Marine Park to Bermagui in southern New South Wales. It also includes the waters surrounding Lord Howe and Norfolk islands. The marine region encompasses subtropical and temperate environments, and incorporates the southernmost coral reefs, 3 seamount chains (Tasmantid and Lord Howe seamount chains, and Norfolk Ridge), the canyons on the eastern continental slope, shelf rocky reefs, offshore reefs and abyssal plains. Physical processes and ecosystems of the marine region are influenced by the EAC. Eddies separate from the main body of the EAC as it flows south along the continental shelf of Australia, forming areas of upwelling and downwelling. Once the EAC reaches around 33°S, the orientation of the coast changes and the EAC begins to separate from the continental shelf. This flow forms the Tasman Front (Figure MAR3), which plays a significant role in water mass transport through the Tasman Sea and out into the broader Pacific Ocean (Ridgway & Dunn 2003, Evans et al. 2016). A component of the EAC continues to flow south as the EAC extension.

Surface waters are generally of low to moderate productivity, and nutrient availability is strongly regulated by vertical mixing of the water column (Bax et al. 2001, Condie & Dunn 2006). Tropical species prevail in the north and are gradually replaced by temperate species in the south. Primary production is generally higher in the southernmost waters of the marine region because of greater vertical mixing associated with the Tasman Front and its eddies (Tilburg et al. 2002). High secondary productivity associated with areas of high eddy activity tends to aggregate species such as pelagic fish, invertebrates, seabirds and marine mammals (Young et al. 2010, 2011; Dambacher et al. 2011). Communities associated with the seamount chains in the marine region tend to have high endemism (de Forges et al. 2000).

The Temperate East Marine Region contains 10 IMCRA 4.0 provincial bioregions and 8 key ecological features (DSEWPaC 2012b):

- shelf rocky reefs
- canyons on the eastern continental slope
- Tasman Front and eddy field
- upwelling off Fraser Island
- Tasmantid seamount chain
- Lord Howe seamount chain
- Norfolk Ridge
- Elizabeth and Middleton reefs.

The marine region supports several industries, including commercial fisheries managed by the Australian, Queensland and New South Wales governments; commercial and recreational vessel activity; recreational fishing; Indigenous activities; and defence operations.

South-east Marine Region

The South-east Marine Region covers Australian waters from the southern boundary of the Temperate East Marine Region, around Tasmania and west to Kangaroo Island in South Australia. It also includes the waters surrounding Macquarie Island (included in the *Antarctic environment* report). The marine region includes a wide range of temperate habitats, including the vast shallow expanse of Bass Strait, shelf rocky reefs, continental margin canyons, groups of seamounts and abyssal plains. Eastern parts of the marine region are dominated oceanographically by the southward extension of the EAC and associated eddy fields (Figure MAR3), which move warm subtropical waters along the east coast of Tasmania during summer. This flow reverses during the winter months, with cool subantarctic waters moving up from the south (Ridgway 2007). To the west, the Leeuwin Current travels seasonally eastwards along the shelf edge east of the Great Australian Bight as the South Australian Current and then south along the west coast of Tasmania as the Zeehan Current (Ridgway & Condie 2004). The continental shelf is relatively narrow throughout most of the marine region. The shelf break intensifies currents, eddies and upwelling, particularly in the areas east of Bass Strait and along the shelf edge from King Island to Kangaroo Island, where it is known as the Bonney Upwelling.

Overall, the South-east Marine Region is relatively low in nutrients and primary productivity (the rate at which new organic matter is developed at the base of the food web), although seasonally enhanced areas of biological productivity, such as the Bonney Upwelling, drive aggregations of pelagic marine life (Figure MAR3; see also Box MAR10). Plant and animal communities in the region are highly diverse, and many endemic species occur throughout the marine region (Wernberg et al. 2011). Several protected and migratory species use the marine region for breeding and/or feeding, including marine mammals, seabirds, tunas and sharks.

The marine region contains 11 IMCRA 4.0 provincial bioregions and 8 key ecological features (DoE 2015a):

- Bonney Upwelling
- East Tasmania subtropical convergence zone
- Bass Cascade
- upwelling east of Eden
- Big Horseshoe Canyon
- West Tasmania canyons
- seamounts south and east of Tasmania
- shelf rocky reefs and hard substrates.

The marine region supports several industries, including commercial fisheries managed by the Australian, New South Wales, Victorian, Tasmanian and South Australian governments; oil and gas exploration and production; small-scale renewable energy; commercial and recreational vessel activity; recreational fishing; Indigenous activities; and defence operations.

South-west Marine Region

The South-west Marine Region comprises Australian waters from the eastern end of Kangaroo Island, South Australia, to Shark Bay, Western Australia. The marine region includes both temperate and subtropical habitats. It incorporates the wide continental shelf of the Great Australian Bight; significant canyon features such as the Perth Canyon, the Albany canyon group and canyons near Kangaroo Island; subtropical and temperate islands and reefs; fracture zones; deepwater plateaus; and abyssal plains.

The marine region is an area of complex oceanography, which is largely driven by the eastern boundary current, the Leeuwin Current (Figure MAR3). The Leeuwin Current transports warm nutrient-depleted water along the shelf break and outer parts of the shelf, seasonally extending across the entire region during the winter months when it is the strongest (Ridgway & Condie 2004). Interactions with the equatorial-flowing Leeuwin Undercurrent and regional topography result in the formation of mesoscale eddies, particularly near the Houtman Abrolhos Islands, the Perth Canyon and Cape Naturaliste (Rennie et al. 2007). Two other current systems contribute to the marine region (Middleton & Cirano 2002):

- The Capes Current—a seasonal equatorial-flowing current, driven by southerly wind stress along the Western Australian shelf—upwells colder water onto the shelf in summer.
- The Flinders Current—an upwelling favourable current—transports water from east to west along Australia's southern shelves.

The low-nutrient environment of the South-west Marine Region results in clear waters and high levels of light penetration, giving rise to a continental shelf characterised by high diversity of algal species and benthic communities. These, in turn, provide habitats for a large variety of species, contributing to high species diversity and endemism in the region. Several protected and migratory species use the region for breeding and/or feeding, including marine mammals, seabirds, tunas and sharks.

The marine region contains 7 IMCRA 4.0 provincial bioregions and 16 key ecological features (DSEWPaC 2012c):

- marine environment surrounding the Houtman Abrolhos Islands
- Perth Canyon and adjacent shelf break, and other west-coast canyons
- marine environment within and adjacent to the west-coast inshore lagoons
- marine environment within and adjacent to Geographe Bay
- Cape Mentelle upwelling
- Naturaliste Plateau
- Diamantina Fracture Zone
- Albany canyon group and adjacent shelf break
- marine environment surrounding the Recherche Archipelago
- ancient coastline at a depth of 90–120 metres

- Kangaroo Island Pool, canyons and adjacent shelf break, and Eyre Peninsula upwellings
- mesoscale eddies (several locations)
- demersal slope and associated fish communities of the Central Western Province
- western rock lobster
- benthic invertebrate communities of the eastern Great Australian Bight
- small pelagic fish of the South-West Marine Region.

The marine region supports several industries, including commercial fisheries managed by the Australian, South Australian and Western Australian governments; oil and gas exploration and production; small-scale renewable energy; commercial and recreational vessel activity; recreational fishing; Indigenous activities; and defence operations.

North-west Marine Region

The North-west Marine Region includes Australian marine waters from Kalbarri, south of Shark Bay, to the Western Australia – Northern Territory border. The marine region includes subtropical and tropical habitats, with extensive areas of continental shelf and slope, plateaus, terraces, coralline algal reefs, pinnacles, shoals, offshore reefs, canyons and abyssal plains. The oceanography of the marine region is subject to the Indonesian Throughflow (Figure MAR3), which brings warm, low-nutrient, low-salinity water from the western Pacific Ocean through the Indonesian archipelago to the Indian Ocean (Schiller 2011). The Indonesian Throughflow also contributes to the Leeuwin Current (Feng et al. 2003). Seasonal fluxes in water transport by the Indonesian Throughflow are associated with the annual monsoon cycle and influence the Leeuwin Current (Schiller 2011). The weakening of the Indonesian Throughflow and Leeuwin Current during the summer months, along with seasonal changes in wind and cyclone activity throughout the marine region, increase mixing of the deeper, cold, nutrient-rich waters with surface waters, increasing biological productivity in what is overall a low-productivity environment. Internal waves resulting from interactions within vertical gradients in water temperature, currents, extreme tidal regimes and the sea floor also increase biological productivity.

The marine region's range of geomorphic features and habitats is reflected in high species diversity, which is predominantly tropical and typical of the Indo–Pacific area. Several protected and migratory species use the marine region for breeding and/or feeding, including marine mammals, marine turtles, seabirds, tunas and sharks—particularly aggregations of whale sharks (*Rhincodon typus*).

The North-west Marine Region contains 8 IMCRA 4.0 provincial bioregions and 13 key ecological features (DSEWPaC 2012d):

- carbonate bank and terrace system of the Sahul Shelf
- pinnacles of the Bonaparte Basin
- Ashmore Reef, Cartier Island and surrounding waters
- Seringapatam Reef and the waters in the Scott Reef complex
- continental-slope demersal fish communities
- canyons linking the Argo Abyssal Plain and Scott Plateau
- ancient coastline at the 125 metre depth contour
- Glomar Shoals
- Mermaid Reef and the waters surrounding Rowley Shoals
- Exmouth Plateau
- canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula
- waters adjacent to Ningaloo Reef
- Wallaby Saddle.

The marine region supports several industries, including commercial fisheries, shipping, oil and gas exploration and production, commercial and recreational vessel activity, recreational fishing, Indigenous activities, and defence operations.






Drivers
influencing the marine environment

Drivers influencing the Australian environment are covered in detail in the *Drivers* report, and readers are encouraged to refer to that report. We briefly summarise the drivers influencing the marine environment here.

Global human population growth—resulting in increased energy and transport requirements, increased demands for food, increased creation of waste, and increased numbers of people wanting to use the ocean for recreational pursuits—continues to be the major driver of marine environmental change (Vitousek et al. 1997, Ruddiman 2013). Although Australia has a relatively low population density, 85 per cent of the population lives within 100 kilometres of the ocean in rapidly growing and increasingly urbanised environments. As well, Australians are living longer. Australia relies heavily on the contribution that its export commodities make to the overall economy, resulting in global market demand having a large influence on resource extraction and use (OECD 2014). Parallel to an increasing and longer-living human population, there is a drive by governments and society to improve overall living standards, develop new economic initiatives and opportunities, increase productivity, and expand the net exports and trade on which Australia already relies heavily for its economic security (e.g. the Developing Northern Australia White Paper).

In total, marine-based industries (e.g. commercial and recreational fishing, energy production, tourism) contributed $47.2 billion to the Australian economy in 2012. They are projected to contribute approximately $100 billion each year by 2025 (NMSC 2015). Resource extraction and production industries contribute to energy security; shipping industries contribute to economic security; wild fisheries contribute to food security; and recreational use of our marine environment contributes to social wellbeing.

Although there are clear benefits to society from these activities, each has the potential to place pressures on the marine environment if not managed for ongoing sustainable use. Further, they have the potential to increase pressures on an environment already undergoing physical and biological modifications associated with climate change, which is altering the physical, chemical and biological properties of the ocean. In association with these changes, species distributions are being altered, including distributions of introduced species. These pressures have flow-on impacts on the many ecosystem services the marine environment provides, including filtering and detoxification, biological production and regulation, atmospheric and climate regulation, nutrient cycling and fertility, and protection of coastal regions (UNEP 2006, Worm et al. 2006, OECD 2012); these ecosystem services are currently estimated to be worth $25 billion to the nation (NMSC 2015).

Although the development of renewable energy industries may reduce our reliance on oil and gas from the oceans, and thereby pressures associated with this form of resource extraction, projections of Australia's population and economic outlook suggest that, in general, pressures on the marine environment associated with increasing demands for resources and generation of waste will continue to increase (CSIRO 2015, NMSC 2015). Increased coordination between policy-makers, industry and society, supported by targeted scientific research, will be required to sustainably manage pressures placed on the marine environment if it is to maintain or increase societal benefits while maintaining the vital ecosystem services it provides.

Marine environment: 2011–16 in context

In the 5 years since SoE 2011, the marine environment has experienced several climate extremes, including one of the strongest La Niña events on record, in 2010–12, and the strongest El Niño event since 1998, in 2015–16 (see Interannual and subdecadal variability for a detailed description of ENSO). Variation in ocean temperatures and circulation associated with the La Niña event, superimposed on rising ocean temperatures associated with climate change, resulted in a marine heatwave (see Hobday et al. 2016 for a definition of such an event) off the Western Australian coast in 2011. The extended period of high ocean temperatures led to widespread bleaching of corals, loss of kelp forests, fish and invertebrate deaths, extensions and contractions in species distributions, variations in recruitment and growth rates, and impacts on trophic (food-chain) relationships and community structure. Cyclone *Yasi*, the strongest cyclone to make landfall in Queensland since at least 1918, also occurred during this La Niña period, causing widespread direct damage to central regions of the Great Barrier Reef, and resulting in high freshwater and sediment input into the coastal waters of the eastern seaboard because of associated widespread flooding (see also the *Coasts* report). The 2015–16 El Niño event, superimposed on an increasing baseline of ocean temperatures associated with climate change, resulted in the highest sea surface temperatures across the Great Barrier Reef on record. These extreme temperatures resulted in extensive coral bleaching and die-off, particularly across the northern regions. The conditions also caused a marine heatwave off the east coast of Tasmania from December 2015 to May 2016, the effects of which are yet to be determined.

There has been steady development in the National Representative System of Marine Protected Areas (NRSMPA) since 2011, especially in the Commonwealth marine area. In November 2012, 40 Commonwealth marine reserves (CMRs) were proclaimed in the South-west, North-west, North, Temperate East and Coral Sea marine regions, completing the NRSMPA in the Commonwealth marine area. The network was reproclaimed in December 2013, and the management plans for all regions except the South-east were set aside. The 10-year South-east Management Plan came into effect in 2013, with management under the Director of National Parks in accordance with the EPBC Act. A review of the new CMRs and how they were to be managed started in August 2014, and the associated reports were submitted to the Australian Government for consideration in December 2015. The review was released in August 2016, and revised management plans for each reserve are currently being developed by the Australian Government. New marine reserves declared across the states and the Northern Territory since January 2011 and reported in the 2014 Collaborative Australian Protected Area Database comprise reserves in the Northern Territory (675 square kilometres [km^2]), Queensland (256 km^2), Tasmania (31 km^2) and Western Australia (10,055 km^2). Management plans for South Australia's marine reserve network were finalised in 2013.

In the fisheries sector, national assessment and reporting of key Australian fish stocks through a collaboration across all government fisheries agencies was initiated in 2012. This reporting framework provides, for the first time, national fishery-wide reporting. The aim is that, over time, the reports will consider other aspects of ecologically sustainable development, such as the effects of fishing on the marine environment, economic performance and governance. A second report was produced in 2014, expanding on the number of stocks assessed in 2012, and a third was released in December 2016. A national strategy for research, development and extension for fisheries and aquaculture (FRDC 2010) is in place under the broader National Primary Industries Research, Development and Extension Framework, which is a collaboration between Australian Government agencies, state and territory agencies, and key research providers. The Fisheries Research and Development Corporation Indigenous Reference Group released key research, development and extension principles in 2015. These were aimed at developing self-management structures for cultural fisheries and supporting sustainable development of traditional harvesting.

In the oil and gas sector, regulatory reform resulting from the commission of inquiry into the Montara oil spill led to the implementation of the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) in 2012. Under the *Offshore Petroleum and Greenhouse Gas Storage Act 2006*, NOPSEMA is responsible for national regulation of safety, oil well integrity, and environmental management of oil and gas operations in Australian waters and in coastal waters where powers have been conferred by the state or territory. With the implementation of NOPSEMA, there has been an increased level of scrutiny of offshore petroleum environmental management through assessment processes and compliance inspections. Investigation and enforcement powers for environmental management have also been strengthened, which has resulted in better understanding of the impacts of activities, greater focus on industry compliance and better preparedness for unplanned events.

Several significant changes to managing commercial vessels in Australian waters have been implemented since 2011 to increase environmental protection. These include:

- designation of the Coral Sea Particularly Sensitive Sea Area
- review of the National Plan for Maritime Environmental Emergencies
- development of the North-East Shipping Management Plan.

The revised National Plan for Maritime Environmental Emergencies, released in 2014, provides a single national, comprehensive and integrated response arrangement for the management of maritime environmental emergencies. In particular, it details Australia's implementation of provisions set out under the international conventions and agreements that Australia is party to with respect to management of maritime environmental emergencies. In addition, vessel routing measures have been implemented off Ningaloo Reef, the southern Great Barrier Reef and south-western Western Australia. The Great Barrier Reef and Torres Strait vessel traffic service has also been extended.

The Intergovernmental Agreement on Biosecurity (IGAB)—an agreement between the Australian and all state and territory governments, except Tasmania—came into effect in 2012. It aims to strengthen the working partnership between governments; improve the national biosecurity system; and minimise the impact of pests and diseases on Australia's economy, environment and the community. The marine sector applies the biosecurity principles and framework of the IGAB through a suite of measures, including management of international and domestic ballast water and biofouling.

The deteriorating condition of the Great Barrier Reef World Heritage Area, and concerns raised by a monitoring mission by the World Heritage Centre and the International Union for Conservation of Nature (IUCN) triggered an assessment of this World Heritage property by the Australian and Queensland governments in 2014. As a result of this assessment, the Reef 2050 Long-term Sustainability Plan was developed, which aims to include all levels of government, the community, traditional owners, industry and the scientific community in the management of external pressures affecting the Reef. In association with the plan, a Reef-wide integrated monitoring and reporting program is currently being developed to measure the success of the sustainability plan and support adaptive management of the World Heritage Area.

A number of strategies focusing on conservation, biodiversity protection and sustainable development of Australia's environment have also been released since 2011, including Australia's Biodiversity Conservation Strategy 2010–2030, the Great Barrier Reef Marine Park Authority's *Science strategy and information needs 2014–2019* and the National Marine Science Plan 2015–2025. Each of these provides frameworks for coordinating research input to manage the marine environment.

At the same time, however, several formal frameworks facilitating national coordination between the Australian Government and the states and territories on marine science strategy and investment have been abandoned. These include the National Oceans Advisory Group, and the Marine and Coastal Committee of the Natural Resource Management Ministerial Council and its supporting National Marine Protected Area Working Group.

Government reviews and inquiries relating to the marine environment conducted during the past 5 years include:

- a review of Australian Government fisheries legislation, policy and management in 2012
- a review of the Australian Government policy on fisheries bycatch in 2012–13
- 2 reviews of the CMRs in 2014–15
- a Senate inquiry into the threat of marine plastic pollution in 2015–16
- a Productivity Commission inquiry into the regulation of fisheries across Australia in 2016.

Pressures

affecting the marine environment

At a glance

Australia's marine environment is experiencing pressures from a wide range of sources that affect its habitats, communities, species and ecosystem functioning to varying degrees. With many pressures affecting the marine environment and its inhabitants at any one time, it can be difficult to attribute observed impacts to individual pressures. It is particularly difficult to understand or predict how individual pressures will interact and what the cumulative impacts will be.

The overarching pressure that is currently affecting the marine environment—and will continue to affect it even with reduction of greenhouse gas emissions—is climate change. Anthropogenically driven ocean warming, superimposed on natural climate variations, and ocean acidification pose risks to Australia's coral reef ecosystems, and giant kelp and other habitats, including deep-ocean communities. Sea surface temperatures are continuing to increase nationally, with waters in the South-east and South-west marine regions increasing at a rate of more than 0.4 °C per decade. There is already evidence that, as waters have warmed, some species have shifted their distributions towards the poles, altering marine ecosystems. Changes to nutrient supply and dissolved oxygen are also projected to occur because of climate change; however, observations are insufficient at present to identify whether changes are occurring.

Extraction of resources—such as seafood, and oil and gas—from the marine environment is highly variable in its distribution and impacts. Many pressures associated with the extraction of resources are highly localised, and the likelihood of recovery of affected habitats, communities and species is high once the pressure is removed. Other pressures are more widespread or more persistent, or both, leaving little likelihood of recovery in the short to medium, and even long, term.

Overall, the footprint of pressures within Australian waters associated with commercial fishing has decreased in the past decade. Pressures associated with recreational fishing are generally stable, although, for some species, recreational catches now exceed commercial catches and are increasing. Pressures associated with the oil and gas industries, marine mining and dumping of waste tend to be localised, and are either stable, declining or increasing, but with the prospect that they may decline because of recent legislation.

Use of the marine environment by commercial and recreational vessels continues to increase. The risks associated with such activities that are not currently actively managed (e.g. anchor scour, ship strike, noise) are also increasing. High, but variable, concentrations of marine debris are found in all marine environments, and it is expected that marine debris will continue to be a ubiquitous problem because of continued growth in plastics production and use. As a result, marine debris has been identified as a key threatening process for marine vertebrate species. There is insufficient understanding of the long-term impacts of chronic noise in the marine environment, or trends in toxins, pesticides and herbicides.

Pressures affecting the marine environment are distributed unevenly, resulting from variable uses of the marine environment on local scales, and from broader spatial and temporal variability in climatic and oceanographic processes.

In general, pressures on the marine environment tend to be greater in inshore environments than in offshore environments because these areas are more readily accessible for human use, closer to coastal infrastructure, influenced by coastal and watershed activities to a greater extent, and exposed to inshore oceanographic processes (which tend to be more energetic than those further offshore) (Evans et al. 2016). The shallower water closer to the coasts also exposes species and habitats in these areas to increased environmental variability. This can result in greater capacity to adapt to change. Habitats or species are at greater risk when they have a lower resistance or adaptability to a certain pressure and/or a lower rate of recovery once the pressure is removed. In deeper areas of the ocean, recovery rates may be so slow that it is impossible to distinguish between recovery taking decades or more and a failure to recover within most management timeframes (Williams et al. 2010b).

Because there are many pressures affecting the marine environment and its inhabitants at any one time, it can be difficult to attribute observed impacts to individual pressures. It is particularly difficult to understand or predict how individual pressures will interact and what the cumulative impacts will be.

While recognising that many pressures that manifest in coastal regions influence the marine environment, pressures associated with the land–marine interface or that predominate in the coastal environment (e.g. coastal development, coastal waterway sedimentation and pollution) are not covered in this report. These are covered extensively in the *Coasts* report. In particular, readers should refer to the *Coasts* report for detail on pressures associated with pollution in estuary and embayment regions, pollution associated with land-sourced input of nutrients, aquaculture, port developments and tourism.

Of the pressures assessed in 2016, those associated with climate change are having the highest impacts on the marine environment, with the condition of physical (e.g. ocean temperature, currents and eddies) and chemical (e.g. ocean acidification, nutrients) features of the environment assessed as either deteriorating or uncertain. Pressures associated with oil and gas have decreased in the past 5 years, and most pressures associated with resource extraction and use are considered to have low impact, with either stable or unclear trends. Pressures associated with marine debris continue to be high, and related conditions for the marine environment continue to deteriorate.

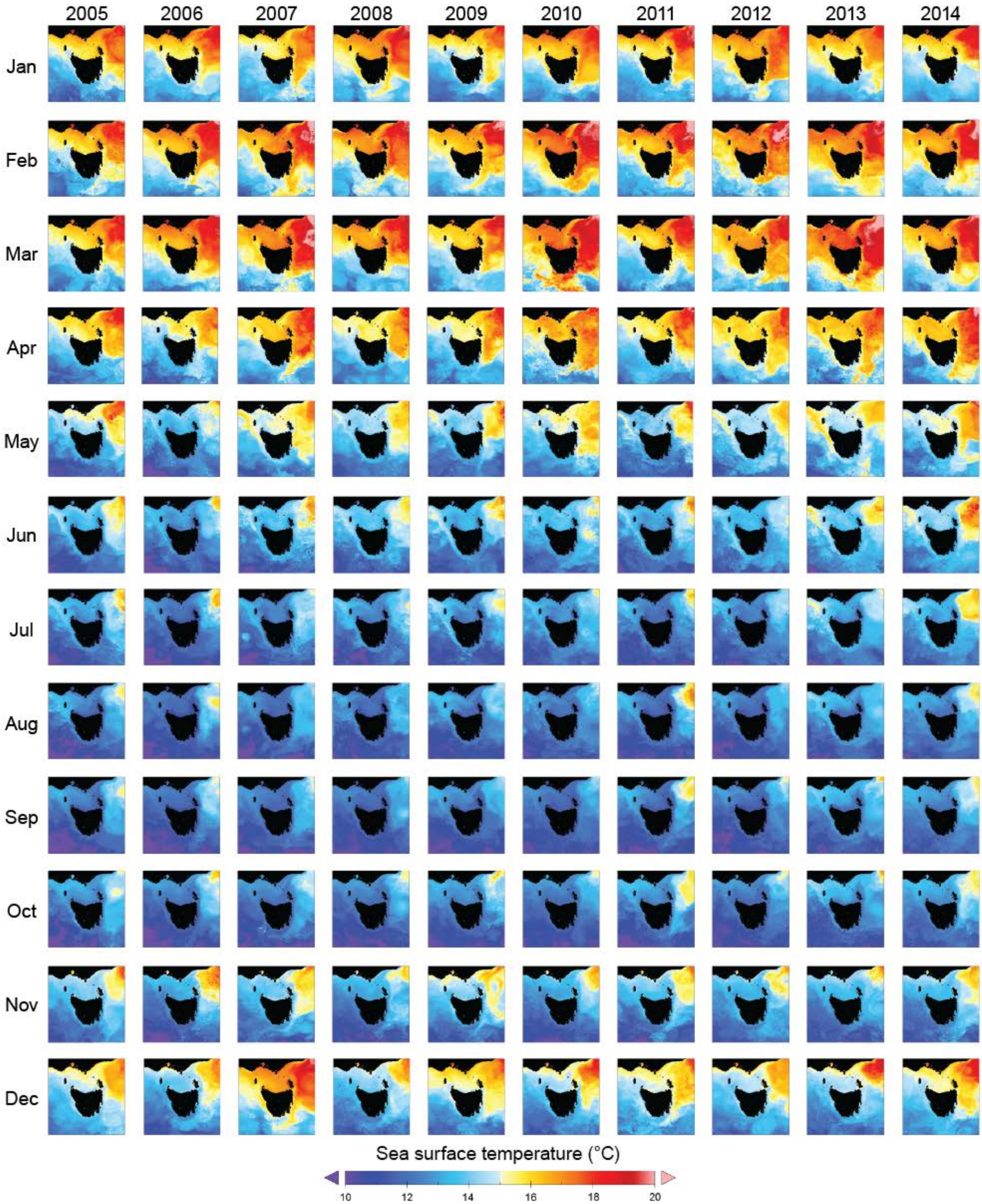
Climate and system variability

Seasonal variability

Climatic variability associated with increased monsoonal activity during the summer months in the tropical north and seasonal cycles in the temperate south leads to variations in water temperature (e.g. Figure MAR4), rainfall patterns (affecting ocean salinity), surface winds, oceanic currents and tidal regimes, which can influence the degree of vertical mixing through the water column (Feng et al. 2003, Ridgway & Condie 2004, Ridgway 2007, Redondo-Rodriguez et al. 2012, Ceccarelli et al. 2013).

These seasonal cycles in ocean physical processes have been relatively stable on evolutionary timescales, and species within the marine environment have evolved in response. Ocean primary productivity demonstrates variation in response to seasonal cycles in ocean processes (Tilburg et al. 2002, Thompson et al. 2015b). This is reflected in secondary producers and higher-order marine organisms that have also evolved to synchronise biological processes such as breeding or migration with these cycles (e.g. Stevens & Lyle 1989, McPherson 1991, Heithaus 2001, Gill 2002, Patterson et al. 2008). Any change in the duration or intensity of seasonal cycles on timescales shorter than that in which organisms in the marine environment can adapt may lead to mismatches in biological processes, resulting in deleterious impacts on marine populations. Understanding how natural variability drives processes within the marine environment, and how extremes in this variability affect marine organisms and processes is therefore essential to both quantifying and understanding the impacts associated with anthropogenically driven climate change.

Current projections of climate suggest that changes to seasonal cycles are occurring and will continue to occur, but with considerable variability across Australia. Climate zones within the marine environment have moved polewards, resulting in shifts in associated seasonality (Lough 2008). Extremes associated with the summer months will become more prevalent (Reisinger et al. 2014), particularly when coupled with ENSO (see Interannual and subdecadal variability). Modelled simulations of the climate under the Intergovernmental Panel on Climate Change (IPCC) emissions scenarios identify that seasonal monsoon and cyclone systems are likely to intensify (Christensen et al. 2013). How these



Source: Data from the Australian Ocean Data Network

Figure MAR4 Monthly averages of sea surface temperature in the South-east Marine Region, 2005–14 will affect seasonal cycles in marine ecosystems is not yet clear, but shifts in the onset of seasonal migrations and breeding have been observed elsewhere (e.g. Dufour et al. 2010, Asch 2015).

Interannual and subdecadal variability

Australia's marine environment is also influenced by cycles in climate on interannual timescales associated with several natural climate phenomena, such as ENSO, the Indian Ocean Dipole (IOD) and the Southern Annular Mode (SAM), also known as the Antarctic Oscillation. Of the climate phenomena that occur in the Southern Hemisphere, ENSO and the IOD potentially have the most widespread influence on the Australian marine environment, habitats, communities and species groups, whereas the influence of the SAM is mostly across the central and southern parts of Australia. Variability in the phases of these climate phenomena change rainfall patterns, sea surface temperatures, surface winds and oceanic currents, which can influence the degree of vertical mixing through the water column and the relative location of cyclone events (McBride & Nicholls 1983, Lough 1994, Lau & Nath 2000, Feng et al. 2010). Changes in the timing and magnitude of seasonal variability caused by these climate phenomena (McBride & Nicholls 1983, Mitchell & Wallace 1996, Lau & Nath 2000, Feng et al. 2010) have flow-on impacts on the marine environment and, in particular, species that have adapted to take advantage of seasonal cycles for processes such as breeding or feeding.

Simultaneous fluctuations in the phases of these climatic phenomena, or particularly strong phases of each, can result in extreme changes in ocean processes, contributing to events such as the marine heatwave that occurred in the waters off Western Australia during the summer of 2010–11 (Pearce et al. 2011, Pearce & Feng 2013). This event, driven by the occurrence of a strong La Niña phase of ENSO, superimposed on long-term increasing water temperatures associated with climate change (see Climate change), resulted in widespread bleaching of corals across the North-west Marine Region. It was also associated with fish and invertebrate deaths, extensions and contractions in species distributions, variations in recruitment and growth rates, impacts on trophic relationships, and shifts in community structure, particularly in relation to kelp forests across the North-west and South-west marine regions (Wernberg et al. 2016). Variations in the catch rates of exploited species were also recorded after the event (Pearce et al. 2011, Pearce & Feng 2013).

The strongest El Niño phase of ENSO since 1998 occurred in 2015–16. Similarly to the Western Australian heatwave, this was superimposed on an increasing baseline of ocean temperatures associated with climate change, and resulted in the highest sea surface temperatures across the Great Barrier Reef on record. These extreme temperatures caused extensive coral bleaching and die-off, particularly across northern regions of the Great Barrier Reef and parts of north-western Australia (see Quality of habitats and communities). A marine heatwave was also recorded off eastern Tasmania from December 2015 to May 2016 in association with the same conditions, although impacts of this heatwave on the marine environment are yet to be established.

The ability to predict climate variability in the marine environment beyond the presence of annual cycles is not well developed, and forecasts beyond 1–2 years are highly inaccurate (Kirtman et al. 2013, Evans et al. 2015). Even our current ability to predict the phase of ENSO varies. It is possible to predict the likelihood of an El Niño event, but it is not so easy to predict its timing or strength. The accuracy of prediction declines rapidly as the time to the event increases, because even small perturbations to the system (such as the random occurrence of a tropical cyclone) can lead to a very different ENSO phase later in the year (Jin et al. 2008).

Predictability of ENSO is further complicated by the diversity of ENSO behaviours. No 2 events are alike, and the onset and progression of each event are characterised by unique changes to sea surface temperatures, surface winds and the mixed layer (Singh et al. 2011). Long-term records of ENSO demonstrate high multidecadal variability, with some decades experiencing less variability in ENSO and others experiencing more (Harrison & Chiodi 2015). Although it is almost certain that climate phenomena such as ENSO will continue to occur and be the dominant mode of interannual variability, the influence that climate change might have on these phenomena is unclear (Brown et al. 2013, Christensen et al. 2013, Evans et al. 2015).

Interdecadal variability

Climate cycles also occur on longer timescales, with the Pacific Decadal Oscillation (PDO; Mantua & Hare 2002) the most important phenomenon influencing the Australian marine environment. The PDO has been described as a pattern of climate variability similar to ENSO, with positive phases having similar effects on the climate to El Niño and negative phases similar effects to La Niña, but operating on scales from 15 years to as long as 70 years (Mantua & Hare 2002). This results in initially abrupt transitions to conditions that are then stable across multiple decades (Hilborn et al. 2003). Interactions between phases of the PDO and ENSO can either modulate or strengthen the phases of ENSO (Cai & van Rensch 2012), with flow-on effects on ocean processes and the marine environment (see Interannual and subdecadal variability). Biological responses to the PDO include changes in primary productivity, which are transmitted through the food chain, resulting in changes in productivity of higher trophic levels (Hare & Mantua 2000, Hilborn et al. 2003). A recent negative phase of the PDO has been associated with increased rainfall and La Niña conditions in the Temperate East Marine Region (Cai & van Rensch 2012). However, how the PDO drives variability is less well understood for the Australian marine environment than for other regions of the Pacific Ocean. Climate variability on decadal scales associated with features such as the PDO is not currently predictable (Evans et al. 2015).

Climate change

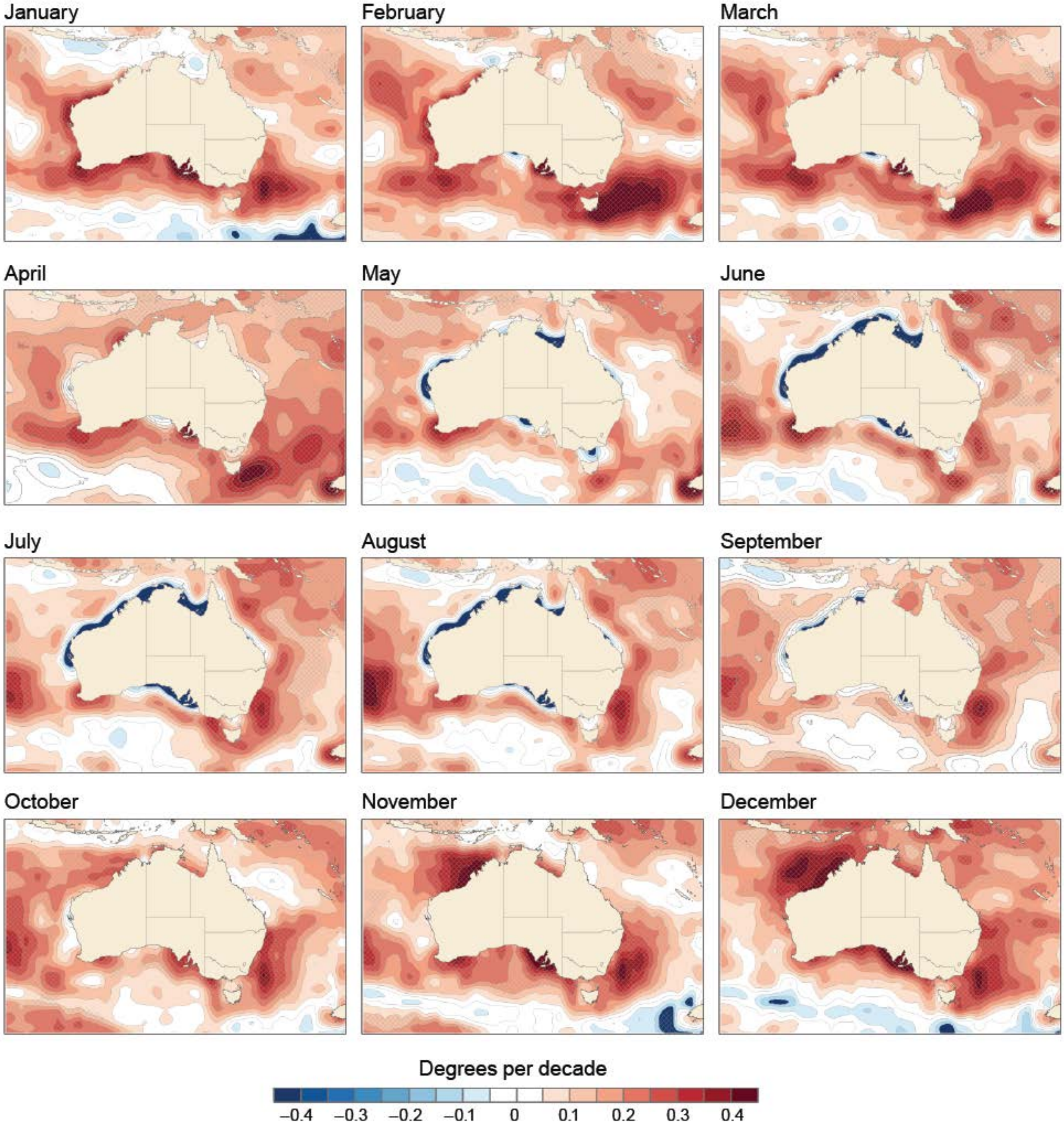
Anthropogenic ocean warming and ocean acidification, superimposed on natural climate variations—in particular, ENSO and decadal variability (Holbrook et al. 2012)—pose key risks to all of Australia's marine environment, from shallow-water habitats to deep-ocean communities (Thresher et al. 2015). These include Australia's coral reef ecosystems (e.g. Gattuso et al. 2014) and giant kelp communities (e.g. Johnson et al. 2011). Changes in the marine environment associated with climate change provide a progressively changing baseline on top of which natural climate variations and their extremes are occurring. This poses challenges for the ability of marine organisms to adapt to changes that are occurring on much shorter timescales than those that have occurred in the past across evolutionary timescales.

In response to changes in the marine environment associated with climate change, significant shifts have occurred in the ranges of various invertebrates and fish (Last et al. 2011a, Bates et al. 2014, Sunday et al. 2015). On the Great Barrier Reef, rising summer ocean temperatures increase the risk of mass coral bleaching (GBRMPA 2014a).

Ocean temperature

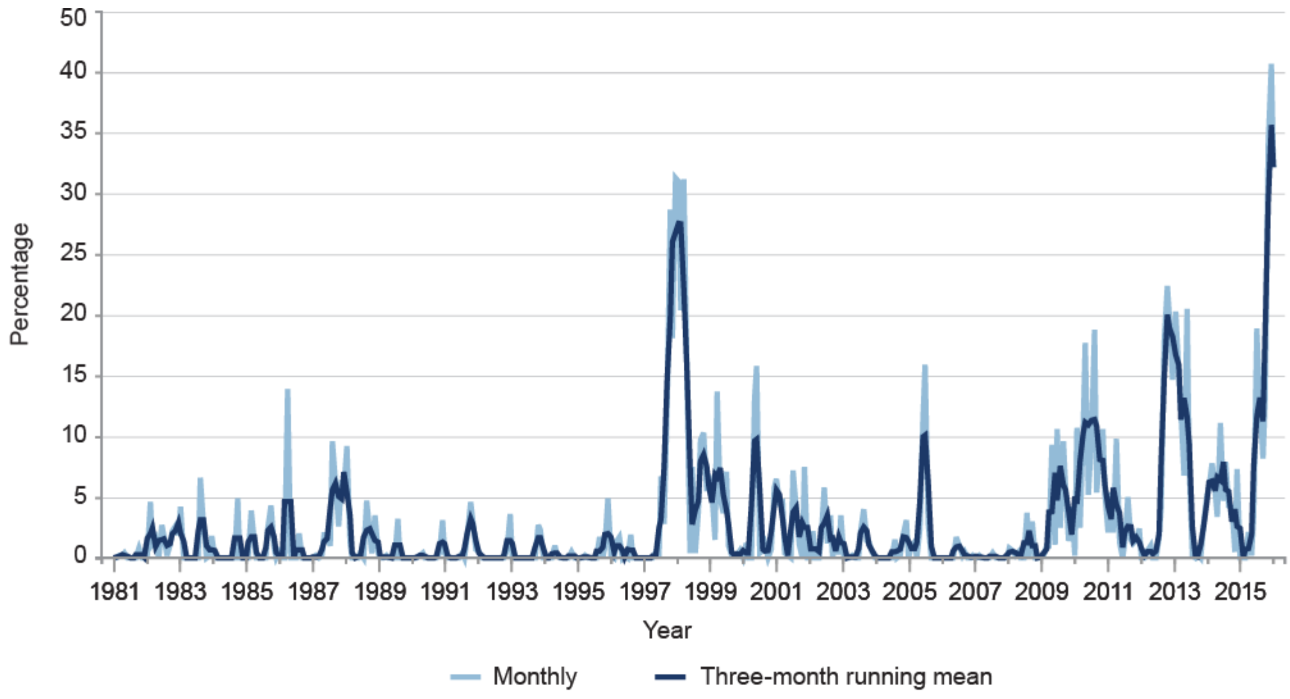
Nationally, as the oceans absorb heat from the atmosphere, sea surface temperatures are continuing to increase. Waters in the South-east and South-west marine regions are increasing in temperature the most, at more than 0.4 °C per decade (Figure MAR5). This compares with an average global trend of 0.12 °C per decade across 1979–2012 (Hartmann D et al. 2013). The surface ocean has warmed across the 21st century at approximately 7 times the rate observed during the 20th century (Sen Gupta et al. 2015), and the frequency of extreme sea surface temperature events in association with ENSO and the IOD has increased (Figure MAR6). Regional and seasonal variations exist in sea surface temperature trends, with winter months showing statistically significant cooling close to the north and north-west Australian coastline (Figure MAR5). Warming of tropical waters on the continental shelf between 10.5°S and 29.5°S has already resulted in the southwards shift of climate zones by 200 kilometres along the east coast of Australia, and by approximately 100 kilometres along the west coast (Lough 2008). Climate change impacts on ocean temperatures are therefore assessed as having a high impact with a deteriorating trend.

There is already evidence that some species, including temperate fish fauna (Last et al. 2011a), have extended their distribution towards the poles as waters have warmed (Poloczanska et al. 2013). The introduction of new species into regions because of expansion of, or shifts in, their distribution has the potential to alter marine communities. This is already happening in some regions, such as the South-east Marine Region (e.g. Johnson et al. 2011). It is likely that more marine communities will undergo major changes to their structure (Hughes et al. 2003). Conversely, it is likely that other species will reduce their ranges when the edge of their range becomes thermally unsuitable and the timescales at which changes are occurring exceed their ability to adapt (e.g. Smale & Wernberg 2013). Already climate extreme



Note: Cross-hatching represents areas where confidence in observed trends is 95 per cent.
Source: Data from the Australian Ocean Data Network and NASA

Figure MAR5 Decadal sea surface temperature trend per month (degrees per decade), 1982–2015



Note: Extreme sea surface temperatures (SSTs) were calculated by comparing monthly SSTs with all other recorded monthly SSTs in the timeseries at a particular grid point. If the SST was higher than all other SSTs recorded for that grid point during that month, it was considered an extreme event.
Source: Data from the Australian Ocean Data Network and NASA

Figure MAR6 Percentage of the Australian exclusive economic zone experiencing extreme sea surface temperatures, 1981–2016

events, when particularly strong phases of natural climate variability such as that associated with ENSO are superimposed on rising temperature baselines, are having widespread impacts on coral reefs, kelp communities, species distributions and species life history dynamics (Pearce et al. 2011, Pearce & Feng 2013, Wernberg et al. 2012, 2016). (See Interannual and subdecadal variability and Quality of habitats and communities.)

Altered temperatures may decouple population processes of functional groups that are currently tightly linked. For example, the breeding processes of many marine species are timed to coincide with peaks in prey species populations, whose timing is often driven by temperature. If the timing of the 2 processes is altered so that they no longer match, this will likely affect larval survival and population recruitment (e.g. Philippart et al. 2003).

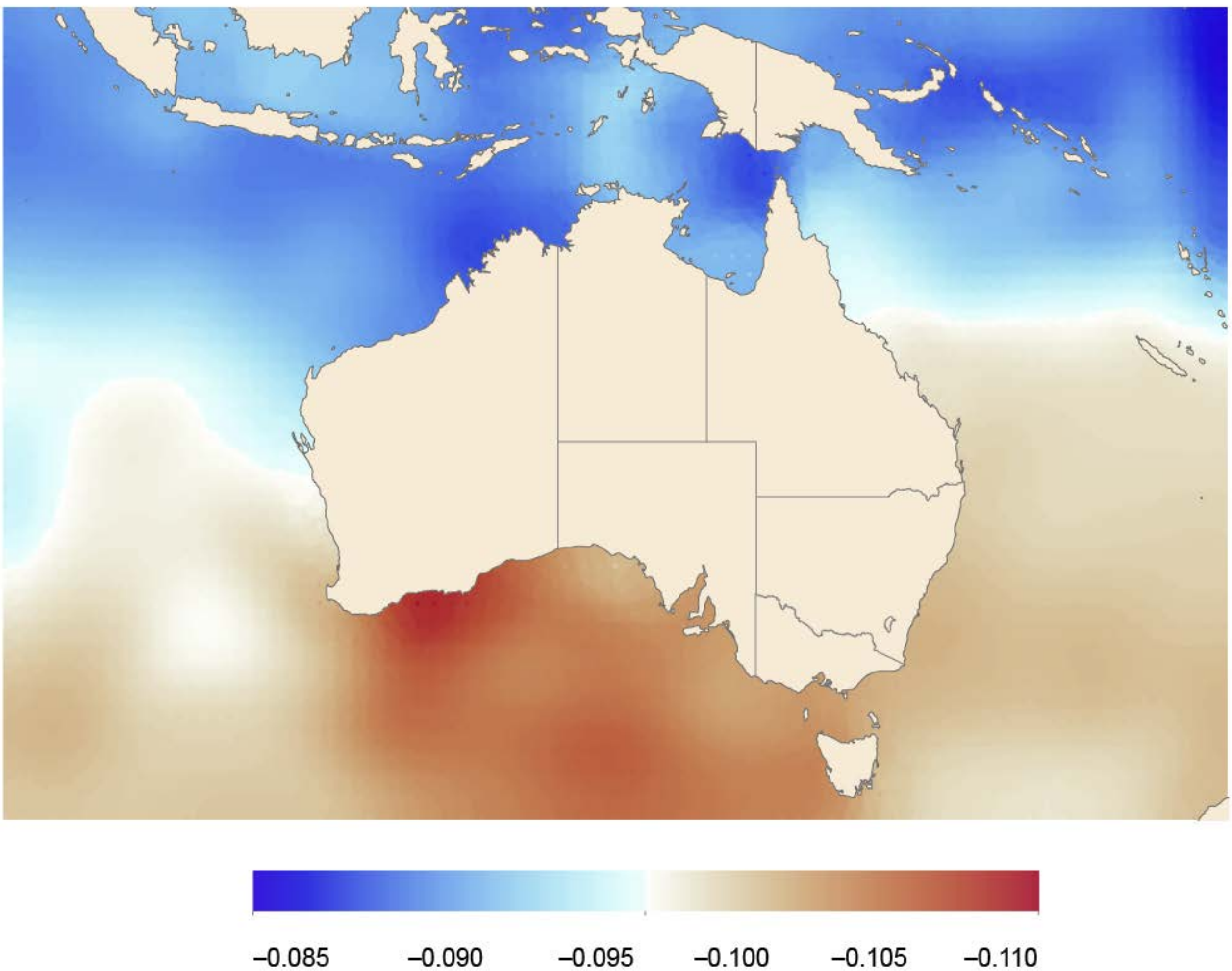
Ocean acidification

The uptake of atmospheric carbon dioxide (CO_2) by the ocean changes the chemistry of sea water. As CO_2 dissolves in sea water, it reacts, lowering the pH of the water and decreasing the amount of dissolved carbonate ions in the water. This process is known as ocean acidification. Since pre-industrial times, the pH of waters around Australia is estimated to have decreased by between 0.08 and 0.10, consistent with global estimates of pH change (Figure MAR7). Superimposed on the large-scale change is variability at seasonal and local scales associated with natural processes, which can be large enough to amplify or offset ocean acidification in a range of environments (Shaw et al. 2013, Waldbusser et al. 2014, Mongin et al. 2016).

Coral reefs and shellfish production are particularly susceptible to decreases in the amount of dissolved carbonate ions in the ocean (Cooley et al. 2012, Dove et al. 2013). Although there is some evidence that particular species, including some noncalcifying algae, may benefit from ocean acidification (Fabricius et al. 2011), many will not. Already in parts of the north Pacific Ocean, where seasonal upwelling of corrosive water occurs, adaptation and mitigation actions have been implemented to minimise impacts on shellfish aquaculture industries (Cooley et al. 2016).

The resilience or adaptability of marine species to ocean acidification is variable (e.g. Browman 2016). Numerous field and experimental studies conducted under conditions projected to occur under high CO_2 emissions scenarios have documented (Munday et al. 2010, Fabricius et al. 2011, Doney et al. 2012):

- decreased growth of reef-building corals and coralline algae, which are the foundation of coral reef ecosystems
- shifts in species composition and distribution
- changes in the neurological functioning of fish
- altered reproductive health, growth and physiology of organisms
- changes in food-web structure.



Source: Lenton et al. (2016)

Figure MAR7 Average decadal change in surface water pH around Australia, 1880–89 to 2000–09

The pH of, and concentration of dissolved carbonate ions in, ocean waters around Australia will continue to decrease as the ocean takes up more atmospheric CO_2. The change in anthropogenic greenhouse gas emissions (either reduction, no change or increase) will determine the rate at which the ocean pH and dissolved carbonate ion concentration continue to decrease (Lenton et al. 2016). However, ocean acidification will persist even if emissions are reduced. Ocean acidification is anticipated to lead to changes in ecosystems, and is thus likely to affect regional economies that rely on healthy and sustainable marine ecosystems, such as tourism, aquaculture and fisheries. Climate change impacts associated with ocean acidification are therefore assessed as having a high impact with a deteriorating trend.

Ocean currents and eddies

Australia's marine environment is influenced by 3 major currents:

- the EAC, a western boundary current system that flows southwards along the east coast of Australia, redistributing heat between the ocean and the atmosphere, and between the tropics and the mid-latitudes
- the Indonesian Throughflow, a major component of the global ocean circulation that moves water between the Pacific and Indian oceans
- the Leeuwin Current, an eastern boundary current that flows southwards off Western Australia, redistributing Indian Ocean heat to the mid-latitudes; this differs from the cooler, equatorwards-flowing currents found along other eastern ocean boundaries.

Australia's ocean boundary currents are important for redistributing heat, fresh water and nutrients along the coastal boundary. Major drivers of variability in these currents are ENSO, the IOD and the SAM, which influence the mass, temperature and salinity transport of the currents, and circulation on the continental shelf (Ridgway 2007, Holbrook et al. 2012, Doi et al. 2013). This, in turn, influences open ocean–coastal exchange (including nutrient supply and larval dispersal), and the variability of wind-driven coastal currents and upwelling.

Under climate change projections, the polewards eddy transport of the EAC extension is expected to increase (Cetina-Heredia et al. 2015), whereas core transport in the EAC, and transport in the Indonesian Throughflow and the Leeuwin Current will decrease (Sun et al. 2012). This will affect the exchange of water between the open ocean and inshore regions. It will also influence nutrient supply and larval dispersal in inshore regions, affecting species that have pelagic larval phases (e.g. some lobsters) and rely on cross-shelf transport.

An increase in the polewards eddy transport of the EAC extension has already been observed from 1980 to 2010 (Cetina-Heredia et al. 2014). This is the result of the separation zone (where the EAC forms the Tasman Front and the EAC extension) occurring at its most southerly extent more often, rather than an increase in the strength of the EAC. This has been linked to decadal variability of the Pacific Ocean subtropical gyre, resulting in changes in the partitioning of the EAC between the Tasman Front and the EAC extension (Cetina-Heredia et al. 2014).

Climate change, coupled with phases of ENSO, has produced anomalously strong changes in both the Leeuwin Current and the EAC, resulting in the marine heatwave in the south-east Indian Ocean during 2010–11 and the marine heatwave off eastern Tasmania during the summer of 2015–16 (Pearce & Feng 2013; see also Climate and system variability and Quality of habitats and communities). Climate change impacts on ocean currents and eddies are therefore assessed as having a high impact with a deteriorating trend.

Nutrient supply

Concentrations of macronutrients (e.g. nitrate and phosphate) in the surface ocean play an important role in controlling the ocean's primary productivity (the rate at which new organic matter is developed at the base of the food web). Surface ocean waters around Australia typically have low macronutrient concentrations. The supply of nutrients into the upper ocean is facilitated primarily by seasonal movement of the mixed layer and eddy-driven mixing (Falkowski et al. 1998, Doney 2006). Wind-induced upwelling is confined to a few localised regions (e.g. along the Bonney Coast in the South-east Marine Region). Although land-based sources of nutrients can be significant, they are largely seasonal as a result of climatic variability in rainfall and confined to localised, nearshore regions (e.g. the inner lagoon of the Great Barrier Reef; Revelante et al. 1982).

As the ocean warms around Australia, it is expected that the upper ocean will become more stratified, which could result in a decline in the vertical supply of nutrients to the surface, reducing primary productivity (Bopp et al. 2013, Lenton et al. 2015; see also Box MAR1). This will have flow-on impacts on marine productivity and fisheries, and, in turn, on higher-order marine animals such as turtles, sharks and seabirds (Brown et al. 2010). In inshore areas, changes in precipitation associated with climate change will influence the frequency and intensity of flooding events, which will have flow-on impacts on sediment and nutrient flows into estuarine and coastal regions (see the *Coasts* report for further details). Increased eddy activity because of the strengthening of EAC eddy transport (see Ocean currents and eddies) may compensate for a decline in the vertical nutrient supply in the Tasman Sea (Matear et al. 2013, 2015).

At present, observations of nutrients in the shelf and oceanic waters around Australia are only sufficient to document the mean state of the ocean, and insufficient data are available to quantify recent trends. It is therefore unclear whether nutrient supply is changing in Australian waters.

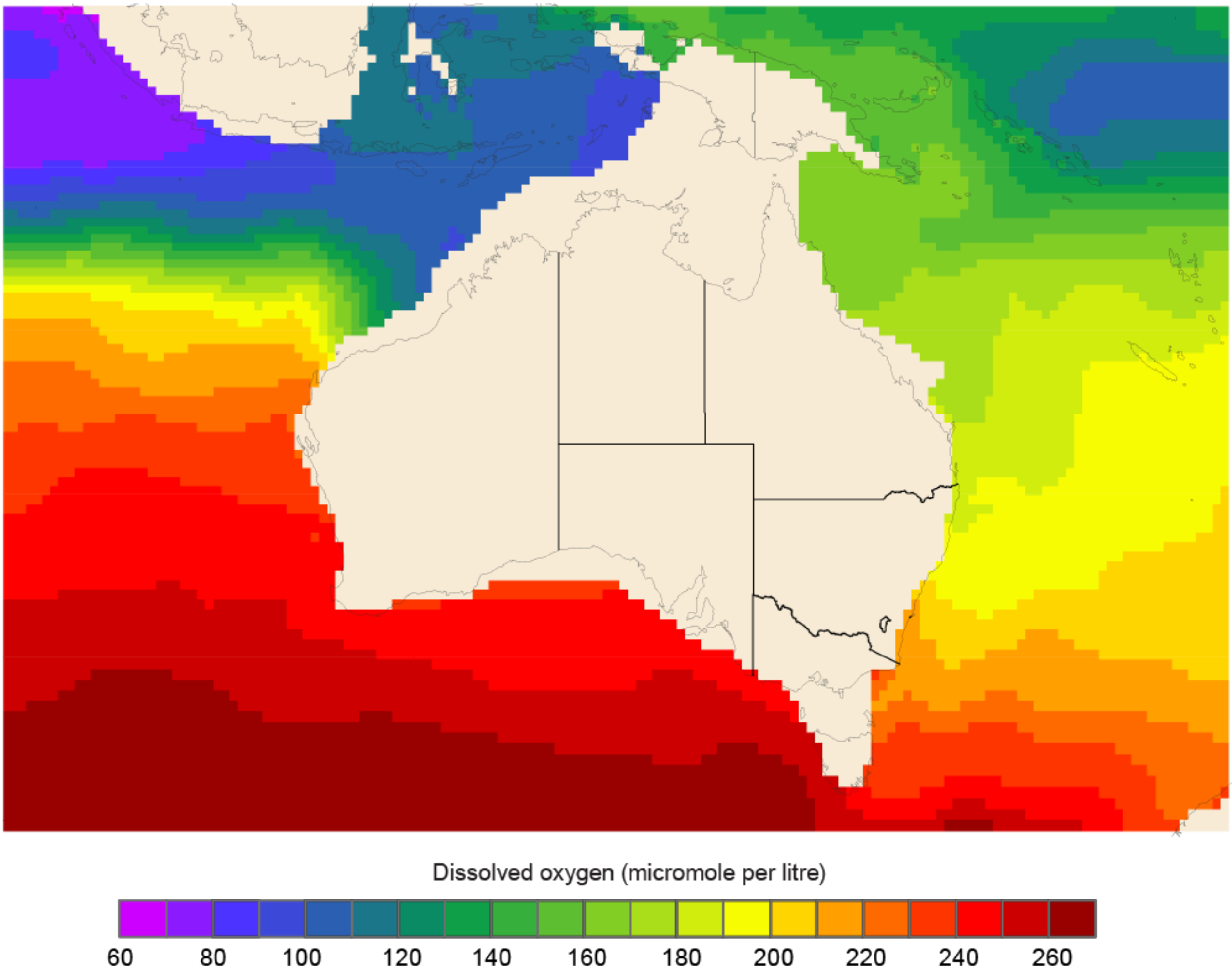
Dissolved oxygen

Oxygen is consumed in aerobic respiration, and most marine ecosystems comprise aerobic organisms that need oxygen to survive. The oxygen content of the ocean varies spatially and temporally, reflecting areas of varying oxygen production and consumption.

Because of the distribution of the highest abundances of aerobic organisms, and therefore the highest rate of oxygen consumption, the dissolved oxygen concentrations in the ocean are lowest in the intermediate water (300–1000 metres; Riser & Johnson 2008). In some inshore regions with limited circulation, and in several subsurface oceanic zones, biological consumption of oxygen can lower oxygen concentrations considerably further; they can reach ultralow values that can be up to 50 times lower (e.g. less than 20 micromoles per litre [μmol/L] and reaching 1 μmol/L at their core) than the oxygen minimum found in intermediate water (Paulmier & Ruiz-Pino 2009). These low oxygen concentrations can lead to ecosystem-wide changes, including loss of biomass of species and food-web complexity, and potentially diminished ecosystem services (Chu & Tunnicliffe 2015).

At the scale of ocean basins, deoxygenation has been observed during the past 50 years and is projected to continue to occur because of warming waters from climate change (Joos et al. 2003, Helm et al. 2011, Andrews et al. 2013). This will result in an overall reduction in dissolved oxygen and an expansion of areas with low oxygen, known as oxygen minimum zones.

Observations of dissolved oxygen in shelf and offshore regions identify Australian waters as being generally well oxygenated with little spatial and temporal variability (Figure MAR8). However, current observations are not sufficient to determine decadal trends on regional scales (CSIRO 2014). Comprehensive measurements from inshore regions outside estuarine and embayment habitats are largely lacking. The application of new oxygen sensor technology through observing platforms, such as the Integrated Marine Observing System (IMOS) National Reference Stations (Lynch et al. 2014) and autonomous profiling floats deployed as part of IMOS, has the potential to enable monitoring of trends in dissolved oxygen.



Source: CSIRO (2014)

Figure MAR8 Annual average minimum dissolved oxygen concentration at 300 metres, derived from observations

Box MAR1 Plankton and climate change

Plankton is the foundation of the marine food web and, ultimately, supports nearly all life in our oceans, including the seafood we eat. Plankton species are sensitive indicators of ecosystem health and climate change because they are abundant, short lived, not harvested, and sensitive to changes in temperature, acidity and nutrients (Richardson 2008). Different pressures affect plankton on different scales. Eutrophication (the enrichment of water with dissolved nutrients that stimulate the growth of aquatic plant life) is a major pressure at the local scale, introduced species and fisheries are pressures at the regional scale, and climate change is a pressure at the continental scale (Edwards et al. 2001, 2010).

There is growing evidence that plankton communities in Australian waters are changing in response to climate change.

Climate change—water temperature

Many plankton species are showing poleward shifts in distribution, with phytoplankton communities off the east coast of Australia observed to have moved 300 kilometres in 60 years (Coughlan 2013). Of note, the algae species *Noctiluca scintillans*, which forms harmful algal blooms, has expanded its distribution in south-eastern Australian waters from 1860 to 2015, blooming for the first time in the Southern Ocean in 2010 (Figure MAR9). This range expansion appears to have been facilitated by ocean warming and an increased frequency in the southerly extension of eddies associated with the East Australian Current (McLeod et al. 2012).

These changes to the distribution of species are also changing the composition of zooplankton communities. Recent analysis of zooplankton data from Port Hacking (off Sydney) has shown that the community temperature index (the temperature preference of species in the community) is 0.7 °C higher than in the 1930s, reflecting a higher abundance of warmer-water species (Clement 2015). Further south off Maria Island (eastern Tasmania), water temperatures have increased by 1.5 °C since 1944 (Ridgway 2007). This has been associated with a marked decline in copepod (tiny marine crustacean) species with preferences for colder water and an increase in those that prefer warmer water (Johnson et al. 2011, Richardson et al. 2015; Figure MAR9). Warm-water zooplankton communities generally comprise species of smaller sizes and consequently lower biomass.

Climate change—ocean acidification

Many plankton organisms—including coccolithophores, foraminifera, mollusc larvae, pteropods (sea butterflies) and echinoderm larvae—have calcium carbonate shells. Oceans with a lower amount of dissolved carbonate ions in the water (because of ocean acidification) can alter the shell-formation processes in calcifying plankton (Orr et al. 2005). Analysis of the abundance timeseries of calcareous organisms at the Integrated Marine Observing System National Reference Stations has shown no overall decline in abundance (Richardson et al. 2015; Figure MAR10). There is some evidence in northern Australia that the shells of 2 pteropods, *Creseis acicula* and *Diacavolinia longirostris*, have thinned and become increasingly porous in the past 50 years, potentially reflecting a reduced capacity of these organisms to produce their shells (Roger et al. 2011).

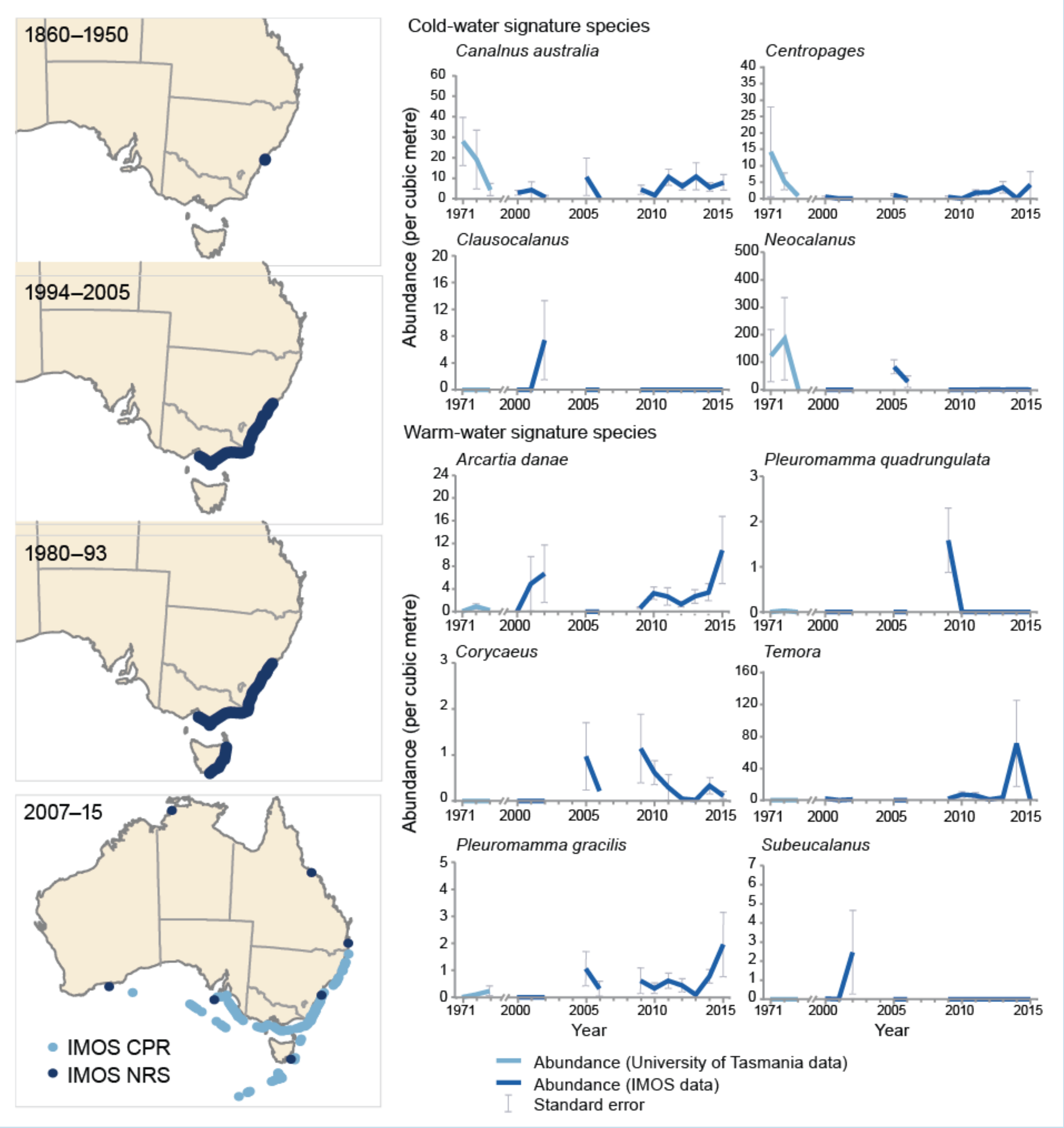
Outlook

As ocean waters warm further, it is expected that greater numbers of tropical plankton species will expand into temperate waters around Australia. Because of their smaller sizes and lower biomass, this will result in reduced food abundance for higher trophic (food-chain) levels (Beaugrand et al. 2003).

The harmful algal bloom species *Noctiluca scintillans* has been implicated in the decline of fisheries in the Indian Ocean (Thangaraja et al. 2007) and has negatively affected production of caged fish (Smayda 1997). Further range expansion of this species could have similar negative impacts on aquaculture and fisheries in Australian waters.

In future decades, ocean acidification is expected to cause a thinning of the shells of some calcifying species and alter the abundance of some plankton species, thereby influencing food webs, and impairing the larval development of commercially important species, including many shelled molluscs (Orr et al. 2005, Martin et al. 2008, Ross et al. 2011, Waldbusser et al. 2014).

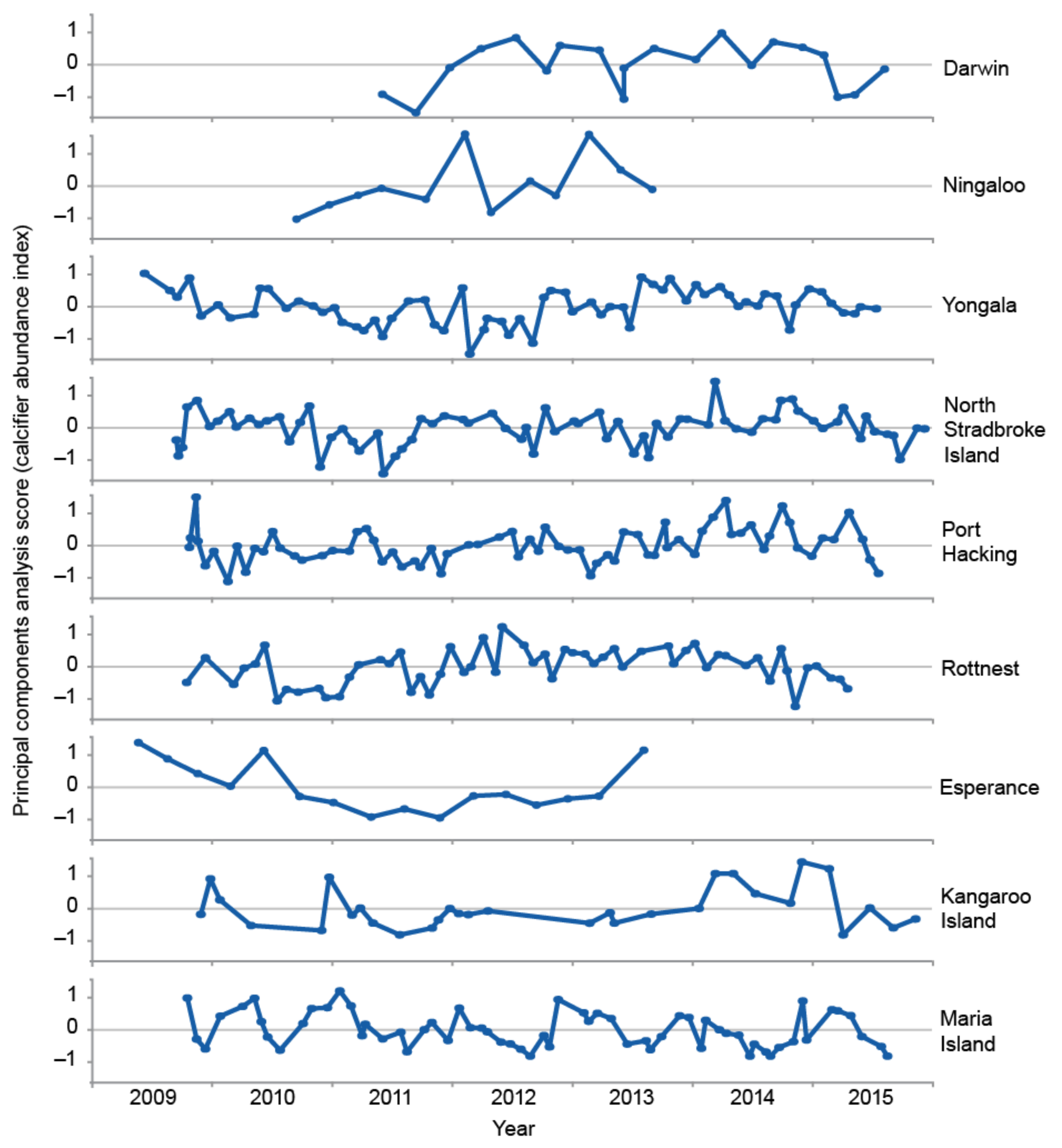
Box MAR1 (continued)



CPR = continuous plankton recorder; IMOS = Integrated Marine Observing System; NRS = National Reference Station
Source: Richardson et al. (2015)

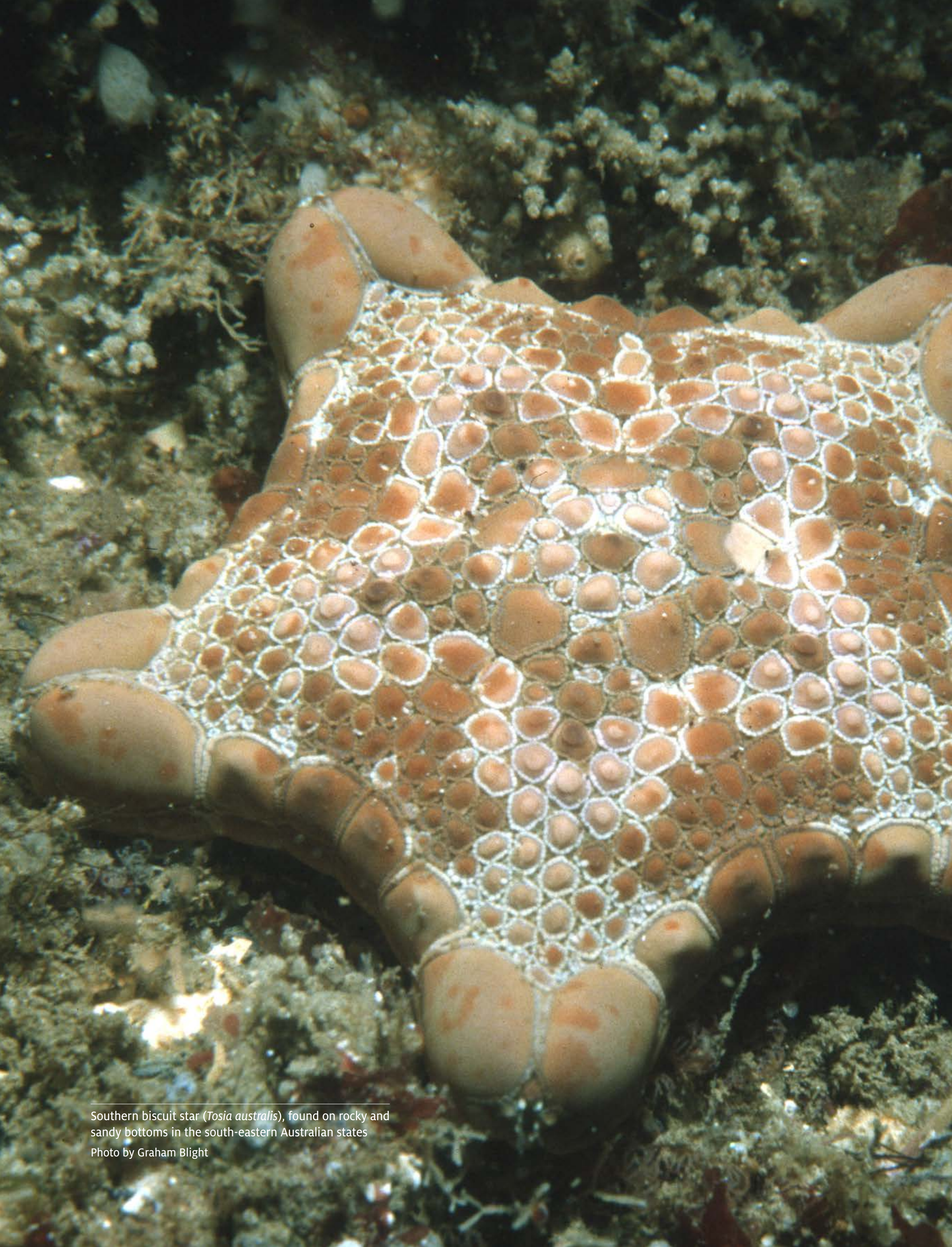
Figure MAR9 Expansion in the distribution of *Noctiluca scintillans*, 1860–2015 (left); zooplankton abundance (mean ± standard error) off Maria Island for cold-water and warm-water species (right)

Box MAR1 (continued)



Note: 1—above the long-term mean; 0—no change; –1—below the long-term mean
Source: Integrated Marine Observing System; Richardson et al. (2015)

Figure MAR10 Timeseries of an abundance index of calcareous plankton (echinoderm and bivalve larvae, shelled gastropods) at each of the Integrated Marine Observing System National Reference Stations, calculated via principal components analysis



Southern biscuit star (*Tosia australis*), found on rocky and sandy bottoms in the south-eastern Australian states
Photo by Graham Blight

Commercial and recreational fishing

Commercial fishing

Australia's commercial wild-caught marine fisheries are highly diverse and contribute significantly to the economy. Scallops; prawns; crabs; squid; coastal fish, such as whiting and flathead; reef fish, such as coral trout; shelf and deep-water fish, such as sardines, ling and blue-eye trevalla; and oceanic tuna and billfish are all caught in Australian fisheries. In 2013–14, wild-caught fisheries generated $1.5 billion, up from $1.4 billion in 2012–13, and produced approximately 150,000 tonnes of seafood for local, domestic and export markets (Flood et al. 2014, Savage & Hobsbawn 2015). Nearly 50 per cent of the total production value is exported, with the majority going to Asian markets, while imports account for almost 70 per cent of the fish consumed in Australia (Savage & Hobsbawn 2015).

The adoption in 1979 of the Offshore Constitutional Settlement aimed to address longstanding jurisdictional issues between the Australian Government, and the states and territories (Gullett 2013). The settlement reinforced shared responsibility for commercial fisheries between the governments of the states and the Northern Territory, and the Australian Government. State jurisdiction extends from the low-water mark to a baseline generally 3 nautical miles offshore, and Australian Government jurisdiction extends from 3 nautical miles to the edge of the national jurisdiction (Vince 2015). Under the settlement, each sector's issues are dealt with separately within 'agreed arrangements'.

Although commercial fisheries operate across all states and the Northern Territory, and out to the limit of the Australian EEZ, fishing effort is not evenly distributed, and commercial fisheries across jurisdictions vary in their distribution and intensity.

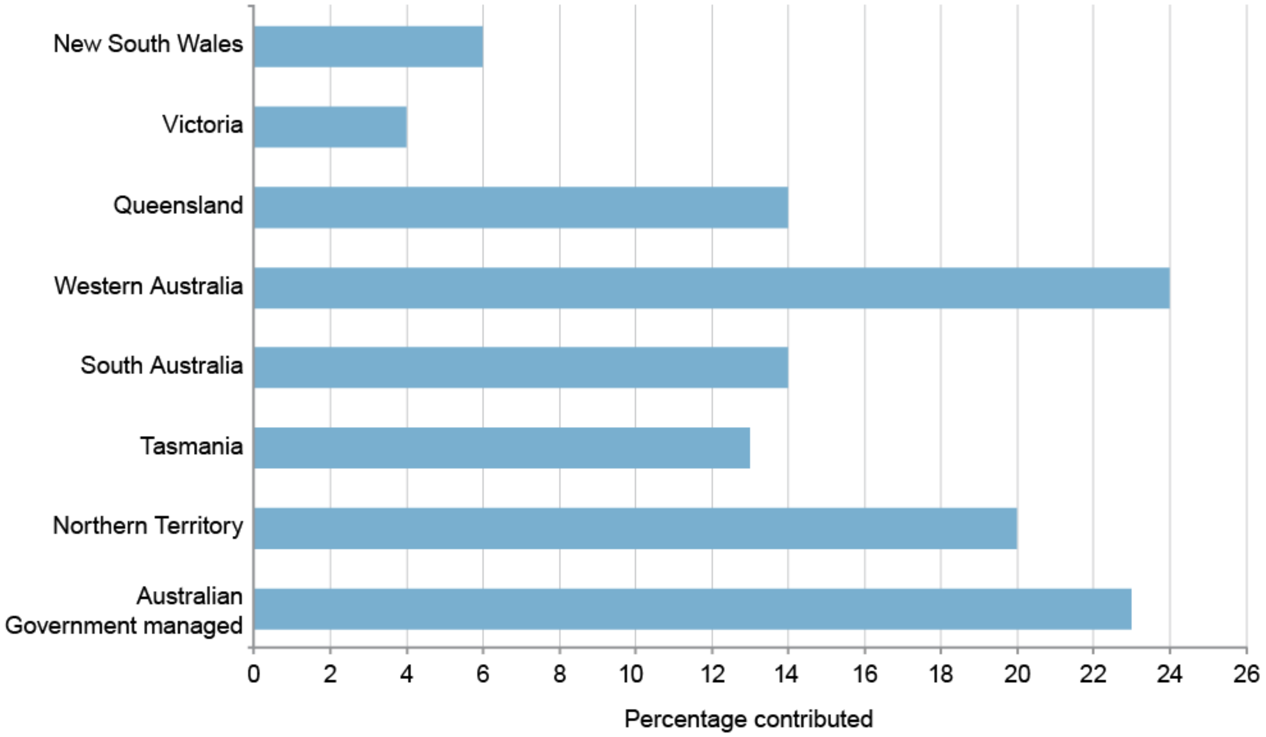
Most commercial fishing catches in 2012–13 were derived from South Australian (44,215 tonnes), Commonwealth (39,118 tonnes) and Queensland (24,859 tonnes) waters, with the remaining states and the Northern Territory catching less than 20,000 tonnes each (Savage & Hobsbawn 2015). The greatest value of catches is derived from the states and the Northern Territory; 23 per cent of the total value of commercial fisheries was derived from Australian Government–managed fisheries in 2012–13 (Figure MAR11).

The impact of commercial fisheries on the marine environment varies, with different fishing gear and fishing methods having different impacts on species that might be caught as bycatch and the habitats where fishing takes place. Methods are highly varied, and include the use of small-scale nets, pelagic longlines and large-scale trawl nets (Flood et al. 2014). Trophic structure and ecosystem productivity can be affected if target or nontarget species are removed at too high a level in the long term (Smith et al. 2011), or if habitats are degraded through commercial fishing (e.g. see Box MAR2). The variability in impacts associated with commercial fishing, the management arrangements in place and changes in these arrangements since 2011 mean that commercial fisheries, on a national basis, are assessed as having a low impact and an improving trend.

The status of the main species caught by commercial fisheries is regularly reported by the Australian Government, the states and the Northern Territory (e.g. QDAFF 2013, Grubert et al. 2013, André et al. 2015, Fletcher & Santoro 2015, NSW DPI 2015a, Patterson et al. 2015a, PIRSA 2015). In addition, the Australian Bureau of Agricultural and Resource Economics and Sciences, in conjunction with the Fisheries Research and Development Corporation, produces annual reports on commercial fisheries and aquaculture statistics, and biennial reports on the status of key Australian fish stocks across state, territory and Australian Government jurisdictions (Flood et al. 2014, Savage & Hobsbawn 2015).

Of a total of 238 identified stocks from 68 species, Flood et al. (2014) assessed 170 stocks across state, territory and Australian Government jurisdictions, focusing predominantly on commercially fished species, but also including recreational catches, where appropriate. Of these stocks, they classified:

- 129 as sustainable
- 7 as recovering from past overfishing
- 19 as being in a state where fishing is too high (but not yet in a state of being overfished)
- 4 as being in a state where environmental processes have reduced the stock to a low point
- 11 as overfished.



Source: Flood et al. (2014)

Figure MAR11 Contribution of state, Northern Territory and Australian Government sectors to the gross value of commercial wild-caught fisheries production, 2012–13

Those stocks classified as overfished occurred in both Australian Government, and state and territory jurisdictions (Flood et al. 2014). The remaining 68 stocks were unable to be assigned a stock status classification, because insufficient information exists to determine stock status or information is conflicting.

In addition to target species, nearly all commercial fisheries catch species that are not the target of the fishery. These are mostly other fish or invertebrate species, but can also include species protected under the EPBC Act in threatened, migratory or marine categories, such as sea snakes, marine turtles, seabirds, sharks and marine mammals.

The EPBC Act allows interaction with listed species if they are undertaken in accordance with an accredited management plan or regime. All Australian Government–managed fisheries have been assessed and accredited under the EPBC Act, on the basis that management plans or regimes include all reasonable steps to ensure that listed species are not adversely affected by fishing operations. Sharks listed under the Act as migratory species (porbeagle, shortfin mako and longfin mako) can be kept and traded if brought up dead, if the operator is fishing in accordance with an accredited fisheries management plan. Live sharks that are listed as migratory species must be returned to the sea unharmed. All interactions (whether animals are dead or alive) must be reported. A memorandum of understanding between the Australian Fisheries Management Authority (AFMA) and the Australian Government Department of the Environment and Energy allows AFMA to report interactions with protected species in AFMA-managed commercial fisheries on behalf of fishers (Table MAR1).

Although interactions with protected species are required to be reported under state or territory legislation and the EPBC Act, information on species caught across state and territory jurisdictions is not as readily available as that for the Australian Government jurisdiction. Further, reporting is often at the species group level rather than the individual species level,

Table MAR1 Number of reported interactions of AFMA-managed fisheries with species listed under the EPBC Act, 2012–15

Fishery	Year	Turtle	Sea snake	Dolphin	Whale	Fur seal/ sea lion	Seabird	Sawfish	Shark	Seahorse/ pipefish
Eastern Tuna and Billfish Fishery	2012	10	0	0	0	0	0	0	1683	0
	2013	15	0	1	0	1	0	0	2015	0
	2014	7	0	0	0	0	0	0	1125	0
	2015	30	0	7	3	0	14	0	2093	0
Northern Prawn Fishery	2012	72	8977	2	0	0	0	476	0	74
	2013	72	8150	2	0	0	0	507	0	140
	2014	36	4787	1	0	0	0	343	0	140
	2015	63	7527	0	0	0	7	307	0	140
Small Pelagic Fishery	2012	0	0	0	0	0	0	0	0	0
	2013	0	0	0	0	0	1	0	0	0
	2014	0	0	0	0	0	1	0	0	0
	2015	0	0	9	0	15	2	0	23	0
Southern and Eastern Scalefish and Shark Fishery	2012	1	0	19	0	217	196	0	288	405
	2013	0	0	9	0	259	94	0	157	0
	2014	0	0	14	0	133	18	0	157	0
	2015	0	0	29	0	128	66	0	166	0
Torres Strait Prawn Fishery	2012	0	242	0	0	0	0	0	0	0
	2013	4	771	0	0	0	0	1	0	0
	2014	4	1091	0	0	0	0	1	0	0
	2015	3	669	0	0	0	0	1	0	0
Western Tuna and Billfish Fishery	2012	6	0	0	0	0	0	0	764	0
	2013	2	0	0	0	0	0	0	325	0
	2014	2	0	0	0	0	0	0	263	0
	2015	3	0	0	0	0	0	0	87	0

AFMA = Australian Fisheries Management Authority; EPBC Act = *Environment Protection and Biodiversity Conservation Act 1999*
Note: Interactions include those with animals that are reported as alive, injured, dead or unknown. Values presented are the total of all categories across all commercial fisheries managed by the Australian Government. All interactions are reported as per reporting requirements under the EPBC Act. Interactions listed are derived from commercial fisheries logbooks and may not include all interactions listed in fishery observer logbooks. Logbook data are not routinely verified, and therefore AFMA cannot attest to the accuracy of these data or authenticate that records are complete. Values are numbers reported and do not account for variability in effort across fisheries.
Source: Protected species interaction reports, Australian Fisheries Management Authority

and few details of individuals caught are collected. This limits the use of reporting frameworks for assessing the impacts of commercial fishing on individual species and populations (see also below). Reporting is largely based on logbook information provided by commercial fishery operators, with observations of interactions by fishery observers, in general, restricted to less than 10 per cent of all commercial fisheries (although, where interactions have been recorded, observer coverage in some commercial fisheries can be as high as 100 per cent).

Total bycatch has been estimated for some commercial fisheries and jurisdictions (e.g. Kangas et al. 2007, Tuck et al. 2013), but there has been no national assessment to date, largely because reporting frameworks are not consistent across jurisdictions.

A framework for assessing the ecological impacts of fishing has been developed and applied to several Australian commercial fisheries to assess the risks to the many nontarget species taken in fisheries managed by the Australian Government (Hobday et al. 2011). However, such assessments and the estimated impacts of fisheries on bycatch species are limited by a general lack of information on bycatch species, resulting in high uncertainty in assessments. Similarly, habitat assessments have been completed for only a small number of fisheries, and these have been mostly semiquantitative. The cumulative impacts of fishing on marine habitats have not been analysed on a national scale (see Box MAR2).

Lemon sharks (*Negaprion brevirostris*), Great Barrier Reef, Queensland
Photo by Great Barrier Reef Marine Park Authority

Box MAR2 Footprint of commercial demersal trawl fishing

The most extensive direct human pressure on the seabed in Australia is demersal trawling for fishes, prawns and scallops by commercial fisheries. Worldwide, it is commonly understood that trawl gear has substantial direct impacts on seabed habitats (Jennings & Kaiser 1998), with most concern surrounding impacts on delicate long-lived structure-forming biota that may be easily damaged and slow to recover (Rice et al. 2015).

Formal assessments of the impacts of demersal trawling on habitats have been completed for only a small number of Australian commercial fisheries (Fulton et al. 2006; Pitcher et al. 2007a,b, 2015, 2016a; Bustamante et al. 2011; Williams et al. 2011; Pears et al. 2012; Pitcher 2013, 2014). These assessments include the largest fisheries and therefore account for a large percentage of the total region in which demersal trawl fisheries occur.

Some other fisheries have implemented qualitative consideration of habitat risks under ecologically sustainable development objectives, and the regional marine planning process attempted a national qualitative assessment of cumulative risks. A major impediment to such assessments, however, is that most regions lack suitable data on seabed habitat types and their distributions—key information needed to determine habitat status. Until recently, there has been no national-scale quantitative analysis of the cumulative spatial extent or 'footprint' of demersal trawl fishing operations (i.e. the area of seabed trawled at least once in a specified period) that may be used to assess the potential for impacts of demersal trawling on seabed habitats in Australia. Further, how the footprint on a national scale might change through time is yet to be assessed.

Calculating footprints

Recently, confidential high-resolution data on trawling effort were collated for all Australian state and territory demersal trawl fisheries, as part of an Australian contribution to an international collaboration. At the same time, Commonwealth trawl footprints were mapped and reported for bioregions at the sub-IMCRA (Integrated Marine and Coastal Regionalisation of Australia) scale (Pitcher et al. 2016b). These effort data, covering 3–5 years after 2007, were converted to a common scale of swept area per square kilometre (R Pitcher, unpublished data). This common scale allowed quantification of the footprint of all demersal trawling as a percentage of each IMCRA shelf mesoscale bioregion (0–200 metre depth) and off-shelf provincial bioregions (restricted to 200–1000 metre depth).

The total national demersal trawl footprint (the area trawled at least once) averaged almost 84,000 square kilometres in any 1 year during the 3–5 year period and 102,000 square kilometres during multiple years, representing 3.2 per cent of the total area of the Australian continental shelf and 3.8 per cent of the Australian slope.

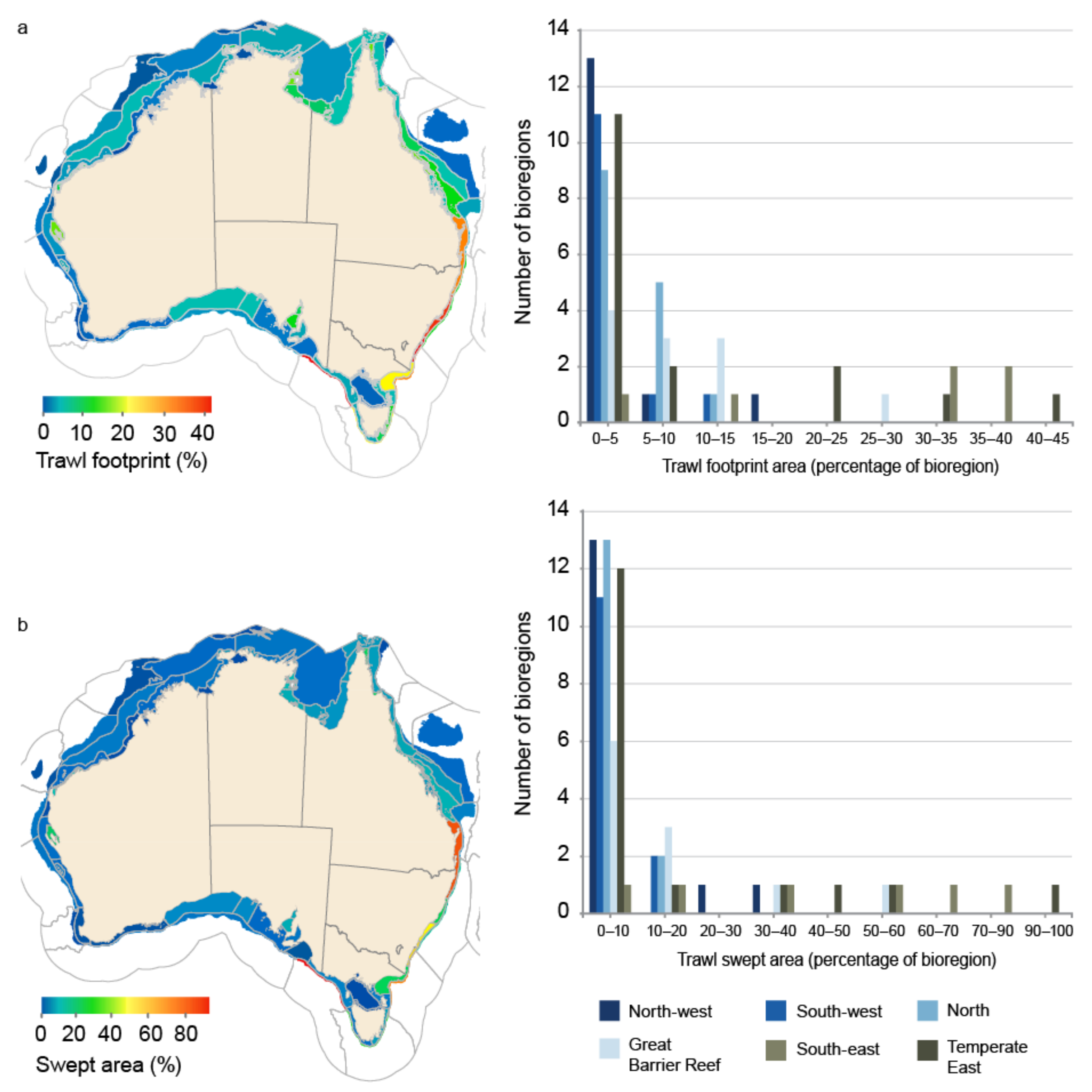
Spatial variation in footprint

The demersal trawl footprint differs substantially among bioregions (Figure MAR12a): half of the bioregions have footprints of 0–2.5 per cent each, two-thirds have footprints of less than 5 per cent each, and more than three-quarters have footprints of less than 10 per cent each. Bioregions with the highest footprints include West Tasmania Transition slope at 42.3 per cent, followed by Batemans Shelf, Hawkesbury Shelf, Manning Shelf, South-east Transition slope and Tweed–Moreton (all 30–40 per cent).

On a marine region scale, the Temperate East Marine Region is most extensively trawled, followed by the South-east Marine Region (where trawling on the slope is most intense) and the Great Barrier Reef (Figure MAR12, insets). Extensive trawling occurs almost continuously from the slope south of Swains Reefs in the Great Barrier Reef to eastern Bass Strait.

Within each footprint (i.e. within the area that has been trawled), those bioregions with the most intensive demersal trawl activity (Figure MAR12b) include the West Tasmania Transition slope bioregion (a swept area of approximately 93 per cent within a footprint of 42.3 per cent of the total area, indicating an average annual sweep of 2.2 times across the footprint) and the Tweed–Moreton bioregion (a swept area of approximately 79 per cent within a footprint of 31.8 per cent of the total area, indicating an average annual sweep of 2.5 times across the footprint). Other intensively trawled bioregions, with relative swept areas of approximately 50–60 per cent and average annual sweeps of approximately 1.5–1.9 times, include the Batemans Shelf, Hawkesbury Shelf, South-east Transition slope and Wet Tropic Coast bioregions. Another ecological subregion with high trawling footprint and intensity is in the outer Great Australian Bight Province (Pitcher et al. 2016b).

Box MAR2 (continued)



IMCRA = Integrated Marine and Coastal Regionalisation of Australia
Source: R Pitcher, unpublished data. Fishery data sources: Australian Fisheries Management Authority; Queensland Department of Agriculture and Fisheries; NSW Department of Primary Industries; Victorian Department of Environment and Primary Industries; Tasmanian Department of Primary Industries, Parks, Water and Environment; South Australian Department of Primary Industries and Regions; Western Australian Department of Fisheries; Northern Territory Department of Primary Industry and Resources

Figure MAR12 (a) Footprint of Australian commercial demersal trawl and dredge fisheries as a percentage of IMCRA bioregions; (b) trawl swept area as a percentage of IMCRA bioregions as an indicator of intensity within footprints; right-hand panel—bar charts of bioregion footprint and swept area by marine region

Box MAR2 (continued)

Temporal variation in footprint

In recent decades, the total annual effort in most demersal trawl fisheries has been declining—in some cases, substantially (Figure MAR13). Consequently, the footprints of these fisheries have also contracted (Great Barrier Reef: Pears et al. 2012; South East Trawl Fishery: Pitcher 2013, Pitcher et al. 2015; Northern Prawn Fishery: W Rochester, CSIRO, pers. comm., 29 February 2016), although the contraction in trawling footprint is not directly proportional to the reduction in effort. For example, in the Torres Strait Trawl Fishery, effort has decreased by 72 per cent during 2005–11, whereas the footprint has decreased by 54 per cent.

Impacts

Quantification of demersal trawl footprints indicates the level of potential risk to seabed habitats, but not actual impact. Actual impact depends on whether sensitive seabed habitats are present within high-footprint bioregions and whether demersal trawling is co-located with such habitats at fine spatial scales. Detailed quantitative assessments of these impacts in the Great Barrier Reef and Torres Strait (Pitcher 2013, Pitcher et al. 2007a,b, 2016a) showed that most habitat-forming biota naturally occurred in environments that were largely not trawled, and thus the majority had been affected to only a minor extent. Only a few worst cases were estimated to have been reduced by up to 23 per cent from their untrawled status when trawl effort peaked in the late 1990s. In the South-east Marine Region (Pitcher et al. 2015), a similar assessment estimated that gorgonians, bryozoans, *Solenosmilia* spp., sponges, soft corals and some other cnidarians had been reduced by approximately 10–20 per cent, and several other taxa had been reduced by approximately 5–10 per cent at regional scales when trawl effort peaked around 2005. In both regions, bottom habitats are predicted to be recovering.

Across most of the Temperate East Marine Region, where the demersal trawl footprint is greatest, there is very little information on seabed habitats, and, as a consequence, the impact of demersal trawling in this region is largely unknown.

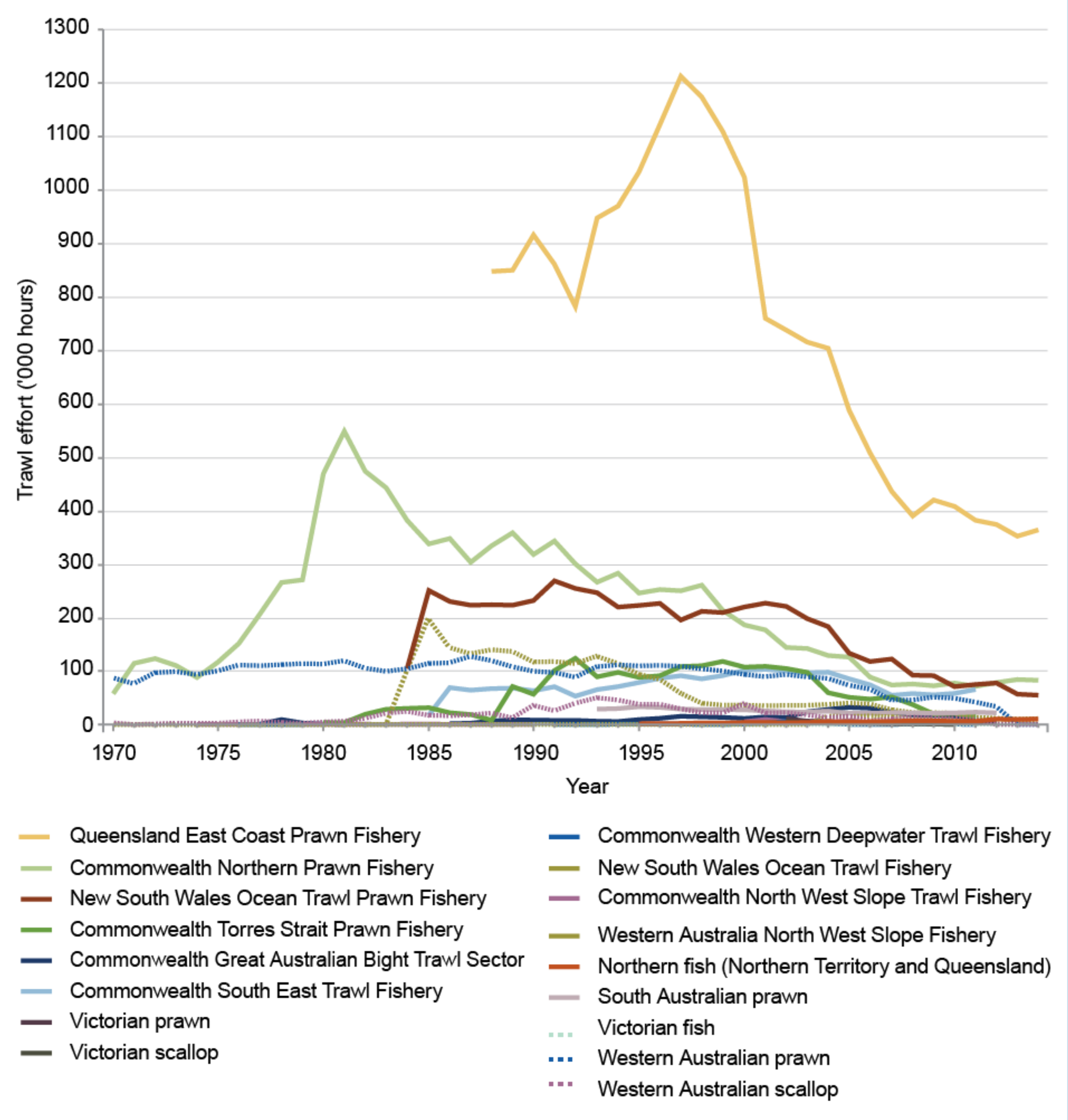
Management

Management and policy actions under ecologically sustainable development objectives have led to restructuring of the commercial industry and licence buybacks in most fisheries. This has resulted in a reduction in demersal trawling effort and consequential contractions in footprints (Pears et al. 2012, Pitcher 2013, Pitcher et al. 2015). In almost all Australian trawl fisheries, the total amount of demersal trawling has declined substantially since effort peaks of 1–3 decades ago, perhaps by as much as 3–4-fold in some cases, to stabilise at lower levels in the past 5 years. Even when effort levels were highest (including records for foreign trawling), it is inconceivable that past footprints could have been greater than about 10–15 per cent of Australia's seabed, and most areas have almost certainly never been trawled. Thus, most areas are unaffected by trawling; even in trawled areas, most habitats are in good condition at landscape scales—although areas of localised impact exist.

Many demersal trawl fisheries have implemented closed areas to protect stock or nursery areas, or to reduce conflict with other sectors. Closures of representative areas have also been implemented in recent years by the Australian Government, the states and the Northern Territory, and the Great Barrier Reef Marine Park Authority. Although these measures may not have specifically intended to reduce demersal trawling footprints, some have effectively achieved this, and recovery of affected sensitive fauna is expected because of associated reductions in trawling impacts (Pitcher et al. 2007a, 2015, 2016a).

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) has also played a role in reducing the effects of trawl fishing. The EPBC Act aims to ensure that fishing is conducted in a manner that minimises impact on the ecosystem, including benthic communities and habitats, particularly for export fisheries. Third-party accreditations, such as those coordinated by the Marine Stewardship Council, are having a similar influence, as industries strive to gain market recognition for the sustainability of their operations and retailers increasingly move to stocking only certified products. Such accreditations require fisheries to have formal management frameworks in place that are independently reviewed and recognised, to ensure sustainability of fishery stocks and maintenance of ecosystems they might affect.

Box MAR2 (continued)



Source: R Pitcher, unpublished data. Fishery data sources: Australian Fisheries Management Authority; Queensland Department of Agriculture and Fisheries; NSW Department of Primary Industries; Victorian Department of Environment and Primary Industries; Tasmanian Department of Primary Industries, Parks, Water and Environment; South Australian Department of Primary Industries and Regions; Western Australian Department of Fisheries; Northern Territory Department of Primary Industry and Resources

Figure MAR13 Annual fishing effort of commercial demersal trawl and dredge fisheries across Commonwealth, and state and territory jurisdictions

Box MAR2 (continued)

Outlook

Current and ongoing management to achieve economic efficiencies and environmental sustainability is likely to continue to reduce fishing effort and associated footprints in many demersal trawl fisheries, with expected ongoing recovery of habitats. In the case of some sensitive seabed habitats, however, this may take a long time (e.g. Williams et al. 2010b).

The biennial *Status of key Australian fish stocks reports* (FRDC 2012) may soon expand and report on the broader ecological sustainability of commercial fisheries, providing a national-level initiative to drive such assessments. It is likely that expanded reporting will include fishing footprints; these should be quantified for biologically informed ecoregions at scales smaller than those identified by IMCRA, similar to those recently completed for Australian trawl fisheries (Pitcher et al. 2016b). Potentially, as timeseries become more extensive, investigations of interannual variability in footprints could also be incorporated into these reports. Recent assessments in several regions have shown that previous unsustainable depletion trajectories in seabed status had reversed, and recovery trends were now predicted. However, lack of data for distributions of sensitive habitats remains a major gap impeding assessment in most regions—most importantly in the Temperate East Marine Region, which has had the most extensive demersal trawling and the least spatial management.

Recreational fishing

Recreational fishing is an important activity for many Australians and contributes substantially to the Australian economy. At a national level, recreational fishing (fresh water and marine) in 2013 was estimated to have an annual economic value of $2.56 billion, based on an expenditure evaluation approach (Colquhoun 2015). In New South Wales alone, approximately 900,000 adults were estimated to participate in recreational fishing in 2011, and it is estimated that expenditure on the marine component of recreational fishing across the state in 2012 was $1.42 million (McIlgorm & Pepperell 2013).

Recreational fishing has not been assessed at the national level to quantify participation, effort and harvest since 2001 (Henry & Lyle 2003). Surveys conducted at the state or territory level since 2001 use varying methods, therefore limiting the ability to compare jurisdictions and scale up results from surveys to provide a more recent national view of fishing activity.

Participation in recreational fishing remains high nationally in absolute terms (i.e. taking into account the number of people participating and the amount of effort put into recreational fishing by individuals). Declines in either the number of people fishing, the time spent fishing (effort) or overall harvest (the number of fish caught) have been reported in Queensland (McInnes et al. 2013), New South Wales (West et al. 2016), Tasmania (Lyle et al. 2014), South Australia (Giri & Hall 2015) and Western Australia (Ryan et al. 2015), noting that, across all states, catches and effort are highly variable across species. In Victoria, surveys of recreational fishers suggest an increase in participation, time spent fishing and overall harvest. However, although surveys in particular areas or for particular species have been carried out in Victoria, a statewide survey has not been conducted since 2008–09. In the Northern Territory, recreational fishing will be surveyed in 2016–17. This will update the results of a 2009–10 survey, which recorded decreases in participation, time spent fishing and overall harvest (West et al. 2012). Most of the overall effort in recreational fisheries is associated with a relatively small number of fishers, which means that these individuals have disproportionately large impacts in terms of total effort and catch (West et al. 2016).

Across all regions, fishing effort is often concentrated in predictable spatial areas, but can vary substantially on seasonal and interannual timescales (Lynch 2014). Most recreational fishing occurs in inshore waters. Although shore-based fishing is popular, more recreational fishers are using boats than in previous years. Boat size is increasing across most states (Lyle et al. 2014, Giri & Hall 2015, Ryan et al. 2015, West et al. 2016), and more advanced fishing technology is being used, resulting in potential increases in effective effort (i.e. the effort associated with individual catches rather than the overall time spent fishing). This has the potential for recreational fishing to have larger impacts on populations of species overall. More remote areas are now being fished, as well as offshore fisheries for pelagic fish, including southern bluefin tuna (*Thunnus maccoyii*; Griffiths & Fay 2015, Moore et al. 2015) and deeper-water species, resulting in shifts in concentration of effort and catches onto particular areas and species. Social media is facilitating rapid transfer of information, which can also lead to concentration of effort in particular areas or on particular species.

Several states (e.g. New South Wales, Western Australia) have implemented networks of fish aggregating devices (FADs) for recreational fishing to increase catch rates for the largely pelagic fish species that aggregate around such structures (Folpp & Lowry 2006). FADs also concentrate effort into particular areas and onto particular species. Up to 30 individual FADs can be used in a network. Although a number of concerns have been raised about the use of high numbers of FADs within commercial fisheries in areas outside the Australian EEZ (see Dagorn et al. 2013), little information is available on impacts on the marine environment of FAD networks deployed for recreational fishing in Australian waters. Artificial reefs, which are regulated under the *Environment Protection (Sea Dumping) Act 1981*, have a similar aggregating purpose. As for FADs, little information is available on impacts of artificial reefs on the marine environment, particularly in relation to recreational fishing. Further detail on artificial reefs can be found in the *Coasts* report.

Obligations for catch reporting and official catch recording systems are lacking for most recreational fisheries; instead, large efforts are placed on developing surveys and other methods to estimate recreational catch (e.g. Griffiths et al. 2010, Georgeson et al. 2015a). For many species, quantitative assessment of catches by the recreational sector is lacking, and few data are available for those catches that are caught and then discarded or released (because of bag or size limits, the species caught being undesired or the catch not being retained for other reasons). In addition, few robust data are available on postrelease mortality rates for most species. This limits any assessment of the impacts of recreational fishing on the marine environment.

For those species where information is available, the amount of recreational harvest can be similar to, or exceed, commercial catches. For example, the recreational tonnage of southern sand flathead (*Platycephalus bassensis*) in Tasmania in 2012–13 was 6 times that of the commercial fishery (Lyle et al. 2014). Of the 10 key species caught by fishers in New South Wales, recreational catches exceeded commercial catches for 5 species, and recreational catches of a further 2 were only slightly lower than commercial catches (West et al. 2016). Recreational catches of barramundi (*Lates calcarifer*) around Cairns are 3 times higher than the commercial harvest by net fisheries (Brown 2016). Recreational and commercial catches within the West Coast Demersal Gillnet and Demersal Longline Fishery in Western Australia in 2008–09 were similar to each other before management of allocations was introduced (IFAAC 2013). The estimated recreational harvest of King George whiting (*Sillaginoides punctatus*) in South Australia in 2013–14 was 1.46 million fish (367 tonnes), which was more than half the amount of this species caught by commercial fisheries (Giri & Hall 2015). Overall, on a national basis, although the extent of information is highly variable, recreational fishing could be having a high impact on the marine environment, with little change in trend in the past 5 years.

Although recreational catch statistics are more uncertain than commercial catches, where data are available on commercially harvested species, they are used in some fishery assessments (e.g. Linnane et al. 2015a, PIRSA 2015). Harvest strategies for some state and Australian commercial fisheries include recreational catches (DAFF 2007, Fletcher & Santoro 2015).

Illegal, unreported and unregulated fishing

Illegal, unreported and unregulated (IUU) fishing can refer to a wide range of issues associated with the reporting, quantification and management of fishing (see FAO 2001). Catches of this nature are driven by world population growth, an increasing demand for fish protein, a desire for greater economic returns in an environment of increasing costs associated with commercial fishing and overexploitation, and overcapacity and diminishing resources within both domestic and international fisheries (Le Gallic & Cox 2006, Sumaila et al. 2006, Agnew et al. 2009). IUU fishing activities undermine sustainable management frameworks for fisheries and can cause, in some cases, significant environmental damage through depletion of biodiversity (FAO 2001). Such fishing practices also harm legitimate fishing activities and livelihoods, jeopardising food security, consolidating transnational crime and distorting economic markets (Agnew et al. 2009, Young 2016).

Global assessments have estimated that IUU fishing in the eastern Indian Ocean and the south-west Pacific

Ocean costs approximately US$425–900 million, noting that IUU catches in the south-west Pacific Ocean are some of the lowest in all regions examined (Agnew et al. 2009). Assessment of trends in IUU fishing showed that IUU activities in the south-west Pacific Ocean declined from 10 per cent of the total catch of the commercial fisheries assessed to 4 per cent from 1980 to 2003, while IUU fishing in the eastern Indian Ocean increased from 24 per cent to 32 per cent (Agnew et al. 2009).

In Australian waters, noncompliance with commercial or recreational fishery regulations or marine park zoning occurs, and is generally considered to be small scale or opportunistic. Most reported illegal fishing is associated with the commercial sector. However, noncompliance with fishery regulations also occurs in the recreational sector; common offences include exceeding quota or bag limits, taking undersized fish, fishing in closed or protected areas, using unauthorised equipment and attempting to sell recreationally caught fish (Putt & Anderson 2007).[2] Within the Great Barrier Reef Marine Park area, illegal fishing (both commercial and recreational) is considered one of the greatest risks to the environmental sustainability of fishing activities (GBRMPA 2014a), although formal assessments of illegal fishing in the park area are few (Davis et al. 2004, McCook et al. 2010). Organised criminal activity is predominantly associated with high-value, low-volume commercial fisheries such as abalone, and with illegally obtained shark fins (Putt & Anderson 2007). Most illegal activity by foreign fishers occurs in Australia's northern waters for a range of species, and in the Southern Ocean for Patagonian toothfish (see also the *Antarctic environment* report).

Some jurisdictions make information on reports of illegal fishing available.[3] However, quantification of IUU fishing nationally is lacking. Further, surveys of fisheries officers tasked with enforcing requirements to prevent IUU fishing identified that many believed their jurisdiction was ineffective in both detecting criminal activity and dealing with criminal activity once it was detected (Putt & Anderson 2007).

Traditional use of marine resources

Traditional use of marine resources is defined here as activities (fishing, collecting, hunting and gathering) by the 2 Indigenous or traditional owner groups of Australia: Aboriginal and Torres Strait Islander people. These activities are part of Aboriginal and Torres Strait Islander peoples' cultures, customs and traditions; satisfy personal, subsistence or communal needs; and are essential for the health and wellbeing of Indigenous coastal people in Australia (Torres Strait NRM Reference Group 2005, Dobbs 2007, Butler et al. 2012). More than 150 Indigenous clan groups along the Australian coastline continue a longstanding connection with sea Country, leading to traditional use of marine resources across a large area of Australia.

Traditional use is generally carried out on foot from the shore, often at low tide, or from small vessels that are usually powered by outboard motors. Although methods used in these activities may have changed through time, the purpose remains the same. The number of traditionally harvested species in marine areas can be up to several hundred (e.g. in Torres Strait; McNiven & Hitchcock 2004); these species include fish, reptiles, mammals, seabirds and molluscs. The intensity of traditional use varies between communities depending on customs, access to Country and social circumstances (Busilacchi et al. 2013a). Contemporary subsistence means that customary harvest is usually part of a hybrid economy that includes commercial fishing, and employment in industry or government (Busilacchi et al. 2013b). There is also a desire for many Indigenous communities to develop commercial enterprises that are focused on marine resources (NLC 2016).

Dugong and marine turtles are key cultural species that are customarily hunted and harvested by many coastal Indigenous communities in northern Australia (NAILSMA 2006, Butler et al. 2012). The hunting of dugong and turtle is an expression of the continuance of long cultural traditions (TSRA 2005, Dobbs 2007). Recent scrutiny of the impact of traditional harvesting on dugong and marine turtle populations, including animal welfare implications, has created some conjecture and even conflict between the desire to conserve dugong and marine turtle populations, and Indigenous interest in managing the diversity of threats (e.g. marine debris and

2 See also 13FISH intelligence reporting line.
3 See 13FISH intelligence reporting line.

vessel strikes) and in maintaining rights to traditional use (Dobbs 2007, Nursey-Bray 2009, Marsh et al. 2015).

The quantity, composition and local status of traditional catch across Indigenous communities are mostly unknown because of a paucity of consistent catch recording systems. Anecdotal reports suggest that harvesting levels may be declining because of changes in community practices and economies that rely more on imported foods, and strengthened awareness of, and community involvement in, sustainable management strategies. This is counterbalanced by the potential for increased geographical range and rates of capture because of technological advances (e.g. outboard motors), young hunters not practising tradition and custom, and expansion in use of the catch from special feasts to common table food (Havemman & Smith 2007).

In the absence of recorded catch numbers, some traditional owners have modified their use of resources to ensure that traditional take remains at sustainable levels through changes to their own practices and partnerships with managing agencies, including through Traditional Use of Marine Resources Agreements (Dobbs 2007). Some isolated instances of catch recording and elicitation of local knowledge have identified higher levels of harvesting within particular regions than previously thought. This highlights the importance of reliable estimates of catches for sustainable management of harvesting (Bussilacchi et al. 2013a). At a national scale, traditional use of resources is considered to have a low impact on the marine environment, with recent trends unclear.

Support to address knowledge gaps and build on existing momentum for long-term community management of cultural resources remains a challenge for some Indigenous communities (see NLC 2016). Appropriate and effective monitoring approaches are needed to determine trends in traditional use and any impacts. A lack of understanding by the public and policy-makers about established cultural rights to traditional use undermines the collection and sharing of harvest information with broader stakeholders. Sensitivities and complexities surround the management of traditional use of marine resources, and need to be identified and handled appropriately.

Torres Strait Regional Authority rangers, in collaboration with traditional owners, play a vital role in monitoring marine turtle populations
Photo by Tristan Simpson

Marine oil and gas exploration and production

Australia has large reserves of gas and substantial reserves of oil, with extraction activities producing 79.4 million barrels of crude oil in 2014 (APPEA 2015). Australian production of liquefied natural gas (LNG) has more than doubled since 1998, and the North West Shelf alone is expected to have an operating life of 45 years (APPEA 2015). In 2015, Australia exported 30.4 million tonnes of LNG with a value of $16.5 billion, and it is expected that Australia will become the world's largest LNG exporter by 2018. In association with the expansion of LNG production and exports, offshore production facilities are also being developed, the first of which is under construction. Once completed, it will be towed onto site in the Browse Basin, around 475 kilometres north-east of Broome. The contribution of the oil and gas industry to Australia's annual economic output is expected to more than double from $32 billion in 2012–13 to $67 billion by 2029–30 (APPEA 2015).

Activities that occur in the oil and gas industry can be largely divided into 4 categories:

- exploration—seismic surveys and drilling
- development—drilling, and construction of submarine infrastructure (including pipelines) and facilities
- operations—production facilities
- operations—decommissioning.

Pressures associated with ports, export facilities, onshore transport of marine oil and gas, and regional population growth associated with oil and gas industries can be found in the *Coasts* report.

Exploration and production

In offshore areas, the Australian Government manages the release of exploration acreages through a nomination process. In 2011–15, the number of offshore areas nominated ranged from 27 to 31 per year, with nominations primarily located in the North-west Marine Region. Smaller numbers were nominated in the South-east, South-west and North marine regions (Table MAR2). Acreages nominated are not always taken up and bid on; 4–10 acreages were re-released for nomination each year during 2011–15.

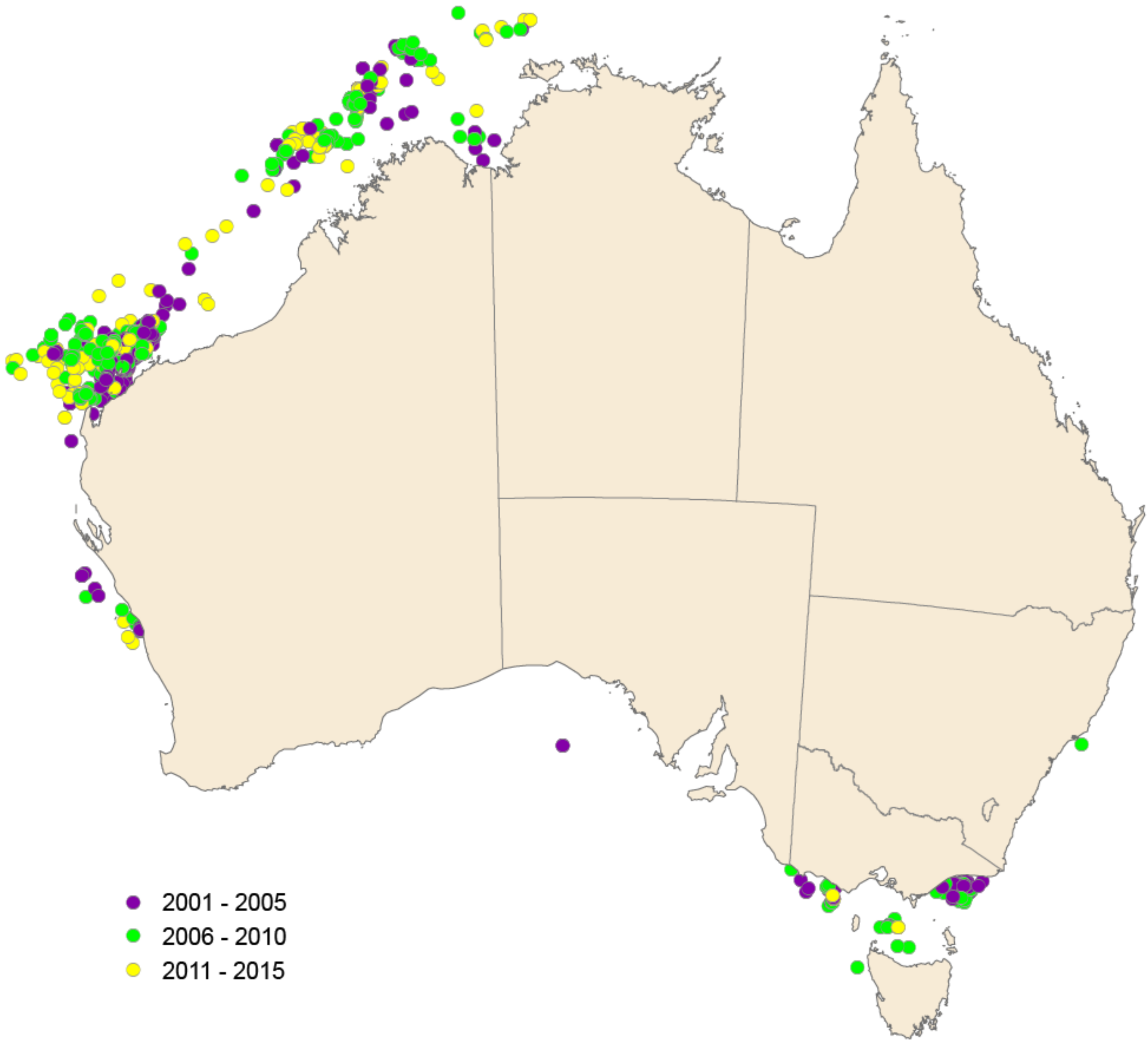
Table MAR2 Number of exploration acreage nominations released by the Australian Government in offshore areas across marine regions

Marine region	2011	2012	2013	2014	2015
North	2	3	3	3	2
Coral Sea	0	0	0	0	0
Temperate East	0	0	0	0	0
South-east	7	7	2	0	6
South-west	3	3	2	1	1
North-west	20	14	24	26	19
Total	32	27	31	30	28

The rising cost of oil and gas exploration, coupled with falling oil and gas prices, has resulted in overall reduced petroleum exploration activity across offshore and inshore waters, with the number of offshore exploration wells drilled falling by more than two-thirds since its peak in 1998. New submissions for environmental management approval, as a potential indicator of offshore oil and gas activity, decreased between 2012 and 2015, with a 33.3 per cent reduction in new submissions in 2015 compared with 2014 (NOPSEMA 2016). The greatest declines in the offshore sector were in drilling and construction activities, whereas operations, decommissioning and seismic activity remained relatively stable (see also Anthropogenic noise). As a result, the oil and gas industry can be considered to have a low impact on the marine environment with an improving trend.

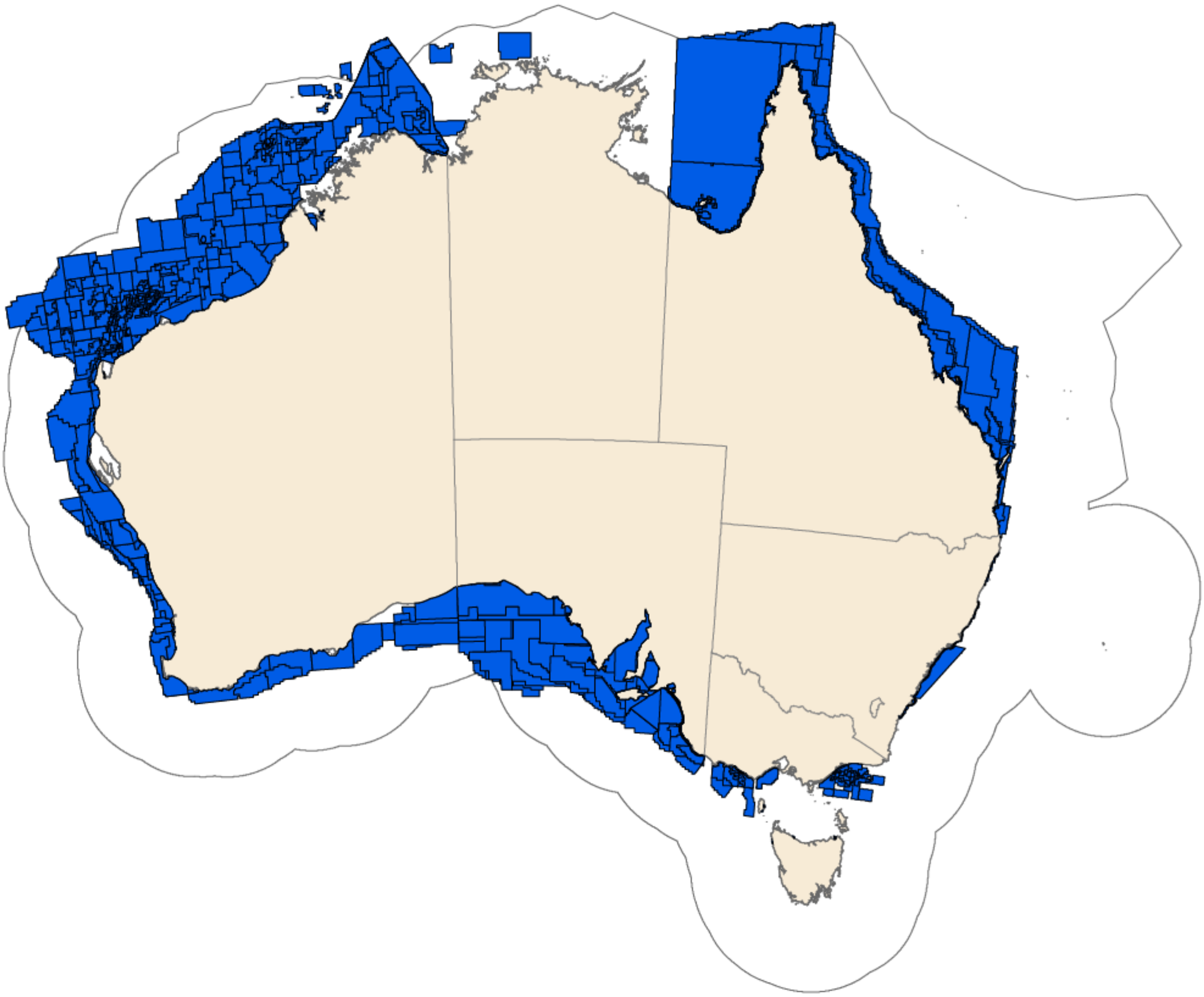
Most extraction activities are currently concentrated in the North-west and South-east marine regions (Figure MAR14), although all regions contain leases with active exploration permits (Figure MAR15). Potential impacts on the marine environment from oil and gas activities are generally well known, and vary depending on the size, type and location of activity.

Oil and gas activities in the marine environment generally occur away from shallow-water nearshore environments; most activities in the nearshore environment are associated with processing and port



Source: National Environmental Science Programme Marine Biodiversity Hub

Figure MAR14 Wells drilled by the oil and gas industry in the marine environment, 2001–15



Source: National Environmental Science Programme Marine Biodiversity Hub

Figure MAR15 Exploration permits for petroleum leases in the marine environment, 2011–15 facilities. Numerous habitats, communities and species groups in the marine environment may be affected by oil and gas activities, including coral reefs, seagrass communities, fish and invertebrate species, and some species that are protected under national and international legislation and agreements. Impacts can include:

- seabed disturbance from the physical footprint of subsea infrastructure and drilling discharges (O'Rourke & Connelly 2003)
- underwater noise from seismic surveys, support vessels, drilling or pile-driving (see Anthropogenic noise)
- artificial light and air quality effects from operating facilities
- seabed and water quality effects from discharges of drilling waste or production discharges (Holdway 2002).

The extent, duration and severity of impacts vary depending on the biological sensitivities of the marine environment near the activity (O'Rourke & Connelly 2003). In many cases, impacts are highly localised (e.g. Carr et al. 1996); however, the long-term chronic effects of many activities on the marine environment are unknown. Quantifying cumulative impacts from activities and separating these from other anthropogenic stressors continue to be challenges for the oil and gas industry, regulators and marine estate managers.

Risks to the marine environment also come from unplanned events such as oil spills. The impacts of unplanned events may be difficult to predict before the event, but have the potential to include significant physical and biological consequences. Knowledge of the risks and impacts of oil spills, and how to prevent or minimise them, has increased dramatically following significant spill incidents in Australia (DRET 2011) and internationally in recent years (see Lubchenco et al. 2012 and associated papers). Greater investment in marine baseline studies, and meteorology and physical oceanography studies has supported modelling and monitoring of activity discharges and their impacts, and increased preparedness for emergency response in the event of an oil spill.[4]

There are still areas for improvement in identifying the impacts and risks associated with oil and gas activities, including:

- field studies that can verify modelled activity impacts
- investigations into cumulative impacts at the appropriate temporal and spatial scales
- improved facilitation of information sharing across common environmental risks
- more consistent incident reporting to both state and territory agencies, and NOPSEMA.

Decommissioning of infrastructure

As offshore oil and gas structures age and approach obsolescence, they require decommissioning. If not properly managed, decommissioning of facilities may not always result in optimal environmental, societal and economic outcomes. Challenges associated with decommissioning are becoming particularly pronounced because of the ageing nature, and associated maintenance requirements, of facilities in some parts of Australia.

Typically, once a well has come to the end of its useful life, it is plugged to prevent fluids and gases from leaking. Generally, regulations require that a well must be abandoned in accordance with good industry practice, to the extent that this practice is consistent with the regulations. Regulations vary in detail across and within jurisdictions, but generally require that remediation uses noncorrosive fluids and plugs that are 'fit-for-purpose' based on industry standards. Effective remediation isolates oil-producing and gas-producing zones from aquifers, and remediates the surface to meet the relevant regulatory standards. Platform structures and pipelines may be removed and used elsewhere, or hauled to shore for scrapping or recycling (Schroeder & Love 2004).

Policies of complete removal assume that 'leaving the seabed as you found it' represents the most environmentally sound decommissioning option. However, some structures (including well structures, and associated pipelines transporting oil and gas from the well) can develop abundant and diverse marine communities during their production lives, and can support communities of regional significance (Macreadie et al. 2011). This produces a conundrum whereby removal of structures is unlikely to represent best environmental practice in all cases (Fowler et al. 2014). Some approaches to this situation have resulted in obsolete structures being left in place as artificial reefs ('rigs-to-reefs'). Such programs are actively debated, and the general view is that decommissioning activities, rather than being directed under general regulations, should be considered on a case-by-case basis (Schroeder & Love 2004, Fowler et al. 2014).

4 For example, Understanding the Great Australian Bight

Marine mining and industry

A wide variety of mineral resources exist within Australia's maritime jurisdiction (Table MAR3). Mining of these resources, however, remains an emerging industry (AIMS 2014). As a result, there is currently a low level of understanding of pressures associated with marine mining and the frameworks required to effectively manage activities within the Australian context.

The global marine mining industry is more advanced, and is supported by a growing body of research investigating likely environmental impacts and mitigation strategies (Halfar & Fujita 2002, Collins et al. 2013). On local scales, impacts are likely to be associated with sea-floor modification (dredging and mineral extraction). More regional environmental pressures are likely to be associated with dislodged sediments, which disperse as plumes, and can cover surrounding habitats and cloud the water column, reducing light and increasing the concentration of particles in the water column. Other regional pressures come from vessel activity associated with the transport of extracted materials (see Marine vessel activity for details of pressures associated with vessels).

Currently, there are no marine mining activities in Australia other than the well-established shell sandmining operation in Cockburn Sound (Western Australia) and sandmining in Moreton Bay (Queensland). Both operations were granted extraction licences by state departments, subject to strict environmental controls, particularly relating to replanting of seagrass meadows (Cockburn Sound) and sediment plumes (Moreton Bay). Other submissions made across jurisdictions to explore and potentially exploit sea-floor resources elsewhere in Australia have been rejected or stalled because of the lack of existing baseline knowledge, lack of community support, and poor understanding of the potential social and environmental impacts of such activities. No national or regional assessments of the likely impacts of marine mining activities have been conducted for Australian waters, and the impacts of marine mining activities cannot be assessed.

Marine renewable energy generation

The marine renewable energy industry is an emerging industry globally. Ocean energy technologies and devices (e.g. offshore wind farms, wave energy generators) are being developed around the world, and understanding of the environmental effects of these devices is a growing area of research, largely driven by technology developers and research agencies in the Northern Hemisphere. To date, most research has focused on acute impacts on individual species. Population consequences and longer-term chronic impacts are poorly understood (e.g. Boehlert & Gill 2010, Shields et al. 2011). Indeed, the infrastructure provided by marine renewable installations, if appropriately managed and designed, may have benefits for the environment, acting as artificial reefs and de facto marine protected areas (Inger et al. 2009).

Researching and understanding the impacts associated with marine renewable energy generation constitutes a major work program of the International Energy Agency's working group on Ocean Energy Systems (IEA-OES Annex IV: Assessment of environmental effects of and monitoring efforts for ocean wave, tidal and current energy systems). This task has focused on 3 interactions between marine energy devices and the marine environment (Copping et al. 2013):

- the physical interactions between animals and marine energy devices
- the acoustic impact of marine energy devices on marine animals
- the effects of energy removal on the physical environment.

Australia is not currently a member of the working group.

In Australia, marine renewable energy generation is a fledgling industry and, to date, has predominantly focused on wave energy (CSIRO 2012), primarily across the southern temperate coasts of Australia. At present, deployments of marine energy generators are limited to 2 precommercial-scale (small-scale—less than 500 kilowatt) power stations (off Perth, Western Australia, and off Port Fairy, Victoria), and a few experimental or prototype deployments. Some interest also exists in developing tidal energy systems in tropical

Table MAR3 Marine mining activities, including potential activities, in the Australian marine environment

Area	Resource	Previous activities	Current and potential activities
Nearshore (located on the continental shelf)	Sands and gravels (mobile sand bodies on the continental shelf and ancient beach deposits)	Building sands Widespread beach replenishment using offshore sandbars Channel deepening	Localised beach renourishment projects occur at various locations Shell sands are being mined as a source of lime in Cockburn Sound Building sands are extracted from Moreton Bay
	Coal (seawards extension of terrestrial deposits)	Offshore black coal seams	No current activity, although brown coal extending seawards from the La Trobe Valley could potentially be mined
	Heavy minerals, including mineral sands (titanium, zirconium, thorium, tungsten, gold, tin, diamond)	Exploration for mineral sands on the continental shelf has identified subeconomic deposits of titanium, tungsten, tin and diamonds Some exploration for diamonds in Joseph Bonaparte Gulf Tungsten mineralisation Alluvial tin resources	No current exploration licences are active
	Iron (seawards extension of terrestrial deposits)	High-grade iron ore	Feasibility is currently under review
	Manganese (seawards extension of terrestrial deposits)	None	Exploration licence was granted, but a 3 year moratorium has since been imposed
	Copper, gold, uranium (seawards extension of terrestrial deposits)	None	Exploration licences have been granted, but no further activity
Deep ocean (located beyond the continental shelf)	Manganese–cobalt nodules and crusts	None	None in Australia, but there is considerable international interest in deposits in the central Pacific Ocean, where exploration licences are granted and controlled by the International Seabed Authority
	Base metals and precious metals (copper, zinc, lead, gold, silver deposits formed by active hydrothermal vents)	None	None in Australia, but there is considerable international interest in deposits in territorial waters of a range of south-west Pacific nations. Several companies are planning to start mining operations in the next decade
	Rare-earth elements (scavenged from sea water and concentrated in sea-floor clay minerals as muds)	None	None—resource is considered speculative

Propeller marks on the dorsal surface of an Australian snubfin dolphin (*Orcaella heinsohni*) and scarring on the dorsal fin, indicating interactions with recreational vessels and fishing line

Photo by Deborah Thiele

northern waters and areas adjacent to the Bass Strait islands. It is currently unclear whether these activities are applicable to large-scale deployment (more than 100 megawatt capacity). Although current impacts of marine renewable energy on the Australian marine environment are unclear, Australia is endeavouring to improve the knowledge base of the environmental effects of wave energy devices in the temperate environments where they are currently being trialled. The current impacts of marine renewable energy generation on the marine environment are very low, and trends are unclear.

Although offshore wind is an established industry for marine power generation in the Northern Hemisphere, it is yet to be established in Australia. However, it can be anticipated that proposals for installations in Australia will be developed and submitted for approval within the next 5 years.

Marine vessel activity

International vessels

International vessels operating in Australian waters mainly comprise large cargo carriers, but may also include smaller commercial ships, cruise vessels and international yachts. As an island, Australia relies heavily on commercial vessels for transportation of its imports and exports. In 2013–14, 1425 million tonnes of cargo moved across Australian wharves, 1221.8 million tonnes of which were international exports and imports. A total of 5499 vessels made 28,714 port calls in 2013–14 (BITRE 2015). International exports comprised 85.7 per cent of this cargo, whereas international imports represented 7 per cent. In addition, there were 670 cruise ship visits.

Very few places in the Australian marine environment are not used by marine vessels (Figure MAR16). Major routes used by vessels traverse a wide variety of habitats and ecosystems, and groundings by vessels and accidents at sea in ecologically sensitive areas impose pressures on the marine environment. Since 2011, 4 ships have been reported as grounded, all within embayment or port areas, and 3 vessels have been involved in collision, capsizing or foundering events.[5] Vessels also interact directly with marine animals via vessel strike (see Box MAR3) and emit constant noise into the ocean (see Anthropogenic noise). Vessels are a source of atmospheric emissions, including carbon dioxide, nitrous oxide and sulfur. Anchoring in offshore areas can cause sea-floor abrasion and damage to benthic ecosystems (Davis et al. 2016). The exchange of ballast water in nearshore port or mooring environments and biofouling of vessels can introduce foreign marine species to the Australian environment (see Introduced species). Biocides used in antifouling paints are toxic when released to the marine environment, and can affect marine species' growth and reproduction, mainly when the coating is dislodged from the hull or through the coating dissolution process in confined inshore waters (see Thomas & Brooks 2010).

The National Plan for Maritime Environmental Emergencies (NESMG 2014) sets out the cooperative arrangements between government and industry to respond to maritime incidents affecting the environment (see also Effectiveness of marine management).

Domestic vessels

Domestic vessels provide important transport linkages between regional Australia and the cities, and smaller vessels provide an important recreational pastime for many Australians—for example, nearshore use of power vessels (e.g. jetskis, powerboats, cruisers) and yachts, and offshore use of powerboats and yachts. Coastal freight comprised 104.3 million tonnes in 2013–14, representing 7.3 per cent of all cargo moving across Australian ports (BITRE 2015). Pressures associated with coastal freight activities are similar to those associated with international vessels (e.g. groundings, introduction of foreign species), whereas high inshore use by recreational vessels adds considerable risk of disturbance and vessel strike of inshore marine animals such as dolphins, dugongs and marine turtles. Anchoring and mooring of vessels (which are largely unmanaged) have direct impacts on seabed habitats and communities (Davis et al. 2014, 2016).

Information about incidents such as groundings, collisions and sinking of domestic vessels is reported to either state or territory marine safety agencies, or the Australian Maritime Safety Authority.

Although reporting associated with commercial vessel activities allows the quantification of pressures associated with some activities (e.g. groundings), other pressures (e.g. noise, ship strike) lack reporting mechanisms, and, as a result, impacts are largely unquantified. How increases in vessel activity might be affecting the marine environment is not entirely clear.

Pressures associated with port facilities and infrastructure are described in the *Coasts* report.

Box MAR3 Vessel strike

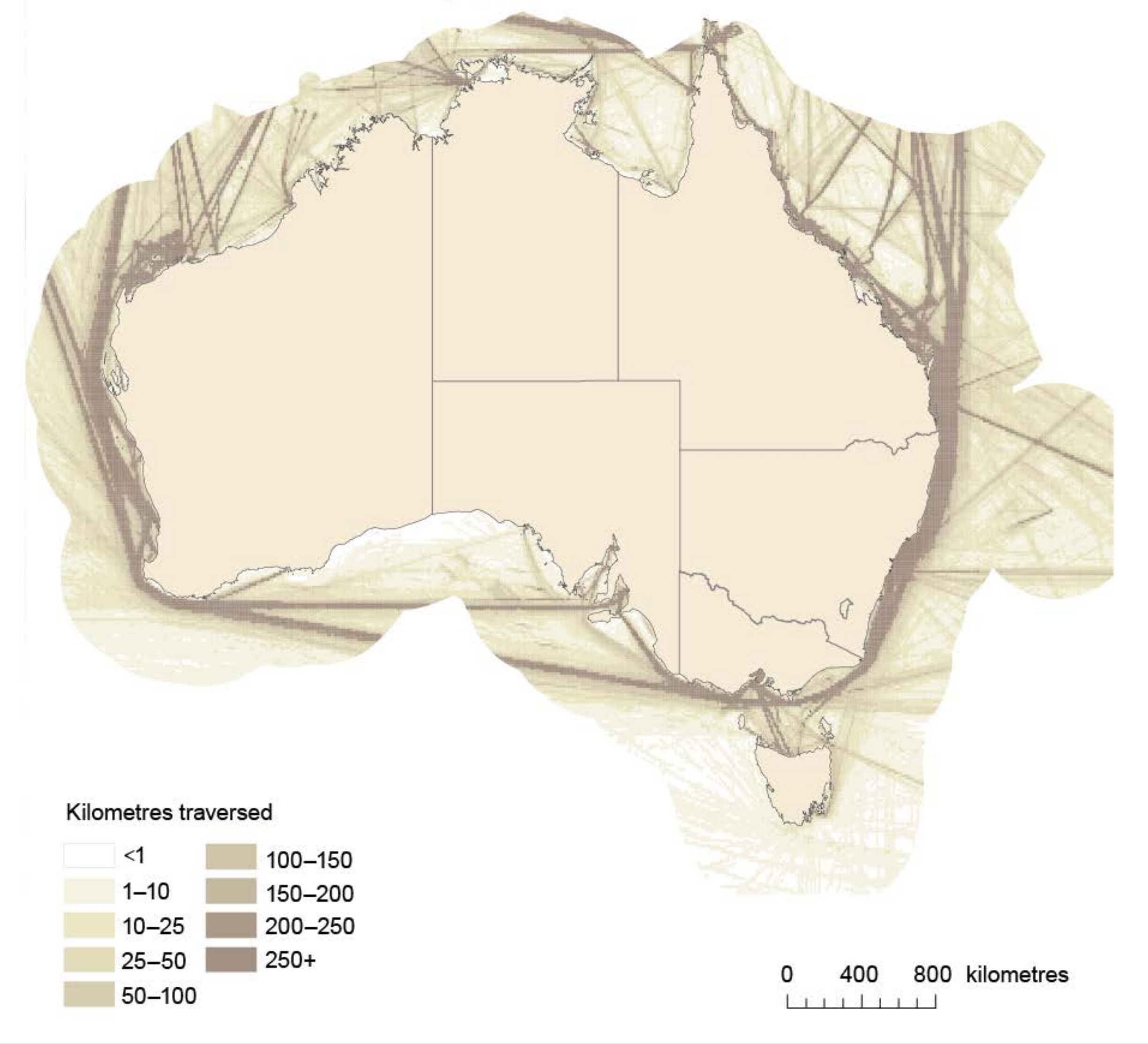
Australia relies heavily on commercial vessels for transportation of its imports and exports, with 99 per cent of Australian trade by volume carried by sea (AMSA 2016). With 85 per cent of the population living within 100 kilometres of the coast, recreational boating is a popular pastime for many Australians. There are very few areas in the Australian marine environment where international and domestic vessel activity does not occur (Figure MAR16).

In association with vessel activities, there is a risk of environmental damage from collision or grounding of vessels (NESMG 2014), and harm to marine animals by vessel strike from all types of vessels. Large, high-speed commercial vessels cause the death of whales worldwide (Jensen et al. 2004), and small recreational vessels regularly injure inshore species such as dugongs (*Dugong dugon*), turtles and dolphins (e.g. Thiele 2010).

Globally, commercial vessel activity has been increasing (Davis et al. 2016). Within Australian waters, commercial vessel activity has grown by approximately 4 per cent each year since the early 2000s (DIRD 2014, BITRE 2015; Figure MAR17). Much of this growth is within significant areas of marine mammal migration and/or breeding, such as the Great Barrier Reef. Use of port areas in regions used by turtles and dugongs is also increasing (e.g. Gladstone Harbour). At the same time, the size of recreational vessels has been increasing across most regions, and activity in remote areas is also increasing (Lyle et al. 2014, Giri & Hall 2015, Ryan et al. 2015, West et al. 2016).

5 See Marine safety investigations & reports.

Box MAR3 (continued)



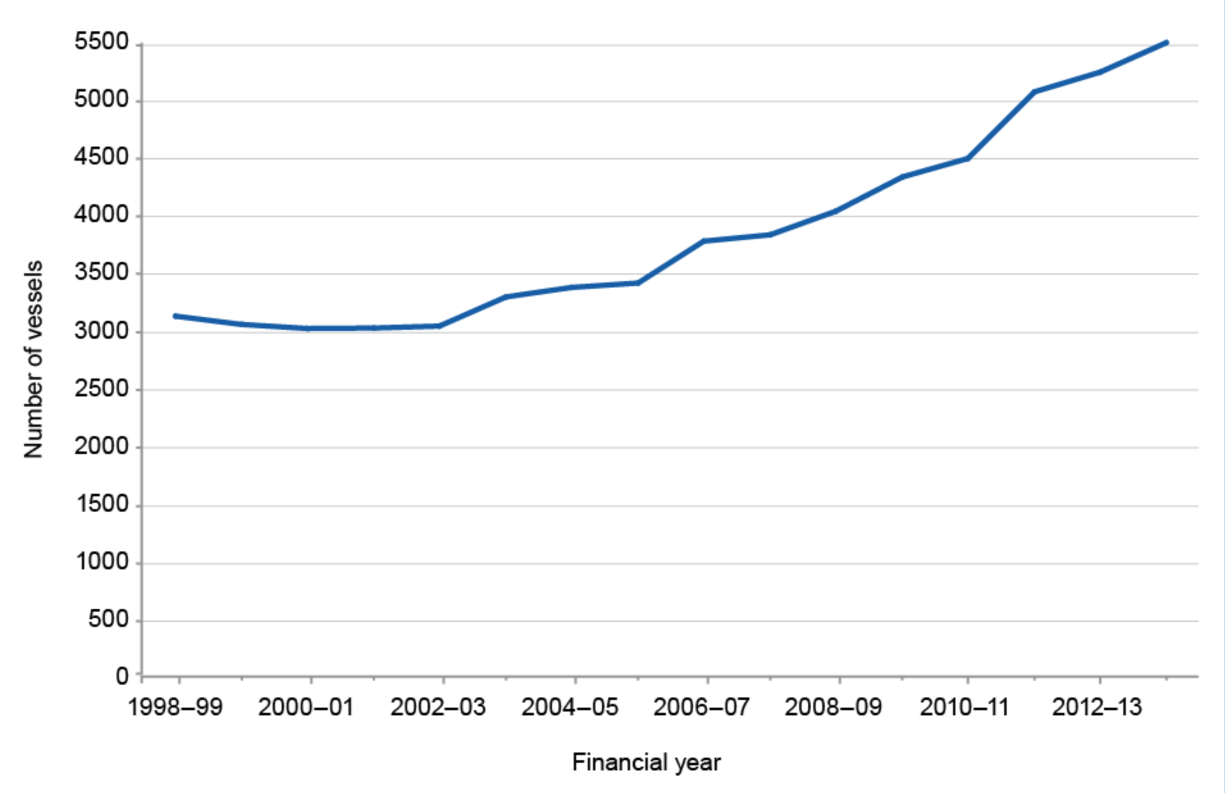
Source: National Environmental Science Programme Marine Biodiversity Hub, based on data from the Automatic Identification System managed by the Australian Maritime Safety Authority

Figure MAR16 Density (kilometres traversed) of vessels more than 24 metres long in the Australian exclusive economic zone

Box MAR3 (continued)

Recently, vessel strike incidents by commercial vessels in Australian waters have predominantly involved humpback whales (*Megaptera novaeangliae*). Based on the behaviour and distribution of animals, the distribution of high-density commercial vessels, and overlaps between the two, mother–calf pairs of humpback whales have the potential to be particularly susceptible. Incidents with southern right whales (*Eubalaena australis*), sperm whales (*Physeter macrocephalus*) and pygmy blue whales (*Balaenoptera musculus brevicauda*) have also been reported.[a] Given the speed and size of modern commercial vessels, collisions with whales have a high probability of being fatal (Vanderlaan & Taggart 2007). Vessel strike, particularly by recreational vessels, was identified more than a decade ago as being an issue for marine turtles in Queensland waters, mainly around Moreton Bay and Hervey Bay (EA 2003).

Quantification of historical impacts of vessel strike on marine animals is difficult, because the collation of records (from live, deceased and stranded animals) of vessel strike has not been consistent over time. It is also difficult to ascertain the specific contribution of vessels of varying sizes and types to the problem, because collisions of many animals, particularly with large vessels, will most likely go unnoticed and are therefore not reported (Laist et al. 2001). For example, in Australia, 109 incidents of vessel strike of whales have been reported through official reporting avenues since 1840 (DoEE 2016). However, in some regions, up to 10 per cent of all resident dolphins have been recorded as demonstrating evidence of vessel strike. The low number of official records of vessel strike from these regions suggests that most incidents of vessel strike remain unreported (Thiele 2010). As a result, the impacts of vessel strike on populations of marine animals remain unknown.



Source: Data from BITRE (2015), used under CC BY 3.0

Figure MAR17 Number of cargo ships involved in coastal or international voyages that made port calls in Australia

Box MAR3 (continued)

Management measures addressing vessel strike

The International Maritime Organization has adopted measures—including precautionary areas, areas to be avoided, re-routing measures and speed restrictions—aimed at minimising vessel strike of whales (Silber et al. 2012). In Australian waters, not enough is known about the spatial or temporal distribution of vessel strike risk or the scale of the issue to implement targeted management measures. Thus, no management frameworks directly addressing vessel strike are in place. However, zoning plans in a number of areas (e.g. Moreton Bay Marine Park) restrict the speed of vessels in an effort to minimise vessel strike of marine animals.

A national vessel strike strategy is being developed by the Australian Government Department of the Environment and Energy (DoEE 2016). The objectives of the strategy are to:

- collect data to understand the scale of vessel strike
- undertake risk assessment and analysis of existing databases
- develop efficient reporting procedures that can be assessed
- develop mitigation measures
- engage with industry regarding information gathering and mitigation.

At the same time, the National Environmental Science Programme Marine Biodiversity Hub is developing approaches to identify areas where there is overlap between the density of vessel activity and marine animal aggregation, as a potential indicator of risk of vessel strike. Such information will be essential for the development of risk management strategies focused on vessel strike.

Outlook

Commercial vessel activity is projected to continue to increase (DIRD 2014). Many populations of animals that are likely to interact with vessels are protected, with some recovering from past exploitation. Some, such as humpback whales, have increased notably (Noad et al. 2011). The combined growth of vessel activity and continuing recovery of populations of protected species such as whales are likely to increase the number of interactions between vessels and these populations. The impacts on marine animal populations associated with increased interactions will remain unquantified without effective reporting and mitigation schemes.

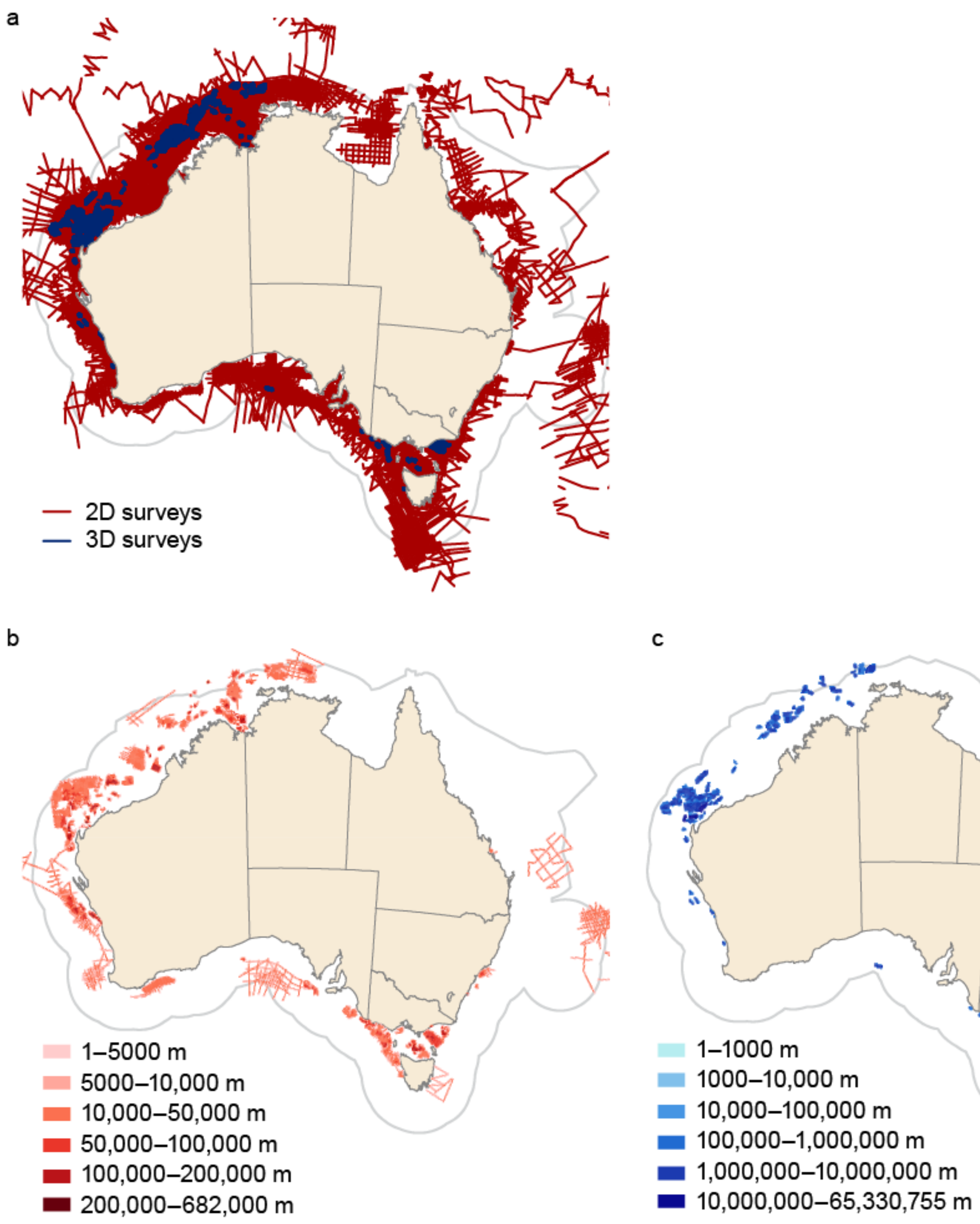
a Australian Transport Safety Bureau marine safety investigations and reports and Australian Marine Mammal Centre National Marine Mammal Database

Anthropogenic noise

Humans and their activities in the marine environment introduce noise into the ocean in various ways. Each activity that generates noise may have different effects, depending on the noise generated, and its frequency, intensity and composition (intermittent, pulsed or continuous sounds).

The main anthropogenic activities producing high levels of noise are seismic surveys of sub-bottom strata (usually using air-gun arrays), active sonars (military, scientific surveying, echo sounders), explosions (associated with military exercises and port construction), pile-driving (wharf construction, offshore platforms), vessels (particularly dynamically positioned vessels), dredging and drill rig activities. Lower levels of noise are produced through general ongoing vessel activity and offshore renewable energy operations. To date:

- seismic surveys have been concentrated in the main oil and gas regions of the North West Shelf and Bass Strait (Figure MAR18)
- military sonar has been concentrated in maritime exercise areas such as Sydney and Perth
- dynamically positioned vessels are associated with offshore facilities
- pile-driving and dredging associated with port development have been concentrated in the north-west and north-east, although dredging activities are routinely conducted in port environs throughout Australia (see the *Coasts* report for further detail).



Source: (a) Data from Geoscience Australia; (b and c) National Environmental Science Programme Marine Biodiversity Hub

Figure MAR18 (a) Transect lines for 2D and 3D seismic surveys, 1961–2012; total metres per square kilometre surveyed for (b) 2D and (c) 3D surveys conducted in Australian marine waters, 2001–2012

Hawksbill turtle (*Eretmochelys imbricata*) near Heron Island, Queensland
Photo by David Harasti

Because of the extent of marine activities generating noise in the marine environment, anthropogenic noise is considered to have high impact.

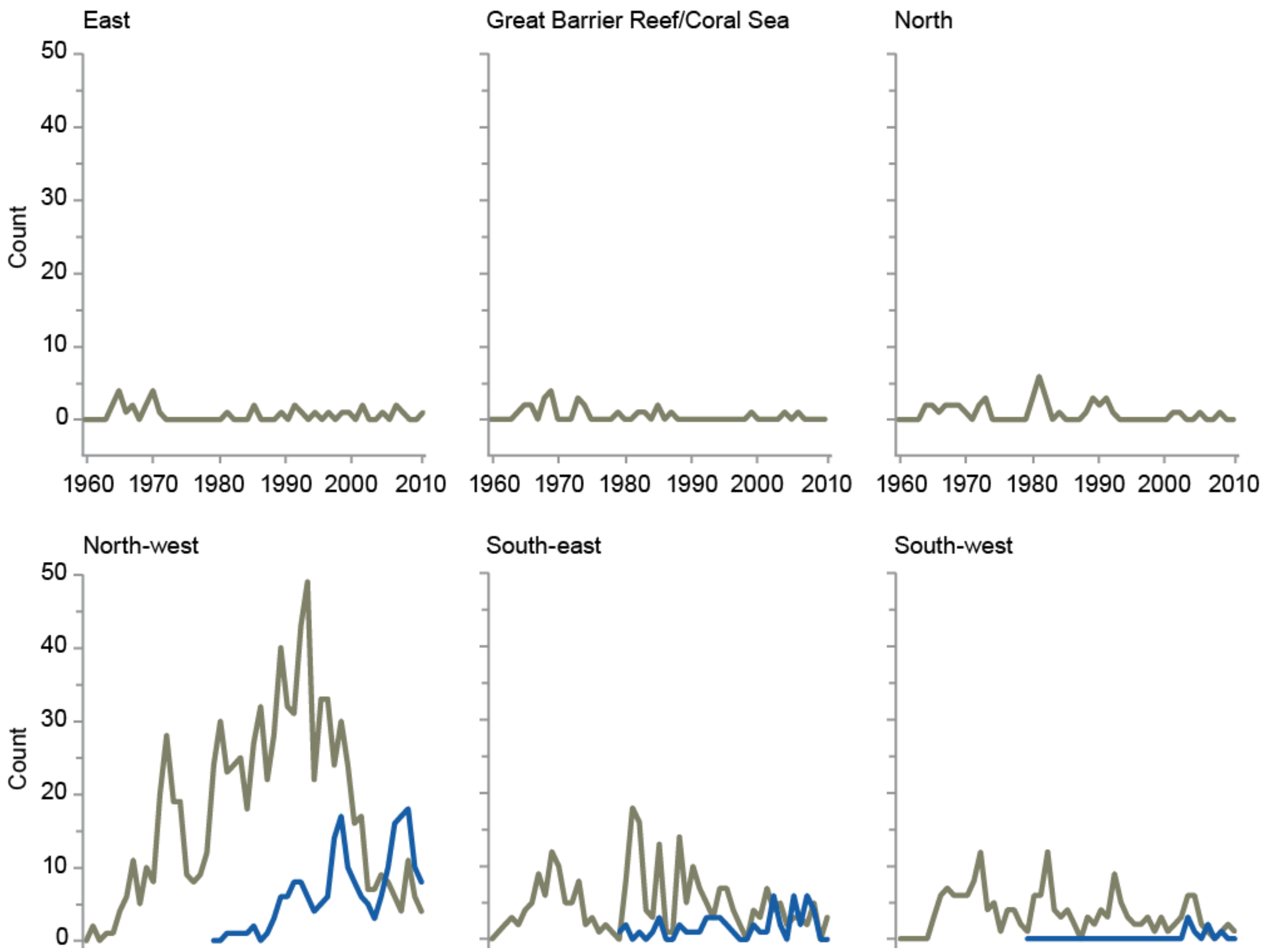
For most marine animals, sound is important for communication; for locating particular features, prey and peers; and for short-range and long-range navigation (Erbe et al. 2015). Sounds from anthropogenic sources can mask vocal communication, disrupt normal behaviours, and cause temporary or permanent threshold shifts in hearing. Explosions can cause physical damage to tissues and organs. These pressures can, ultimately, have adverse impacts on foraging and reproduction, and individual health and fitness, which can manifest as population effects (OSPAR 2009, Cato 2010).

Enough is known about hearing in marine mammals and, to some extent, fish to model the effects of noise on hearing and, to some extent, on masking. Far less is known about behavioural responses and their significance. Within Australian waters, most of the emphasis has been on experimental assessment of the impacts of air-gun noise on marine mammal behaviour, with fewer studies of the impacts on fish. More recently, there have been some studies on invertebrates, and so the baseline understanding of impacts—in particular, acute impacts—is growing (McCauley et al. 2003; Cato et al. 2012, 2016; Fewtrell & McCauley 2012; Miller & Cripps 2013; Dunlop et al. 2016). However, chronic effects associated with ongoing low-level noise are not well understood across all species groups (Hawkins et al. 2015).

Substantial data on noise have been collected globally, allowing the characterisation of noise from most anthropogenic sources. Records of activities generating noise can be used to estimate trends in the occurrence of sources of anthropogenic noise (e.g. Figure MAR19). However, this does not directly equate to the amount of noise entering the marine environment, because activities can generate varying levels of sound depending on the source, and sound propagates through the water column in varying ways depending on the location, time of year and regional oceanography.

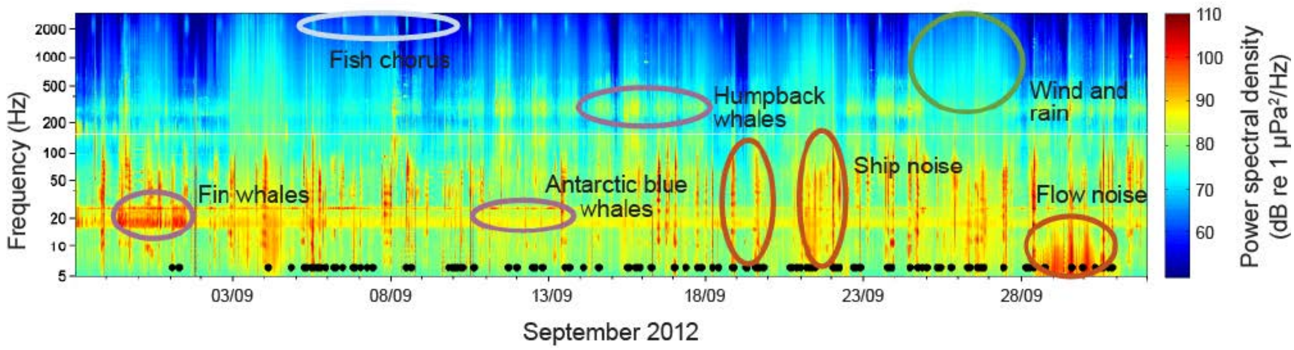
Before 2008, regular monitoring of noise in the Australian marine environment was spatially and temporally limited, and the establishment of soundscapes and any trends in soundscapes was therefore also limited. With the establishment of the IMOS network of National Reference Stations (Lynch et al. 2014), coordinated ongoing monitoring of noise in the marine environment now occurs at several stations, predominantly in the southern half of Australia. Monitoring efforts are facilitating characterisation and quantification of the marine soundscape (Erbe et al. 2015; Figure MAR20), and the establishment of trends at the station sites. Analysis of acoustic data from the National Reference Station moored offshore from Perth has identified that soundscapes are dominated by physical and meteorological (wind, waves and rain), biological (marine animals such as whales and fish) and anthropogenic (predominantly marine vessel activity, which was present 25 per cent of the time) sound sources (Erbe et al. 2015). However, the limited nature of monitoring of noise in the marine environment precludes an assessment of recent trends. Therefore, trends of anthropogenic noise remain unclear.

Considerable variability exists in the outlook for the major activities generating noise, with flow-on effects on the types of noise expected to contribute to the marine environment. High point-source activities are expected to remain stable (sonar, pile-driving, dredging) or decrease (seismic surveys). Activities generating lower levels of noise, such as marine mining, marine renewable energy and vessel activity, are expected to increase. How increases in these activities will affect the Australian marine environment is currently not clear, but they may result in a shift in anthropogenic contributions to marine soundscapes towards ongoing low-level noise.



Source: Data from Geoscience Australia

Figure MAR19 Number of 2D and 3D seismic surveys in each marine region, 1960–2010



Note: The black dots indicate when a ship passes within 20 kilometres of the sound recorder.
Source: Erbe et al. (2015)

Figure MAR20 Spectrogram showing the main contributors to the marine soundscape in the Perth Canyon

Marine debris

Within the marine environment, marine debris is sourced from both the land (rubbish flushed out to sea; see further detail on coastal pollution in the *Coasts* report) and marine industries (loss of equipment, often from fishing operations). Although marine debris can be found in all areas of the marine environment in the Australian EEZ (see Box MAR4), northern Australia is especially vulnerable because of the proximity of intensive fishing operations (including international operations) to the north of Australia, regional difficulties in surveillance and enforcement, and ocean circulation and wind patterns that appear to promote accumulation of floating debris (Kiessling 2003).

Entanglement of marine animals in debris can cause restricted mobility, drowning, starvation, smothering, wounding and amputation of limbs—all of which can result in death. One of the major threats to marine wildlife through entanglement is ghost nets. These are fishing nets that drift through the ocean unattended for years or even decades, 'ghost fishing' and entangling and killing commercially valuable or threatened species (Laist 1987, 1997; Macfayden et al. 2009). To date, more than 13,000 nets have been removed from beaches and estuaries by organisations such as GhostNets Australia. Surveys of ghost nets in the northern Australian region found that, of the approximately 50 per cent that could be identified, only 4 per cent originated from Australian fisheries (Gunn et al. 2010).

Floating plastics are also a major threat because they are resistant to breakdown, and thus persist and accumulate in the marine environment. Many are ingested by marine animals, and remain in the stomach and accumulate, eventually causing starvation. Plastics are also a potential source of toxic chemicals (Lavers et al. 2014). These chemicals, once leached out of the ingested material and transferred into the blood and tissues of individuals, may cause sublethal health effects in wildlife, even at very low contamination levels (Tanaka et al. 2013). Marine life as small as plankton is affected by debris in the form of 'microplastics' (less than 5 millimetres in diameter), which are a widespread and ubiquitous contaminant of marine ecosystems across the globe. This form of marine debris has been reported as causing decreased feeding because of ingestion, and reduced mobility because of adherence to the external carapace and appendages of exposed zooplankton (Cole et al. 2013). Microplastics have also been linked to the degradation of molecular, cellular, physiological and, ultimately, ecological processes within the marine environment (Browne et al. 2015).

Data on the distribution of debris at sea are scarce, largely because of the expense of collecting these data, which requires use of aircraft or vessels. Some progress has been made in predicting the distribution of marine debris at sea (see Wilcox et al. 2013, 2015; Eriksen et al. 2014), which was surveyed for the first time in Australian waters in 2013 (Hardesty et al. 2014).

Despite initiatives banning the use of some plastic products, the use of plastics continues to grow globally. As a result, the pressures being placed on the marine environment by dumped, discarded and lost debris continue to increase (Jambeck et al. 2015). This was reflected in a review of the threat abatement plan for the effects of marine debris on vertebrate marine life (DEWHA 2009a), which concluded that the objectives of the plan had not been met and the plan needed to be revised (DoE 2015b). Impacts on the marine environment associated with marine debris are high, with a deteriorating trend.

Box MAR4 Marine debris

Marine debris is recognised as a globally important pressure in the marine environment, with increasing reports of impacts on marine biodiversity reported during the past 4 decades (Gall & Thompson 2015). Debris entering the marine environment can include consumer items such as glass and plastic bottles, aluminium and metal cans, plastic bags, balloons, rubber, metal, fibreglass, cigarettes, and microbeads included in personal care products. Marine debris can range in size from multitonne fishing nets to microscopic pieces of plastic that have broken down from their original size. Marine debris includes those materials that are transported from the land into coastal environments and the ocean, as well as materials intentionally or unintentionally discarded at sea. It is estimated that more than 6–12 million tonnes of plastic waste enter the oceans each year (Jambeck et al. 2015).

In Australia, marine debris has been identified as a key threatening process for threatened and endangered vertebrate fauna. Around three-quarters of items found on Australian beaches are plastic polymers (Hardesty et al. 2014). Marine debris also has socio-economic impacts: it transports species (introduced or native) and can be a navigation hazard. There are also increasing concerns about the risks to human health, because of the accumulation of pollutants in the tissues of seafood species that have ingested marine debris (Rochman et al. 2015). High but variable concentrations of marine debris are found in all marine environments (Hardesty et al. 2014, Critchell et al. 2015, Critchell & Lambrechts 2016), and it is expected that marine debris will continue to be a ubiquitous problem because of the continued growth in the production and use of plastics.

Key components of the marine environment affected by marine debris

Marine fauna as small as plankton and as large as whales are known to interact with marine debris (Vegter et al. 2014). Entanglement, ingestion and chemical contamination are the 3 main types of interaction (Wilcox et al. 2015). Corals, lugworms, molluscs, commercial fish (Hall et al. 2015, Rochman et al. 2015), seabirds (Acampora et al. 2013, Verlis et al. 2013), sea turtles (Schuyler et al. 2013, Wilcox et al. 2013), sea snakes (Udyawer et al. 2013), pinnipeds (Page et al. 2004, Lawson et al. 2015), dugongs (GBRMPA 2014a), whales (Evans et al. 2002, Hammer et al. 2012) and dolphins (Chatto & Warneke 2000) are all reported to be affected by marine debris. Significant quantities of plastics have been reported in the digestive tracts of several species of marine vertebrates in Australian waters.

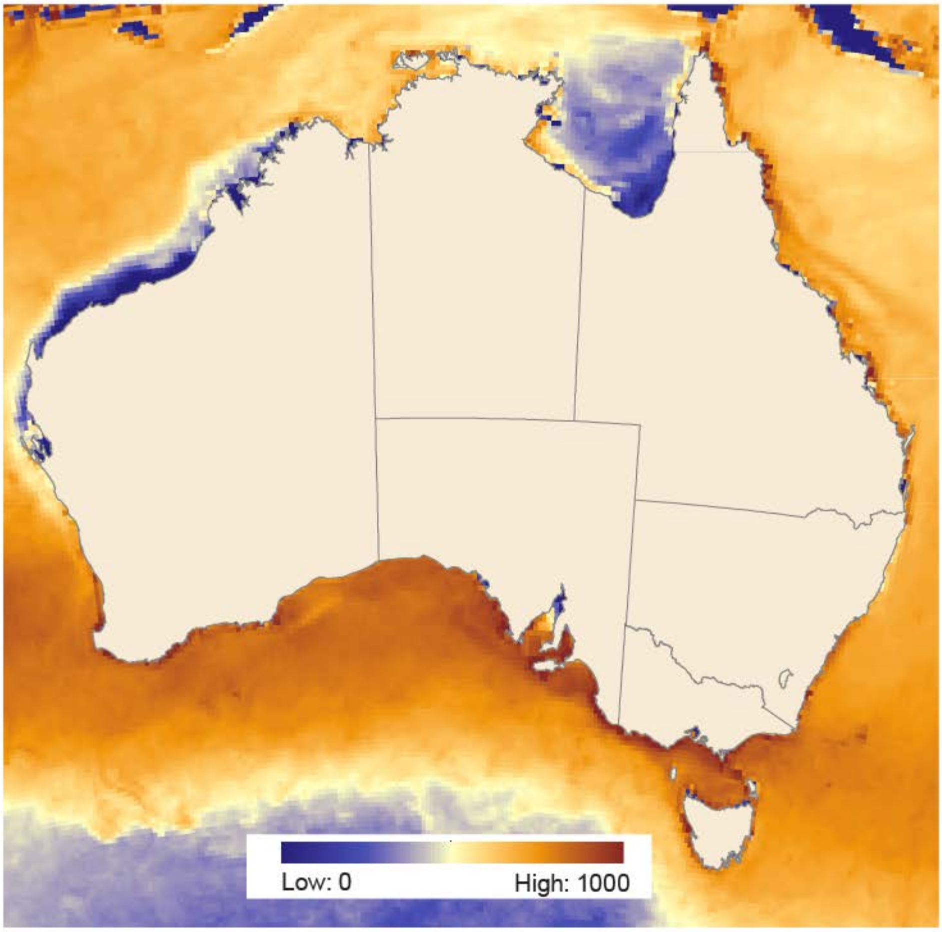
Major uncertainties and knowledge gaps

A recent circumnavigation of Australia during which floating plastics were recorded found concentrations as high as 40,000–80,000 pieces per square kilometre, but more commonly ranging from 1000 to 40,000 pieces per square kilometre. This was the first survey of its kind, and it highlights both the variability of plastics in the marine environment and the lack of consistent, large-scale monitoring (Hardesty et al. 2014). Data from this project have contributed to a global assessment that modelled the distribution of plastics in the marine environment (Figure MAR21). This global assessment identified that, although the waters around Australia contained lower concentrations of small (0.33–1.00 millimetre) items of marine debris, concentrations of larger (more than 1.00 millimetre) items of marine debris in some locations around Australia were comparable to those measured in other parts of the world (Eriksen et al. 2014).

Major uncertainties persist with regard to:

- population-level impacts of marine debris from entanglement of, and ingestion by, marine fauna, including sea turtles, marine mammals, seabirds, and commercially and recreationally caught food fish
- the frequency and potential economic impact of transport of species on marine debris
- changes (or trends) in debris distribution, origins and losses into the environment
- the cost of marine debris to fisheries and small businesses in Australia
- the potential impact of ingested plastics on human health from seafood.

Box MAR4 (continued)



Source: Based on Eriksen et al. (2014)

Figure MAR21 Predicted concentrations of floating debris (more than 200 millimetres in diameter) per square kilometre in Australian waters

Outlook

The amount of debris entering the marine environment is expected to increase, with a corresponding increase in impacts on the marine environment, and an associated increase in socio-economic, environmental, navigation and hazard impacts. Policies are currently under consideration or have been implemented across local council, state and territory, Australian Government, and international jurisdictions that aim to reduce the amount of debris entering the oceans and affecting wildlife (including plastic bag bans, container deposit schemes, and bans on microbeads in personal care products). A sustained, multifaceted approach that involves manufacturing industries, consumers, recycling, infrastructure, litter traps, and coastal and inland clean-up activities, as well as education, outreach and awareness raising, is required to reduce debris in the marine environment.

Toxins, pesticides and herbicides

The group of chemicals typically regarded as pollutants encompasses a large array of compounds, and is generally divided into chemical compounds and metals. Estimates of the number of chemicals produced anthropogenically range as high as 100,000 (Menditto & Turrio-Baldassarri 1999 in Hale & La Guardia 2002, Islam & Tanaka 2004); however, assessments of the toxicity and bioaccumulative nature of these are limited. Most research has included only a few classes of compounds, notably the halogenated hydrocarbons, a limited number of metals, and polyaromatic and non-aromatic hydrocarbons (Reijnders 1994, Hale & La Guardia 2002). Because these compounds resist degradation, and can be transported atmospherically and oceanographically from source points to remote areas, they will continue to persist in the environment, and reach a long-term global equilibrium rather than decline (Iwata et al. 1993, Tanabe et al. 1994). There are also concerns that climate change may be altering contaminant pathways and exposure (Wöhrnschimmel et al. 2013, McKinney et al. 2015).

Most pollutants identified in marine animals are incorporated into tissues via dietary intake, with many accumulating through the food web (Islam & Tanaka 2004). Consequently, animals feeding at high trophic levels tend to have higher tissue concentrations than those feeding at lower trophic levels (Aguilar et al. 1999). Various pollutants have been reported to be associated with deleterious effects on the immune, endocrine and nervous systems of marine animals, disrupting growth, development, sexual differentiation and resistance to disease (e.g. Reijnders 1994, Skaare et al. 2000, Tanabe 2002, Hammer et al. 2012). However, direct associations between contaminants and these effects are few, and most studies lack substantive evidence of sublethal effects because of numerous physiological and environmental confounding factors. This limits the ability to quantify the direct and indirect pressures that pollutants may be exerting on the marine environment.

Coordinated, ongoing monitoring of pollutants in the marine environment outside estuarine and enclosed embayment environments on a national scale is lacking (see further details on coastal river, and estuary and nutrient pollution in the *Coasts* report). Most reporting is ad hoc, and limited to measurements of the concentrations of contaminants in the tissues of various species (e.g. Haynes & Johnson 2000, Evans 2001, Evans et al. 2003, Templeman & Kingsford 2010, Brodie et al. 2012, Weijs et al. 2013) or modelling studies (GBRMPA 2014a). Most pollutant data, particularly from outside the Great Barrier Reef region, are now dated, and contemporary information is required concerning the distribution and impact of pollutants in the marine environment. Several fish species are monitored for concentrations of a small number of metals, polychlorinated biphenyls and other chemicals as part of the Australia New Zealand Food Standards Code (Standard 1.4.1), which produces guidelines on the consumption of these fish. Because of the ad hoc nature of most assessments, establishing trends in the concentrations of pollutants in the marine environment is not possible.

Dumped wastes

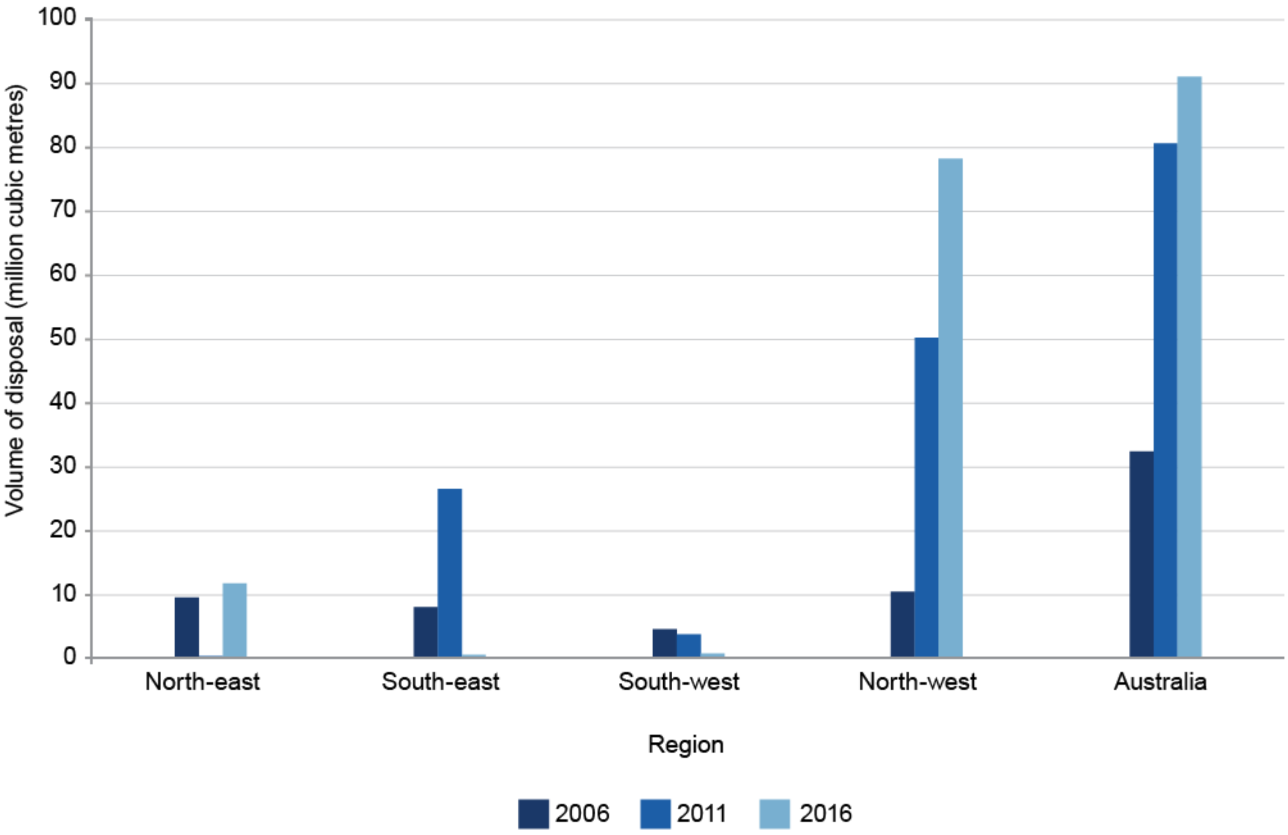
By volume, dredging contributes the largest pressure associated with dumped wastes (not including marine debris, toxins, pesticides and herbicides) on the marine environment. In 2011–15, 90 million cubic metres of sediment from dredging were disposed of in the marine environment (Ports Australia 2014, 2015). Dredging associated with the development or maintenance of port facilities around the coast of Australia is a necessary and unavoidable activity, which is vital to the continuity of the Australian economy (see also pressures associated with dredging, as detailed in the *Coasts* report). Disposal of dredged material is most commonly by placement on the sea floor in specially designated areas.

Pressures arising from this practice include direct burial of biota and less direct impacts arising from resuspension of sediments placed on the sea floor. Although the footprint of disposal sites is relatively small on the scale of Australia's continental shelf, the area affected by remobilised material is potentially larger and less well known (McCook et al. 2015).

The impacts of placing sediment in these areas are closely monitored, and effects in the disposal areas are well documented. Impacts are usually relatively short lived, particularly when sites are in shallower waters, where natural sediment regimes and the organisms that are found within them are generally highly dynamic (Jones 1986, Engler et al. 1991, Harvey et al. 1998, Neil et al. 2003, Bolam et al. 2006). Areas occupied by benthic primary producers, such as seagrass and other macrofauna, are avoided. Fauna likely to be affected are infaunal polychaete worms, molluscs and crustaceans. Most dredging projects report that the impacts detected by their monitoring programs are within expectations and approved levels (Ports Australia 2014, 2015).

The amount of dredged material disposed of at sea in the past 5 years has increased markedly compared with that reported up to 2011 (Figure MAR22). This is largely associated with 2 large port developments in north-western Australia's Pilbara region: Gorgon and Wheatstone. Generally, there appears to have been a strong increase in the volume of dredged material being disposed of in the Pilbara region in the past decade. Project approvals involving dredging and disposal in the region have been granted for 34 million cubic metres at Anketell Port and 42 million cubic metres at Port Hedland. Given the decline in resource development since 2014, this trend may abate in the short term. Additionally, there appears to be an increased willingness on the part of port operators to dispose of dredged material on land for later re-use (potentially driven by national guidelines), which may also reduce impacts on the marine environment.

Statistics relating to the volume of dredged material disposed of at sea annually and the cumulative area footprint of these dredge material placement areas (DMPAs) are not routinely made available. This limits any assessment of the footprint of dredging pressures and how this might be changing over time. It is possible to monitor dredge plumes using satellite imagery; however, these images do not provide information on plumes in subsurface waters, and it is difficult to differentiate between dredge plume and benthic features in shallow, clear water (e.g. Evans et al. 2012). In addition, the processes of resuspension and transport of sediment, particularly fine sediment, placed on the sea floor are



Source: Data from Ports Australia

Figure MAR22 Volume of dredged material disposed of at sea, 2006, 2011 and 2016 relatively uncertain (SKM 2013, McCook et al. 2015). This uncertainty has led to contentious debate about the more general impacts of at-sea placement of dredged material beyond the immediate DMPA footprint. On a national basis, the impacts of dumped wastes on the Australian marine environment are currently considered to be low with an increasing trend, largely driven by disposal of dredged material in specific, limited regions (e.g. the North-west Marine Region).

Additional pressures

Localised, small-scale pressures on the marine environment associated with offshore tourism activities, such as offshore pontoons and cruise vessels (mostly confined to the Great Barrier Reef and the North-west Marine Region), are possibly being exerted on coral reef environments. Boat-based watching or targeted swimming activities focused on species such as whale sharks *(Rhincodon typus)* and minke whales *(Balaenoptera acutorostrata)* may also place pressures on the marine environment. Trials of a tourism operation focused on swimming activities with humpback whales (*Megaptera novaeangliae*) in the Ningaloo region, similar to that already occurring with whale sharks, occurred in the winter season of 2016. Most activities are highly managed, and any impacts are assumed to be minor and short lived, although pressures on these environments and species—particularly those that are long term and chronic in nature—are largely unknown. A comprehensive assessment of the pressures associated with tourism is provided in the *Coasts* report; those associated with the Great Barrier Reef are addressed in the *Great Barrier Reef outlook report 2014* (GBRMPA 2014a).

The cumulative pressures of natural variation, human activity and climate change are impacting marine communities and modifying habitats

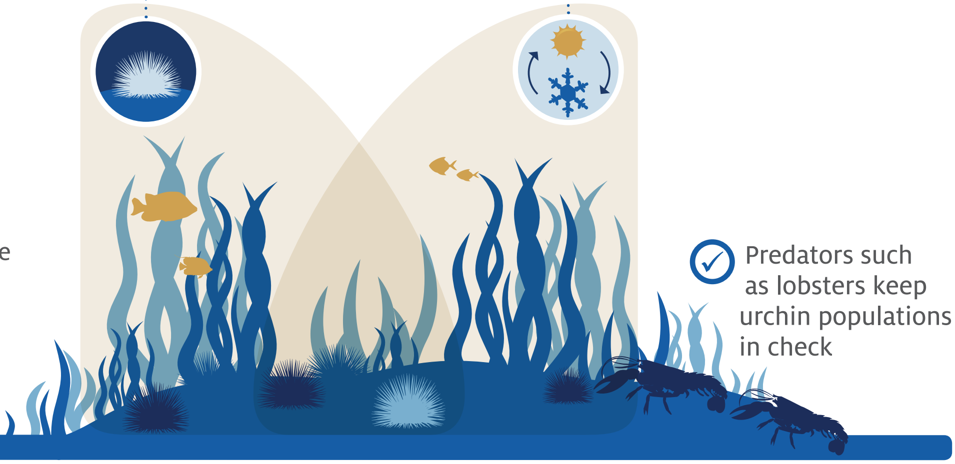
Natural pressures on kelp forests include:

plant-eaters such as urchins ...

... and seasonal and longer climate cycles such as ENSO that temporarily cause warmer water conditions

Kelp is a macroalga that grows in cool, shallow sea water

- Kelp provides important habitat and food for many marine species in temperate environments
- Kelp is beach harvested for human consumption and other products (e.g. pharmaceuticals)

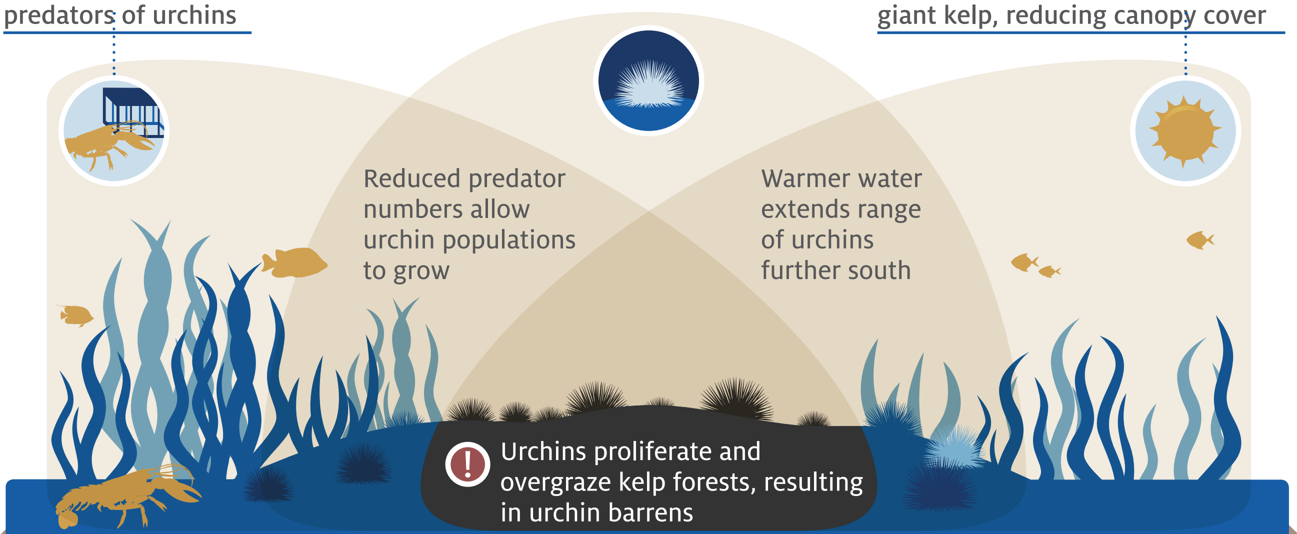


Predators such as lobsters keep urchin populations in check

Human activity, such as fishing, and climate change exacerbate natural pressures, causing a reduction in the extent of giant kelp forests.

Fishing reduces abundance of natural predators of urchins

Warmer, less nutrient-rich waters reduce the growth and survival of giant kelp, reducing canopy cover



Giant kelp forests across southern Australia were the first marine community to be listed as threatened under the EPBC Act in 2012.

School of Moorish idols, Lord Howe Island Marine Park, New South Wales
Photo by Reef Life Survey

Assessment summary 1
Pressures affecting the marine environment

Component	Summary	Assessment grade: Very high impact	High impact	Low impact	Very low impact	Confidence: In grade	In trend	Comparability: To 2011 assessment
Climate and system variability	How climate variability across multiple timescales will be affected by climate change is poorly understood			?		●	●	X
Climate change—sea temperature	Ocean warming and extreme events will continue to significantly impact and stress marine ecosystems		↙			●	●	⬙
Climate change—ocean acidification	Ocean acidification will have widespread impacts across marine ecosystems. The state and trend are for open-ocean surface water only		↙			●	●	⬙
Climate change—ocean currents and eddies	The boundary currents are highly variable because of changes in the large-scale ocean gyre circulation and major climate drivers		↙			●	●	⬙
Climate change—nutrient supply and cycling	Improved understanding of the relative role of key physical drivers is needed, and better understanding of recent trends is required for future projection assessments		?			◒	○	◇
Climate change—ocean salinity	Spatially highly variable; mean surface salinity patterns have intensified during the past 50 years			↙		●	●	◇
Climate change—dissolved oxygen and oxygen minimum zones	Observed changes are few in open-ocean environments, and there are currently insufficient temporal data to assess trends. Based on model projections, dissolved oxygen is expected to decline			?		◒	○	⬙
Commercial fishing	Many pressures have been reduced through management. However, some significant pressures still exist for several target and bycatch species, and several species and habitats are not recovering from past pressures			↗		●	●	◇

Assessment summary 1 (continued)

Component	Summary	Assessment grade: Very high impact	High impact	Low impact	Very low impact	Confidence: In grade	In trend	Comparability: To 2011 assessment
Recreational fishing	Pressure from recreational fishing is substantial for specific species. Trends, however, are variable across marine regions		—					
Traditional use of marine resources	Traditional use is generally considered localised and sustainable, but future effective monitoring is required for quantifying trend			?				
Oil and gas exploration and production	Pressures remain localised, with the greatest activity occurring in the North-west and South-east marine regions. Exploration activity in the Great Australian Bight is increasing			↗				
Marine mining and industry	Sea-floor modification is localised. More regional environmental pressures are likely to be associated with disturbed sediments	Not assessesed						X
Marine renewable energy generation	Industry-scale deployments are sparse, with few quantitative data on environmental pressures. Pressures are likely localised				?			
Marine vessel activity	Vessel activity is continuing to increase in all regions, resulting in a range of increased risks			?				
Anthropogenic noise	Monitoring is currently spatially and temporally limited, although data now exist to quantify noise. Pressures are mostly localised, although some sources can have large spatial and temporal footprints		?					X
Marine debris	Increasing losses of debris into the marine environment are expected to continue, with a corresponding increase in impacts on marine fauna, and associated socio-economic, environmental, navigation and hazard impacts		↙					

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
Toxins, pesticides and herbicides	Very little is known about levels of toxins, pesticides and herbicides outside coastal regions and the Great Barrier Reef. Impacts are assumed to be low	?			
Dumped wastes	The state of coastal sea-floor habitats is good, although the potential for cumulative impacts is increasing, and these impacts are possibly evident in localised areas	↙			

Recent trends

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

Grades

- **Very low impact:** There are few or negligible impacts from this pressure, and accepted projections indicate that future impacts on the marine environment are likely to be negligible
- **Low impact:** There are minor impacts from this pressure in some areas, and accepted projections indicate that future impacts on the marine environment are likely to occur, but will be localised
- **High impact:** The current environmental impacts from this pressure are significantly affecting the values of the region, and projections indicate serious environmental degradation in the marine environment within 50 years if the pressure is not addressed
- **Very high impact:** The current environmental impacts from this pressure are widespread, irreversibly affecting the marine environment, and projections indicate widespread and serious environmental degradation in the marine environment within 10 years if the pressure is not addressed

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 marine environment

At a glance

Reporting on the current state and recent trends of the biological and ecological components of the marine environment is highly variable across Australia's marine estate, and is often inadequate for robust assessment. There are few coordinated, sustained monitoring programs at the national level for the marine environment, and most monitoring is restricted to fisheries assessments and short-term programs in localised regions. Reporting also varies in terms of spatial and temporal coverage, parameters measured, methods used and key indicators. This results in varying certainty in the state and trends reported for the state of the environment (SoE) assessment.

Generally, habitats and communities in the Temperate East and the South-east marine regions have been subject to higher historical impacts, such as bottom-trawling impacts on shelf and slope communities, than those in other regions. The condition of habitats and communities in the Great Barrier Reef to the end of 2015 is considered to range from poor and deteriorating (corals) to good and stable (macroalgae, offshore banks and shoals). Large canopy-forming seaweeds are still prevalent in many locations around Australia, but increased water temperatures and range extension by the sea urchin *Centrostephanus rodgersii* in south-eastern Australia have led to the loss and overgrazing of kelp beds in temperate rocky reefs, resulting in a poor and deteriorating state and trend for this habitat. Giant kelp forests of south-eastern Australia were the first marine community to be listed as a threatened ecological community under the *Environment Protection and Biodiversity Conservation Act 1999* in 2012.

Most species groups assessed are regarded to be in good condition overall, although information is lacking to assess the condition or trend of many species and species groups because they are not regularly monitored, if at all. Trends are stable or improving for most fish species, except inner shelf reef species, which are highly spatially variable—some are in good condition and stable, whereas others are in poor condition and deteriorating. Shelf demersal and benthopelagic fish species, while in poor condition, are considered as generally improving, with a few exceptions. Some species have improved from past declines (e.g. long-nosed fur seals, southern Great Barrier Reef green turtles, humpback whales, the eastern stock of orange roughy), and others are currently stable (e.g. mesopelagic and epipelagic fish species, shy albatross). Some species have declined because of cumulative impacts associated with high mortality from bycatch within fisheries, impacts associated with coastal nesting/breeding sites and climate change (e.g. flesh-footed shearwater, Australian sea lion, north Queensland hawksbill turtle, some demersal shark species).

Overall, the state of components of the marine environment identified in SoE 2011 as providing biophysical and ecological indicators of marine health shows the marine environment to be in good condition in 2016, although several indicators are highly spatially and temporally variable, and determining trends is difficult. Overall, on a national scale, water column turbidity in open-water environments has decreased; this is largely the result of improved wastewater treatment, reduced nutrient inputs, and improved management of agricultural practices and associated run-off. Observed reductions in primary and secondary productivity are considered to be associated with reduced nutrient supply because of ocean warming. Changes to ocean currents have affected connectivity within marine ecosystems, as observed through shifts in species distributions, especially in south-eastern Australia. There has been trophic (food chain) restructuring of some ecosystems as a result of commercial and recreational fishing, pollution, introduction of foreign species, and habitat modification. Some of these impacts are irreversible, but the effects are generally unknown. Introduced species, blooms and infestations of jellyfish and algae, diseases, and animal kills appear to be stable, whereas trends in crown-of-thorns starfish outbreaks are unclear.

Australia's marine environment encompasses the seabed; the water column; physical, biogeochemical and ecological processes that play an important role in shaping the marine environment; and habitats, communities and species groups, which all interact in highly complex ways.

The current state and trends of these components result from past and present pressures placed on them, their resilience (see Resilience of the marine environment for the definition of resilience used in this report), adaptation to the pressures, and any mitigating management frameworks.

Reporting on the current state and recent trends of Australia's marine environment is highly variable, because the extent of available information differs across Australia's marine estate. There are few coordinated, sustained biological monitoring programs at the national level for the marine environment, and most monitoring is restricted to fisheries assessments and short-term programs in localised regions. Information from such monitoring programs will therefore only reflect the state and trends of the marine environment at that site, and is unlikely to be indicative of larger regions. Reporting varies in terms of spatial and temporal coverage, parameters measured, methods used and key indicators. This results in varying certainty in the state and trends reported for the SoE assessment.

Several important exceptions to overall monitoring of the marine environment are highlighted here and detailed further in Sustained ocean monitoring. The IMOS National Reference Stations build on historical sampling for temperature, salinity and nutrients, and also provide observations of dissolved oxygen, carbon, turbidity, currents, chlorophyll a, phytoplankton and zooplankton at 7 key locations (originally 9) around the nation's shelves (see Lynch et al. 2014). The IMOS national facilities provide sustained coverage of benthic communities, zooplankton and midwater pelagic fish. The Reef Life Survey brings together scientists, managers and citizen scientists across Australia to monitor shallow reef biodiversity (see Box MAR5). The Long-term Temperate Marine Protected Areas Monitoring Program and the Australian Institute of Marine Science have also been monitoring shallow reef locations across southern Australia and along the Great Barrier Reef, respectively, for more than 20 years. Some outputs from these programs are now integrated, encompassing 15 regions Australia-wide.

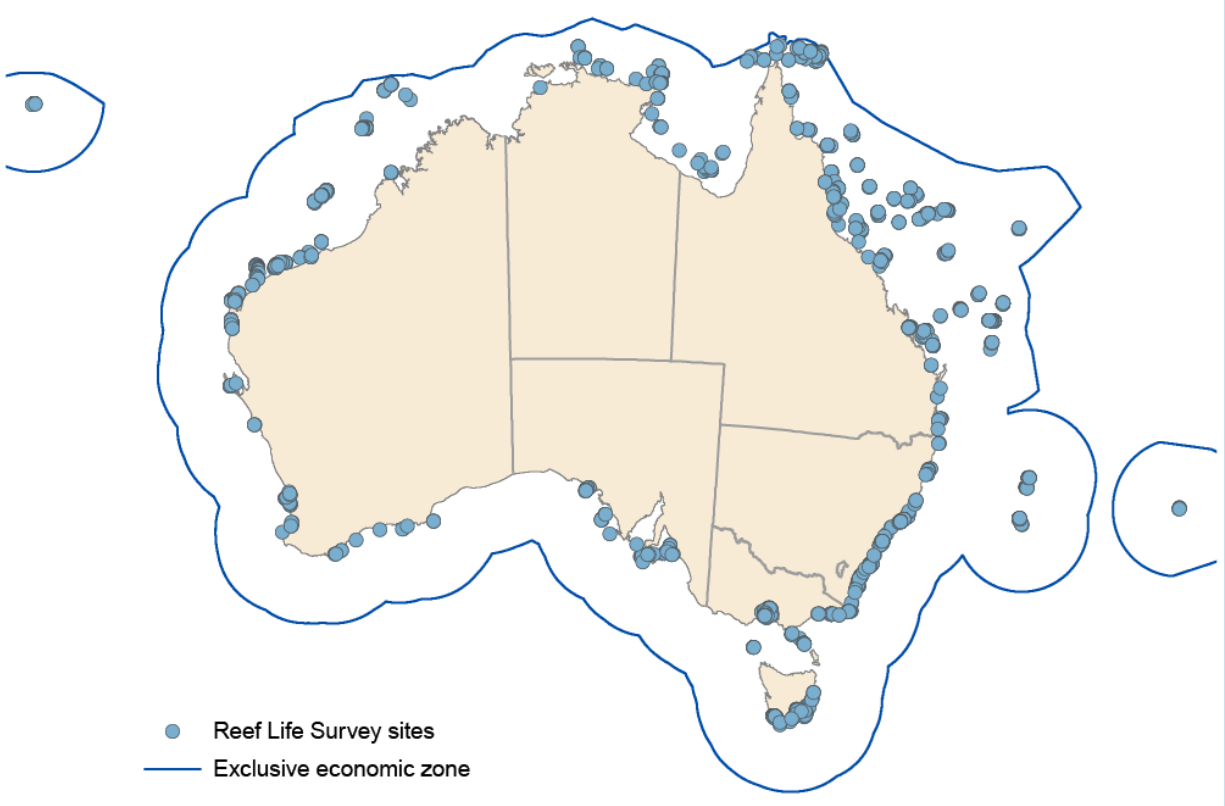
The following section summarises expert-led assessments of marine habitats, communities and species groups; and physical, biogeochemical, biological and ecological processes in the marine environment for each marine region, using the format established in SoE 2011 (see also Approach). Many of the assessments draw on information from monitoring programs across jurisdictions, but also highlight the knowledge gaps for many components of the marine environment and the uncertainties associated with the information collected to date. For most components (habitats, communities and species groups), current state and recent trends have been summarised at the marine region level. However, direct comparisons between marine regions at the summary level are not made because of the varying spatial and temporal coverage of datasets between regions; the varying certainty for assessments undertaken; and inconsistencies in the variables measured, methods used and analyses undertaken in the monitoring of many habitats, communities, species groups, and physical, chemical, biological and ecological processes. For example, although 713 canyons have been mapped across Australia's continental margin, information on the state of benthic communities that occupy these features has only been collected for a select few (see Kloser et al. 2014). Direct comparisons of the state of canyons across marine regions is not possible without making large assumptions about the state of canyons that have no information available. Detailed information on the state and trends of habitats, communities and species groups within the Great Barrier Reef Marine Park is in GBRMPA (2014a). Available regional updates are provided in the introductory text for each of the subsections in this part of the report, or in the case studies.

Box MAR5 National assessment of shallow reefs

The Reef Life Survey, supported by the Australian Government's National Environmental Science Programme, is using standardised monitoring methodology to provide a national assessment of shallow rocky and coral reef biodiversity (in waters less than 25 metres deep) around Australia's coasts, and at offshore islands and reef systems (Figure MAR23). The survey gathers information on reef fishes; large mobile invertebrates such as sea urchins, crown-of-thorns starfish, lobsters and abalone; and habitat-forming seaweeds and corals. Results from the Australian surveys are directly comparable with global reef surveys conducted by the same organisation.

Current state of Australia's shallow reefs

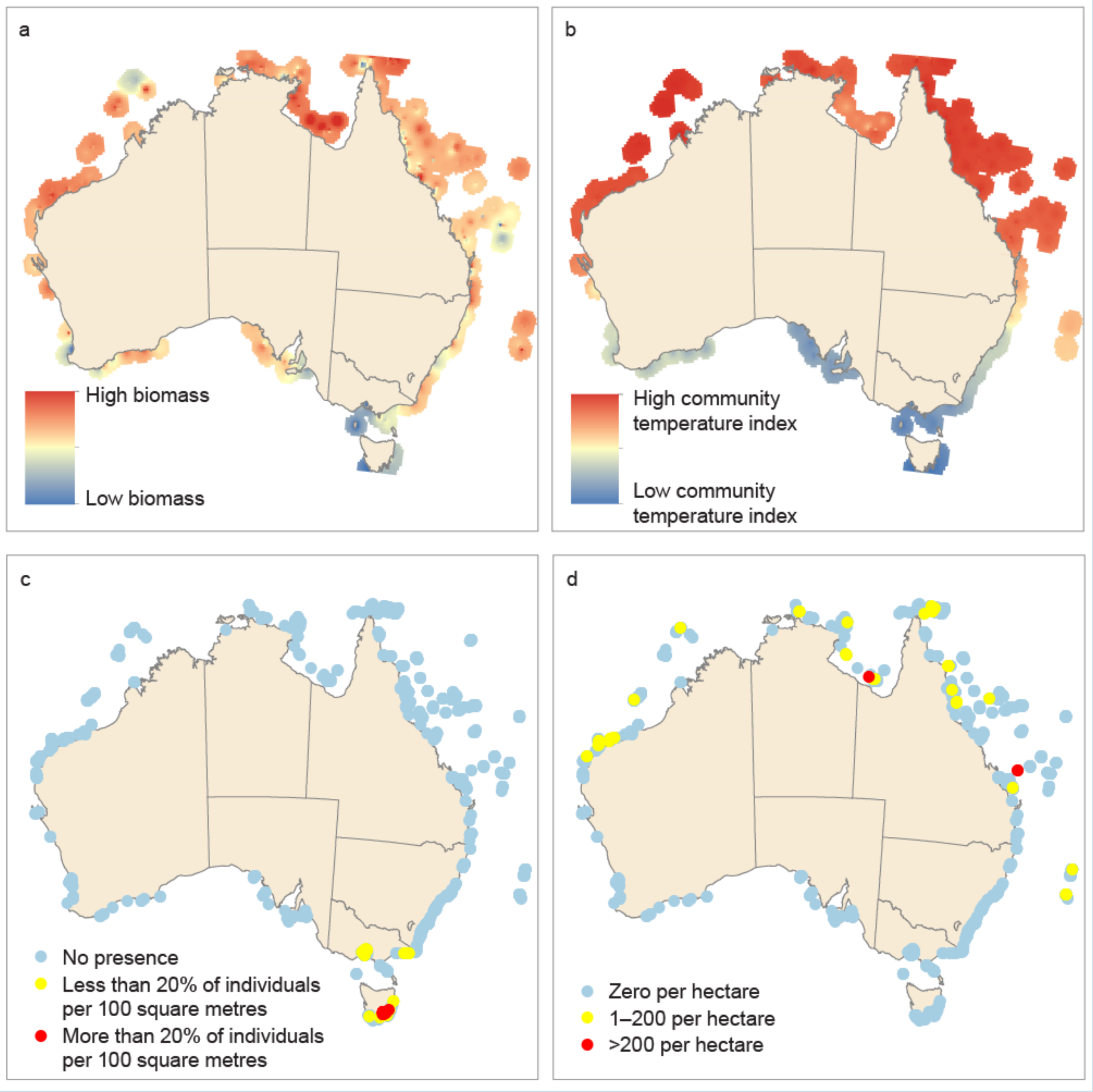
Australia's shallow reefs are in good condition compared with those in many other countries, but substantial pressures have meant that the condition of many is deteriorating. Large areas of some iconic reefs, such as Ningaloo Reef and the Great Barrier Reef, have suffered from loss of coral habitat and predatory reef fishes because of human and environmental pressures since 2011 (Figure MAR24).



Source: Reef Life Survey

Figure MAR23 Reef Life Survey sites surveyed, 2010–15

Box MAR5 (continued)



Source: Reef Life Survey

Figure MAR24 Distribution of reef biodiversity indicator values for coral and rocky reefs surveyed by the Reef Life Survey around Australia, 2010–15: a) biomass of large fishes more than 20 centimetres in length (an indicator of fishing impacts); b) community temperature index (baseline to assess temperature-related ecosystem change); c) proportion of the surveyed mobile fauna on the substrate that are introduced species; d) density of crown-of-thorns starfish

Box MAR5 (continued)

Pressures from recreational and commercial fisheries are particularly important for larger fish species and lobsters (e.g. Frisch et al. 2012, GBRMPA 2014a), whereas ocean warming is having widespread impacts on the composition of communities in temperate zones. The 2011 marine heatwave in Western Australia had a large impact on shallow-water reef biodiversity, with widespread coral bleaching in the North-west Marine Region, and loss of kelp habitats and changing fish communities in the South-west Marine Region (Pearce et al. 2011, Wernberg et al. 2016).

Cyclones and storms have also had substantial impacts on coral communities at Ningaloo Reef and parts of the Great Barrier Reef. Coral structures of the inner Great Barrier Reef have been adversely affected by siltation and nutrification. The impacts of crown-of-thorns starfish populations are variable across coral reefs. Introduced species and heavy metal pollution have had serious impacts on the rocky reefs of the Derwent Estuary in Tasmania and, to a lesser degree, in Port Phillip Bay, Victoria. There are healthy populations of large reef fishes at offshore and remote northern locations (see also Quality of habitats and communities and Species groups).

Marine protected areas (MPAs), fishery regulations, and improved catchment and waste management practices are the main management measures currently in place. Since 2011, more MPAs have been established across Australia's marine estate, and management plans for these have been implemented, particularly in South Australia (see also Environment protection systems). Management associated with established MPAs is having positive effects in these areas. Improved regulations for many reef fisheries have been enacted. Nutrient inputs to the inshore environment are mostly declining because of sewerage infrastructure upgrades and improved catchment practices, although there have been localised increased loadings of nutrients associated with rapid expansion of fish farms in Tasmania (also see GBRMPA [2014a] for details about the impacts of nutrients on the Great Barrier Reef).

Accelerating deterioration is likely unless regulation of recreational fisheries improves. Storms, cyclones and mass coral bleaching events are less predictable, but increases in intensity (cyclones) and frequency (bleaching) are expected under many climate change scenarios.

How a national assessment can help track reef condition

Survey observations are now providing a comprehensive baseline for accurately assessing the spatial distribution of future trends. Establishment of national trends in changing patterns of inshore marine biodiversity will be facilitated through further roll-out of Reef Life Survey locations and the collection of longer timeseries in these locations.

Southern right whale *(Eubalaena australis)*, with calf in the Great Australian Bight Marine Park, South Australia

Photo by Georgina Steytler

State and trends of marine biodiversity

Quality of habitats and communities

Eighteen habitats and communities, ranging from the nearshore to the abyss, and from the seabed to the water column, were assessed for their current state and recent trends. Habitats and communities were assessed across 4 spatial regions associated with defined depths of the total water column recognised as representing distinct faunal compositions:

- the inner shelf environment (0–25 metres in depth)
- the outer shelf environment (25–250 metres)
- the slope environment (250–700 metres)
- the abyss environment (more than 700 metres).

It should be noted that not all regions around Australia include all depth ranges. For example, the North Marine Region does not have any areas with a sea floor deeper than 700 metres.

Generally, habitats and communities in the Temperate East and South-east marine regions were reported to be subject to higher historical impacts than in other regions, such as those associated with fishing by bottom trawlers on shelf and slope communities (Pitcher et al. 2016b). Condition of habitats and communities in the Great Barrier Reef ranges from poor and deteriorating (coral) to good and stable (macroalgae, offshore banks and shoals), with high spatial variability in the state and trends of habitats and communities. Overall, average coral cover across reefs within the Great Barrier Reef system declined from 28 per cent in 1986 to 13.8 per cent in 2012 (Figure MAR25), mainly because of consecutive cyclones and outbreaks of crown-of-thorns starfish[6] (see State and trends of indicators of marine ecosystem health), with those in the south declining most severely. More recent surveys of the Great Barrier Reef have reported both increases and decreases in coral cover, with trends highly variable across sites monitored. High rainfall in 2010, 2011 and 2012 was observed to result in localised increases in nutrient inputs and phytoplankton community biomass in the Great Barrier Reef lagoon (Thompson et al. 2015a, 2016). An extensive survey of the Great Barrier Reef and the reefs of the north-west was carried out in the first half of 2016. This recorded widespread and extensive bleaching of coral reefs, particularly in the north-east, as a result of high water temperatures associated with overall increasing water temperatures (see Ocean temperature) and an extreme El Niño event (Figure MAR26). Consequently, the overall condition of habitats and communities may differ from that reported in GBRMPA (2014a). Further detail on the state and trends of habitats and communities in the Great Barrier Reef is provided in GBRMPA (2014a).

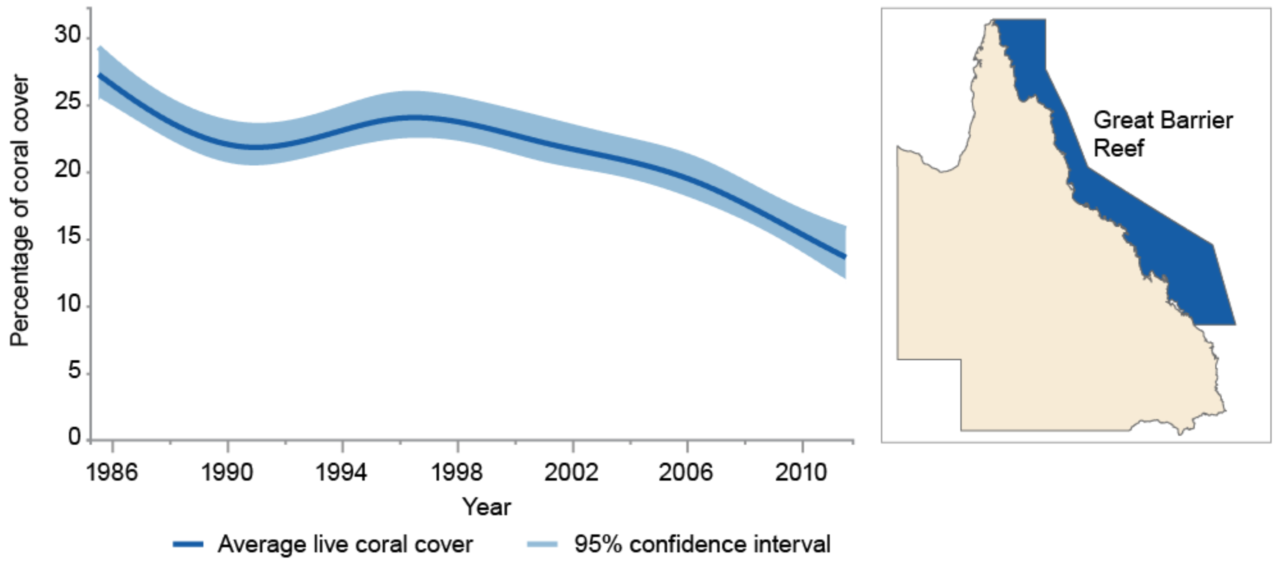
North Marine Region

The relatively lower use of the marine environment and the remoteness of much of the North Marine Region mean that habitats and communities across this area are assumed to be in very good condition, although very few data exist from the region, and there are few long-term datasets that can be used to determine trends. Knowledge of the state of seabed habitats in the region is largely limited to the outer shelf regions of the Gulf of Carpentaria (e.g. Bustamante et al. 2011), Torres Strait (e.g. Pitcher et al. 2007b), and the carbonate banks and terraces of Van Diemen Rise (Przeslawski et al. 2014).

A recent voyage of discovery in the western parts of the Oceanic Shoals Commonwealth Marine Reserve established baselines for midwater species assemblages and sea-floor communities of carbonate banks, terraces and pinnacles within the reserve. The reserve has been identified as a hotspot for sponges, with more species and communities found within the reserve than in surrounding sea-floor areas. A total of 57 new species for the region, 7 new species for Australia and 13 new species for the Indo–Pacific region were recorded during the survey, including several species that are identified by the IUCN as vulnerable, near threatened and endangered.

Mapping of prawn trawl operations across the region (Pitcher et al. 2007b) suggests that seabed communities of sponges and corals appear to be mostly unaffected by domestic fishing operations, largely because such mapping analyses place most sponge and coral communities in areas that do not overlap with trawl fisheries. However, this is yet to be verified by in situ studies, including more recent assessments of trawling operations and consideration of historical trawling by

6 Animals of the phylum Echinodermata are seastars, rather than starfish; the common name 'crown-of-thorns starfish' is used in this report because it is currently more widely recognised, although this terminology is slowly changing to 'crown-of-thorns seastar'.



Note: The solid line represents modelled coral cover based on analysis of data collected from 214 reefs across the region.
Source: De'ath et al. (2012)

Figure MAR25 Great Barrier Reef hard coral cover, 1986–2012

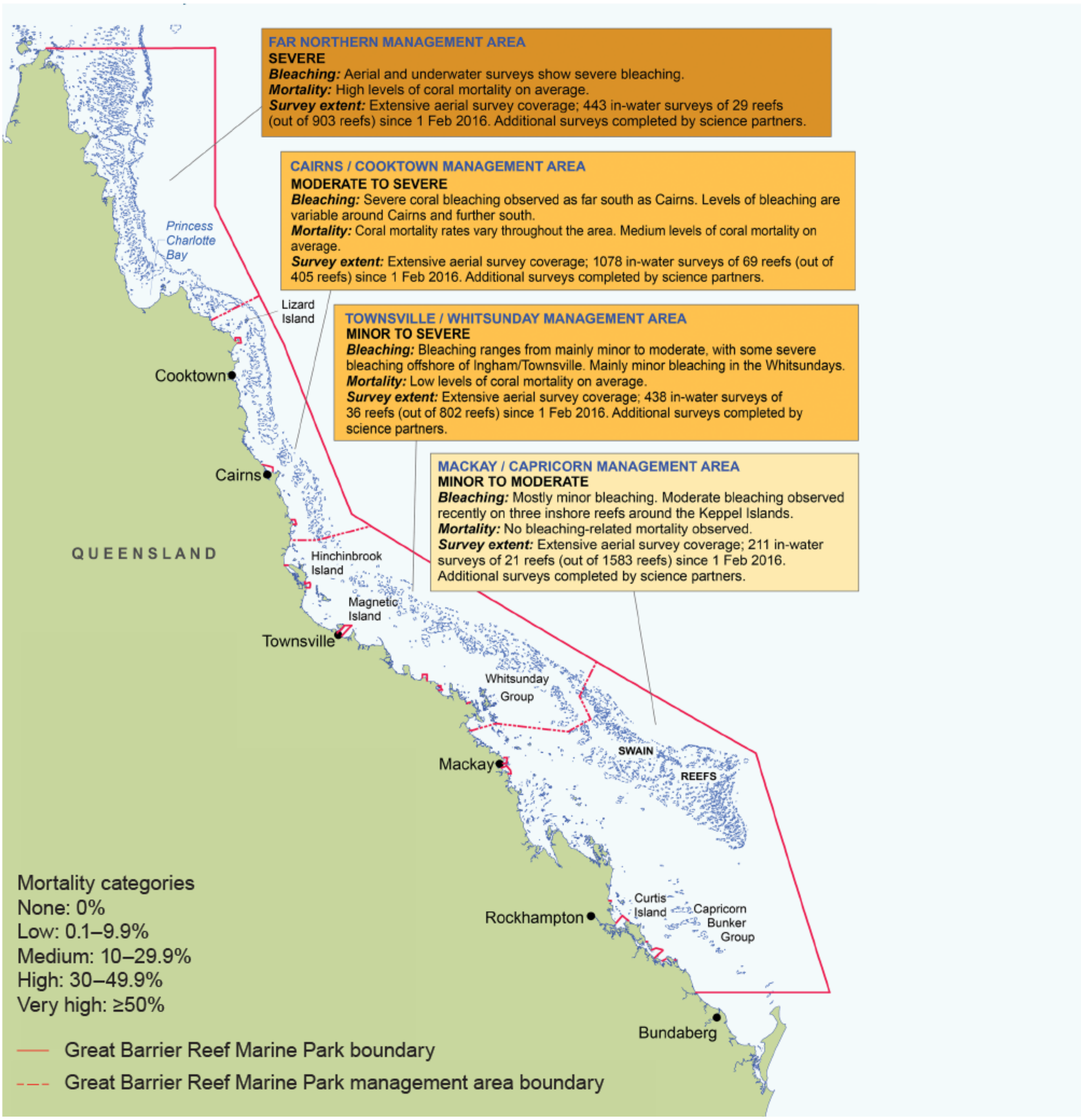
foreign vessels through the region. The trawling footprint across the marine region is estimated to be less than 15 per cent of the total area of the marine region, and the swept area within the footprint (as a measure of the intensity of trawling) is estimated to be less than 20 per cent (see Box MAR2).

Observations of reefs collected to date by the Reef Life Survey suggest that offshore reefs are in good condition (see Box MAR5), although trends are unclear. Above average rainfall across much of northern Australia in 2011, 2014 and 2015 introduced higher nutrient loads into the water column, with mixed responses by plankton communities, as measured by the IMOS National Reference Station at Darwin. Monitoring from this station suggests that communities are stable, but the highly variable nature of community biomass results in unclear trends in populations (see also State and trends of indicators of marine ecosystem health).

Coral Sea Marine Region

The habitats and communities of the Coral Sea Marine Region are generally assumed to be in very good condition, largely because of the offshore nature of the marine region. Information on habitats and communities throughout the region is largely lacking, with most information available relating to offshore coral reefs and shoals. Less is known about slope, abyss, canyon and seamount habitats and communities (see Ceccarelli et al. 2013). Surveys of offshore reefs have observed that damage from cyclones and coral bleaching characterises most of the central and northern Coral Sea reefs, but those in the south of the Coral Sea appear in very good state (albeit with some evidence of fishing impacts; see Box MAR5). Reefs in the Coral Sea protected from fishing in the former Coringa–Herald and Lihou Reef national nature reserves are showing signs of recovering fish populations (Edgar et al. 2015), and Elizabeth and Middleton reefs have fish communities that are considered to be in good condition by global standards (Edgar et al. 2014). Above average rainfall has occurred in the region in several years since 2011, although consequences for habitats and communities are unknown.

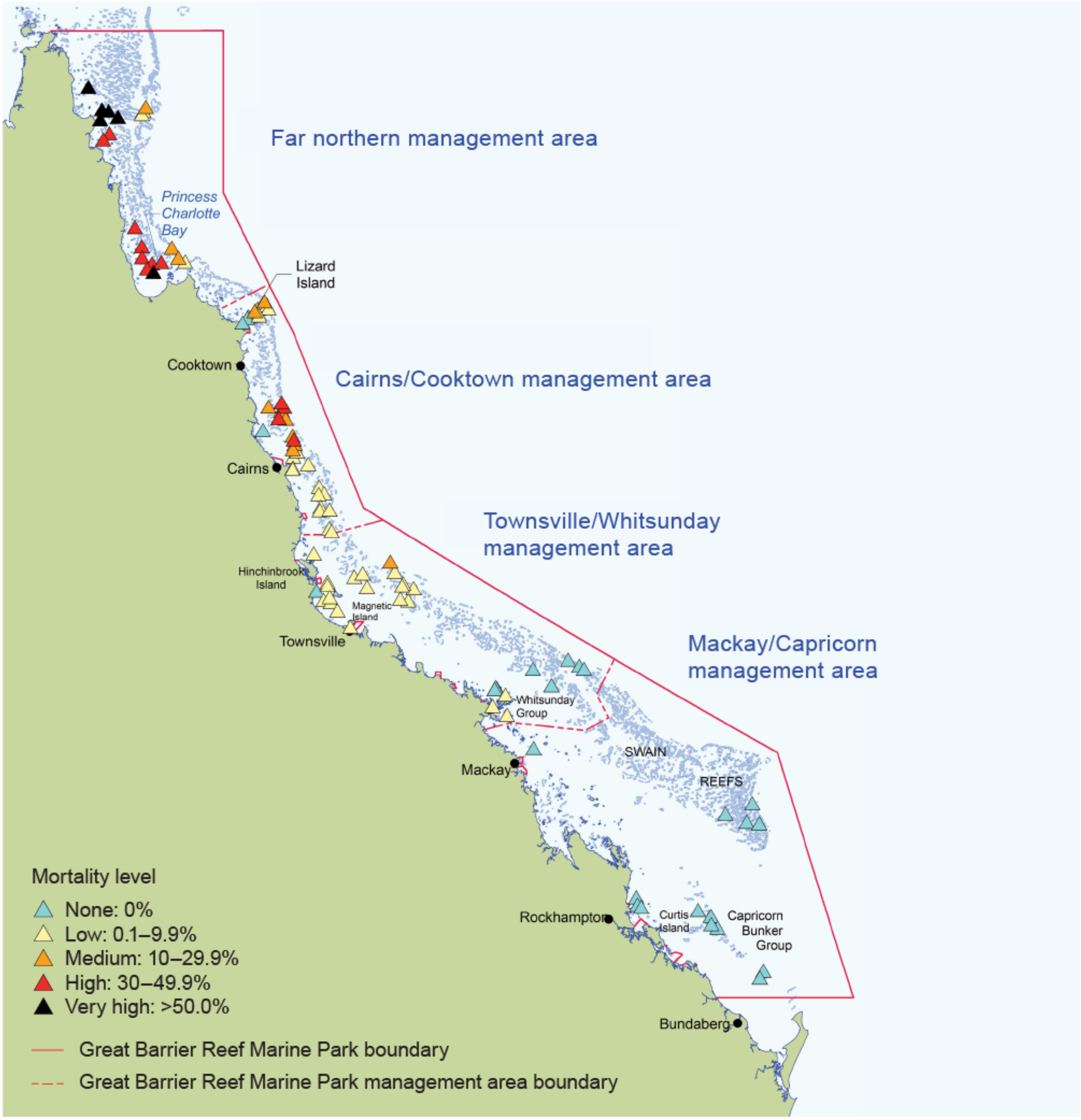
a



Source: Coral bleaching, Great Barrier Reef Marine Park Authority, used under CC BY 3.0

Figure MAR26a State of coral bleaching of the Great Barrier Reef associated with climate extremes, 2015–16

b



Note: Data are based on the latest surveys conducted between 1 March 2016 and 3 June 2016. Since surveys were last conducted around Lizard Island, further mortality has been reported on reefs at this location. Initial estimates indicate mortality levels are likely to have increased.
Source: Coral mortality, Great Barrier Reef Marine Park Authority, used under CC BY 3.0

Figure MAR26b State of coral mortality of the Great Barrier Reef associated with climate extremes, 2015–16

Temperate East Marine Region

The outer shelf and upper slope of the Temperate East Marine Region are important areas for commercial fishing—operations that have occurred throughout the marine region for more than 100 years. Seabed communities are particularly affected by bottom trawling, which has been estimated to have a footprint of 30–40 per cent of the shelf area and less than 20 per cent across the slope (see Box MAR2). Within the footprint area on the shelf, the swept area is estimated to range from approximately 80 per cent in the north to 20–60 per cent in the central and south parts of the region. On the slope, the swept area is estimated to be less than 30 per cent.

Modelling suggests that gorgonians, bryozoans, *Solenosmilia* spp., sponges, soft corals and some other cnidarians have been reduced by approximately 10–20 per cent from their untrawled status, and several other seabed species groups have been reduced by 5–10 per cent (Pitcher et al. 2015). Decreasing fishing effort in the past decade has led to a declining trawling footprint, which has reduced the impacts on these communities. Fishery closures and marine reserves offer additional protection for seabed communities. The lack of observational data on the distributions of sponges and corals throughout the Temperate East Marine Region restricts any assessment of ongoing impacts and recovery from past impacts.

The large, brown, canopy-forming algal species *Phyllospora comosa* has disappeared from around 70 kilometres of coastline around Sydney (Coleman et al. 2008). This is likely to be from the effects of water pollution. Although the lack of early baseline data precludes a definitive understanding of the causes of sea urchin *Centrostephanus rodgersii* barrens (where increasing urchin populations have overgrazed kelp beds) throughout the marine region, it is likely that historical reductions in the abundance of urchin predators such as blue groper and eastern rock lobsters may be partly responsible. Urchin barrens have been estimated to extend through more than 50 per cent of algal bed habitat along the central and southern coasts of New South Wales, but with considerable site variability (Andrew & O'Neill 2000).

Seabed habitats and communities are also affected by anchoring of container and bulk-carrier vessels in the marine region, which scours the sea floor. Vessel activity across Australia is currently increasing, with associated impacts also likely to be increasing (Davis et al. 2014; see also Box MAR3 and Marine vessel activity).

Knowledge of taxa contributing to upper slope benthic communities is largely limited to the Lord Howe and Norfolk Ridge area (see Williams et al. 2011, Harris et al. 2012). Information on the outer shelf and abyss is lacking, although a survey of abyssal depths off Australia is scheduled for 2017. Above average rainfall and river run-off during 2011 supplied much of the east coast of Australia with above average sediment and nutrient loads, but the consequences for pelagic habitats and their communities are largely unquantified.

South-east Marine Region

Similarly to the Temperate East Marine Region, the outer shelf and upper slope of the South-east Marine Region are important areas for commercial fishing. Bass Strait also contains relatively high concentrations of activities associated with oil exploration and production (see Marine oil and gas exploration and production). Both activities have affected seabed communities across the region, with impacts around oil platforms considered to be largely localised around the platforms themselves, although no coordinated ongoing monitoring of benthic communities is currently occurring. Commercial fishing activity has been identified as a key human activity affecting bryozoan reefs, and deep shelf coral and sponge communities (see Box MAR2).

The footprint of trawling across shelf areas throughout the marine region has been estimated to range from 25 per cent in the east to less than 5 per cent in the west. On the slope, it is estimated to be as high as 40 per cent. This highlights the spatial variability in historical impacts on seabed communities and their current state. Within the footprint area on the shelf, the swept area is estimated to range from approximately 40 per cent in the east to less than 10 per cent throughout parts of Bass Strait. In slope regions, the swept area within the footprint ranges from approximately 50 per cent to approximately 80 per cent in western areas of the region. Although fishery closures and the introduction of marine reserves are reducing ongoing impacts on these communities, recovery of habitat-forming biota on the outer shelf and upper slope is predicted to be very slow (Williams et al. 2012).

Limited data regarding benthic habitats and their condition are available for Australian seamounts outside the Tasmanian seamounts cluster. Within this cluster, all seamounts with peaks at depths less than approximately 1100 metres have been subject to bottom trawling (Koslow et al. 2000, Althaus et al. 2009). Although fishery closures and the implementation of marine reserves have permanently excluded bottom trawling from most seamounts in the region, recovery from past trawling is expected to be slow. Seamounts subject to bottom trawling have shown no change consistent with recovery in faunal assemblages across periods of 10 years (Williams et al. 2010b).

Large canopy-forming seaweeds are still prevalent in many locations throughout the marine region, but range extension by the urchin *Centrostephanus rodgersii*, particularly in eastern parts of the region, has led to overgrazing of kelp beds in temperate rocky reefs where populations of the urchin occur. This has had substantial impacts on natural habitats (Ling 2008, Ling et al. 2015). Further loss of kelp beds may be avoided and recovery of some grazed areas may be possible if populations of urchin predators such as lobsters and large fish are allowed to increase. In Tasmania, significant warming of ocean waters in the past 30 years has resulted in the loss of more than 90 per cent of cover of *Macrocystis* spp. on the east coast (Johnson et al. 2011). This loss of extensive beds of a major habitat-forming species has resulted in giant kelp forests of south-eastern Australia being listed as a threatened ecological community under the EPBC Act. Long-term, localised impacts of nutrients from major urban centres throughout the marine region have reduced *Ecklonia* cover, and changed algal communities from a canopy-dominated state to a turf (Gorman et al. 2009).

Introduced species are preying on native invertebrates, including commercial species (e.g. the Northern Pacific starfish, *Asterias amurensis*; Ross et al. 2003), and altering seabed habitats and communities (e.g. the New Zealand screw shell, *Maoricolpus roseus*; Reid 2010). Increased inshore aquaculture can introduce higher nutrient loads into the inner shelf water column, affecting macroalgal assemblages up to 100–400 metres from farms (Oh et al. 2015; see also the *Coasts* report).

Information on habitats in abyssal regions is largely restricted to geomorphic features in the southern Tasmanian area. Most areas surveyed contain relatively high abundances of habitat-forming species. Seamount peaks have been found to have relatively low abundances; this is thought to be the result of bottom-trawl fishing (Thresher et al. 2014). Warming of the water column has resulted in range extensions of several species in addition to *C. rodgersii*, affecting habitats and altering plankton communities throughout the region (see Box MAR1).

South-west Marine Region

Overall, the habitats and communities in the South-west Marine Region are in good condition. However, few long-term datasets exist that can be used to determine trends in seabed habitats and communities across the region. Increasing pressures associated with industries (e.g. oil and gas exploration activity in the Great Australian Bight, the coastline's potential for renewable energy developments, marine vessel activity) and climate change indicates an increasing need for baseline and monitoring data.

Information on outer shelf, slope and abyssal habitats is limited for the South-west Marine Region, with sparse data available for the Great Australian Bight (James et al. 2001, Rogers et al. 2013) and for selected locations along the Western Australian continental margin (Williams et al. 2010a, Fromont et al. 2012). Recent surveys conducted under the Great Australian Bight Research Program and the Great Australian Bight Deepwater Marine Program will contribute substantially to our knowledge of benthic and pelagic habitats and communities on the outer shelf, slope and abyss, adding to our understanding of this area within the marine region.

The footprint of bottom trawling throughout shelf and slope regions is estimated to be less than 20 per cent, with the total swept area within the footprint estimated to be less than 40 per cent (see Box MAR2). The highest impacts of bottom trawling have been on benthic communities in the Spencer Gulf in South Australia.

Large canopy-forming seaweeds are still prevalent in many locations surveyed in south-western Australia, although there are documented examples of habitat loss from the south-east Indian Ocean marine heatwave (e.g. Wernberg et al. 2012). The heatwave caused the northern extent of the canopy-forming species *Ecklonia* to contract south by more than 100 kilometres (Wernberg & Smale 2015, Wernberg et al. 2016), and had similar influences on other canopy-forming algae such as *Scytothalia dorycarpa* (Bennett et al. 2015). Warming

Southern fan worm *(Sabellastarte indica)*, found in rocky reefs in southern Australia
Photo by Graham Blight

of the water column has been associated with declining abundance of phytoplankton communities (Siegel et al. 2013; see also State and trends of indicators of marine ecosystem health).

Ongoing monitoring of the water column is currently facilitated through an IMOS National Reference Station located off Perth; sampling at an additional site off Esperance ceased in 2013. Spatially and temporally variable sampling is facilitated through other IMOS facilities. Long-term trends of warming are correlated with declining phytoplankton biomass (Siegel et al. 2013) as low-biomass tropical communities move further south (Thompson et al. 2015a).

North-west Marine Region

Habitats and communities of the North-west Marine Region are assumed to be in good condition, mostly because of the remoteness of large parts of the marine region, although there are very few data or long-term datasets that can be used to determine trends. Localised areas where habitats and communities are being impacted either directly or indirectly, through increased recreational use of the marine environment, are likely to exist. Habitats where large capital dredging projects and substantial shipping activities associated with oil and gas development are occurring are also likely to be affected, such as those in the Pilbara area.

Offshore habitats are considered to be in good condition based on the distribution of bottom-trawling fishing, although modelling of the recovery of seabed habitats and communities after extensive historical bottom trawling in the 1970s and 1980s suggests that these habitats are likely to remain depleted (Fulton et al. 2006). This is yet to be verified with in situ observations. The bottom-trawling footprint associated with more recent is estimated to be less than 20 per cent across the marine region, with the trawl area swept within the footprint less than 40 per cent (see Box MAR2). The highest impacts of bottom trawling on benthic communities have occurred in Shark Bay.

The state of reef communities varies across the marine region, with a recent sequence of high summer water temperatures causing varying degrees of bleaching and coral mortality in different areas, notably from Exmouth to the Abrolhos Islands in association with the marine heatwave of 2011. Elevated water temperatures continued across coastal and offshore Pilbara waters in 2012 and 2013, resulting in bleaching of much of the western Pilbara and Montebello Islands Marine Park. Bleaching impacts associated with climate extremes driven by increasing baseline water temperatures and the 2015–16 El Niño event are yet to be fully determined; however, surveys conducted to date have shown that large areas of bleaching occurred at Scott and Seringapatam reefs, and parts of the inshore Kimberley coast, but little or no bleaching was observed in more southerly areas such as Ningaloo Reef and the Montebello Islands. Many habitats and communities lack long-term ongoing monitoring, which limits the establishment of trends, although Ningaloo Reef and some offshore reefs have ongoing monitoring programs. Many nearshore reefs in the north-west have been little studied, and recent surveys have found surprisingly diverse communities. Ongoing monitoring of the water column, facilitated through an IMOS National Reference Station located at Ningaloo Reef, ceased in 2013.

Assessment summary 2

State and trends of habitats and communities

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Seabed, inner shelf (0–25 metres)	Significant local to regional-scale impacts in the South-east and Temperate East marine regions. Empirical studies on vulnerable assemblages are required to quantify the extent and implications of perceived impact	?			
Seabed, outer shelf (25–250 metres)	The state is likely poor to good in the South-east and Temperate East marine regions (and potentially poorest for the Temperate East Marine Region). Quantitative data for composition and distribution of soft-sediment fauna are lacking	↗			
Seabed, slope (250–700 metres)	Seabed habitats are spatially restricted, with varying impacts as a result of pressures, resulting in varying state and trends. State is poor to very poor but improving in the South-east and Temperate East marine regions, and good and stable elsewhere	↗			
Seabed abyss (more than 700 metres)	Habitats vary in state across depths. Those at 700–1500 metres are spatially restricted; those in the South-east Marine Region are poor because of fishing impacts	—			
Water column, inner shelf (0–25 metres)	Information available is localised and limited to the tropics; there are insufficient data to accurately assess regional or national trends	?			
Water column, outer shelf (25–250 metres)	The lack of a timeseries of in situ observations from large parts of Australia's marine environment limits the assessment to satellite detection of status for only a few parameters. There is considerable regional variability, and evidence of responses to climate variability dominates over longer-term climate change impacts	?			

Assessment summary 2 (continued)

Component	Summary	Assessment grade: Very poor	Poor	Good	Very good	Confidence: In grade	In trend	Comparability: To 2011 assessment
Water column, slope (250–700 metres)	Trends are weak, spatially variable and unclear throughout most regions; those in the South-east Marine Region are largely positive (increasing)			?				
Water column, abyss (more than 700 metres)	State and trends of biological components of the water column are unknown but assumed to be good			?				X
Canyons	Current state varies from highly impacted to largely pristine or functionally intact. That in the South-east Marine Region is poor			?				
Seamounts	Habitats range from very good to very poor, with trends stable to improving. Recovery from historical fishing pressure is expected to be extremely slow and impeded by ocean acidification		—					
Offshore banks, shoals and islands	Comprehensive spatial coverage, but level of assessment for state is coarse. Assessment of trend at the national scale still lacks a high level of confidence, with information only available for Lord Howe Island			—				
Coral reefs (less than 25 metres)	Severe storms, bleaching and crown-of-thorns starfish have affected north-eastern reefs, while many regions in the north-west have been affected by bleaching		↙					
Deepwater corals and sponges (25–250 metres)	The South-east and Temperate East marine regions are below trend (potentially poorest in the Temperate East). Empirical studies on vulnerable assemblages are required to quantify implied trawl impacts		↗					

Assessment summary 2 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Deepwater corals and sponges (more than 250 metres)	Exposure of slow-growing fauna to direct fishing impacts results in highly variable condition across depth ranges and between regions. Grades range from very poor in upper slope areas in the South-east Marine Region to very good in abyssal habitats	Good; Stable	Adequate	Adequate	X
Fringing reefs—temperate rocky reefs	Trend data are lacking for most areas. The Temperate East and South-east marine regions are in the poorest state, and the South-west Marine Region has demonstrated recent deterioration	Poor; Deteriorating	Limited	Limited	Not comparable
Bryozoan reefs	Condition varies, ranging from poor in the South-east Marine Region and potentially very poor in the Temperate East Marine Region; other regions are assumed to be good, although there are few data. Empirical studies on vulnerable assemblages are required to quantify implied trawl impacts	Poor; Stable	Adequate	Adequate	Somewhat comparable
Algal beds	Nationally in good condition, but generally in poorer condition in the Temperate East and South-east marine regions as a result of warming and the cascading effects of fishing	Good; Deteriorating	Adequate	Adequate	Somewhat comparable

Recent trends

- Improving
- Deteriorating
- Stable
- Unclear

Grades

- **Very good:** All major habitats and communities are essentially structurally and functionally intact and able to support populations of dependent species
- **Good:** There has been some minor loss of habitats and communities in some areas, leading to minimal degradation but no persistent, substantial impacts on populations of dependent species
- **Poor:** Degradation, alteration or loss of habitats and communities has occurred in a number of areas, leading to persistent, substantial impacts on some populations of dependent species
- **Very poor:** There is widespread degradation, alteration or loss of habitats and communities, leading to persistent, substantial impacts on many populations of dependent species

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**

Species groups

The Australian marine environment is home to a plethora of species; 33,000 have been catalogued, 17,000 remain to be catalogued, and there may be 5–10 times as many yet to be discovered (Butler et al. 2010, Poore et al. 2015). Surveys of the marine environment regularly record new species even in areas that have been surveyed before, and half of the taxa captured in deep-sea environments may be new to science.

Fourteen species groups for which information and data were available were assessed for SoE 2016. These groups largely comprise those caught by fisheries or protected under the EPBC Act. Information for some species, including marine turtles and seabirds, is largely limited to information on land-based nesting or breeding areas (discussed in greater detail in the *Coasts* report), with little information available about their life at sea. Several species that use the marine environments of Australia (e.g. marine turtles, marine mammals, seabirds, billfish, tunas, sharks) demonstrate connectivity with regions outside the Australian EEZ, and many of the pressures currently affecting these populations are associated with high fishing effort or high bycatch rates in areas external to the Australian EEZ. Within the Australian EEZ, varying pressures are exerted on species and species groups across their range, because many species and species groups are widely distributed throughout Australia's marine environment.

Even in areas where biodiversity has been surveyed, a good understanding of what ecosystems may have looked like before they were modified by human impacts is lacking. Apart from assessments on commercially caught species, very few species groups are regularly monitored. Consequently, empirical information on species status and trends is not available. It is also not possible to determine whether local declines in some species groups (e.g. sea snakes at Ashmore Reef) have resulted from declines in overall populations or distributional shifts in populations at particular sites. Species groups that have important ecosystem roles (e.g. algae, sponges, phytoplankton, zooplankton) are covered under assessments of habitats and communities, or biological processes.

Whale shark *(Rhincodon typus)*, Ningaloo Marine Park, Western Australia
Photo by Erik Schlogl

The current status of those species targeted by fisheries has been derived from the most recent assessments available and, where possible, under single reporting frameworks. However, not all species are reported under single reporting frameworks. Reporting frameworks differ in their methodologies and may differ slightly in their assessments. Where relevant, details of the reporting framework from which assessments have been derived are provided.

Most species groups assessed are in good condition overall, although information is lacking to assess the condition or trend of some groups. Trends are stable or improving for most fish species, except inner shelf reef species, which are highly spatially variable, with some in good condition and stable, and others in poor condition and deteriorating. State and trends often vary for species within groups:

- Some species have improved from past declines (e.g. long-nosed fur seals—*Arctocephalus forsteri*, southern Great Barrier Reef green turtles—*Chelonia mydas*, humpback whales—*Megaptera novaeangliae*, the eastern stock of orange roughy—*Hoplostethus atlanticus*).
- Other species are currently stable (e.g. mesopelagic and epipelagic fish species, shy albatross—*Thalassarche cauta*).
- Several species have declined because of cumulative impacts associated with degradation of their nesting habitat (see the *Coasts* report for further details); and high mortality as a result of bycatch within fisheries, climate change and potential ingestion of marine debris (e.g. flesh-footed shearwater—*Puffinus carneipes*, Australian sea lions—*Neophoca cinerea*, north Queensland hawksbill turtles—*Eretmochelys imbricata*, some demersal shark species).

Within the Great Barrier Reef Marine Park, the status of populations of most species has been assessed as good, although it had deteriorated from previous assessments; inshore and southern parts of the Great Barrier Reef are in worse condition than those in the north (GBRMPA 2014a). Declines have been reported in some fish, shark and seabird species, and dugongs (detailed in the *Coasts* report). The bleaching event associated with climate extremes in 2015–16 that had an extensive impact on the less disturbed northern areas of the Great Barrier Reef should be noted (see also Quality of habitats and communities). The flow-on impacts on species and species groups are yet to be quantified. Further detail on the state of species groups in the Great Barrier Reef Marine Park is in GBRMPA (2014a).

North Marine Region

Long-term monitoring of populations of species within the marine environment of the North Marine Region—other than those that are the target of commercial fisheries—is sparse. As a result, identified trends in populations are few. Similarly to marine habitats and communities, species groups found within, and using, the region are assumed, in the absence of supporting information, to be in good condition, because of the relatively lower use of the marine environment and the remoteness of much of the North Marine Region. Several species that use the area (e.g. marine turtles, dolphins, sharks, rays) demonstrate connectivity with regions to the north, and some populations are impacted by pressures (e.g. high fishing effort, high bycatch rates) in areas external to the Australian EEZ (e.g. Gunn et al. 2010). Sea snakes are known to be regularly caught in trawl fisheries in the region (see Commercial fishing); however, there are no ongoing monitoring programs to identify the current state of populations or trends in populations throughout the marine region. Some sawfish species that occur through the region are listed under the EPBC Act, and research aimed at quantifying population abundance and connectivity of stocks has been initiated since SoE 2011. Recent assessments of species and their stocks currently targeted by fisheries in the region (noting that some also occur within the Coral Sea and North-west marine regions; Flood et al. 2014 and references therein) have classified:

- 24 species or species stocks in good condition and sustainably fished
- 1 species or species stock recovering from past depletion
- 2 species or species stocks in poor condition and currently overfished
- 8 species or species stocks undefined (not enough data to determine state).

Coral Sea Marine Region

Long-term monitoring of populations found within the Coral Sea Marine Region and those that use the region—other than those subject to commercial fishing—is sparse. As a result, identified trends in populations are few. Again, similarly to marine habitats and communities, species groups in the Coral Sea Marine Region are assumed, in the absence of supporting information, to be in good condition because of the remote and offshore nature of the region. Several species that use the area (e.g. marine turtles, whales, tunas, billfish, sharks, rays) demonstrate connectivity with regions to the north and east of the region, and some populations are impacted by pressures (e.g. high fishing effort, high bycatch rates) in areas external to the Australian EEZ; these include hawksbill turtles and many shark species.

Recent research suggests that, in terms of fish communities, the region is more biogeographically complex than previously thought (Last et al. 2011b). Recent assessments of the Coral Sea Fishery managed by the Australian Government (Flood et al. 2014, Hansen & Mazur 2015 and references therein) have classified:

- 5 species or species stocks in good condition and sustainably fished
- 6 species or species stocks in poor condition and currently overfished
- 2 species or species stocks undefined (not enough data to determine state).

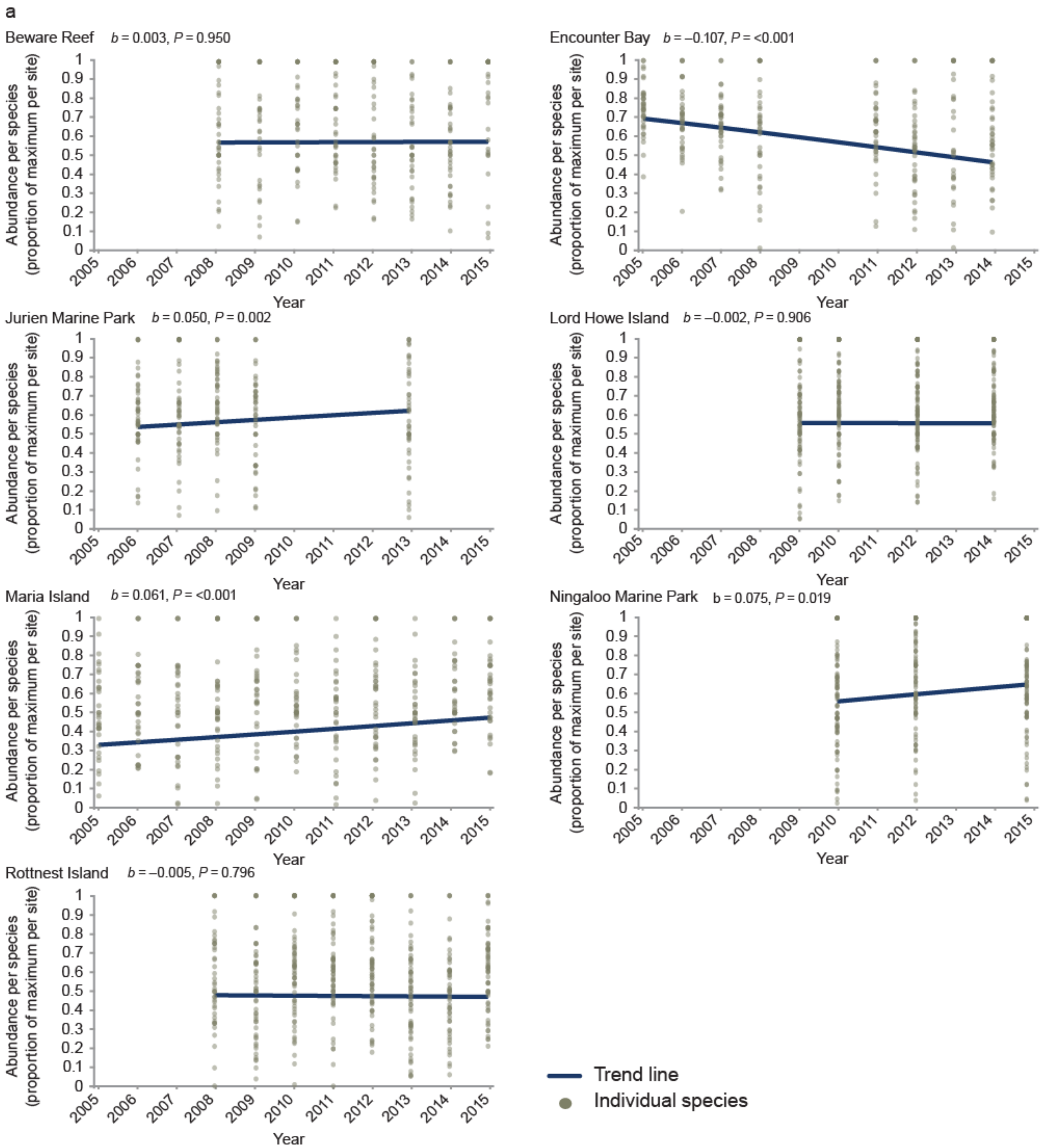
Many tunas and billfish commercially caught by fisheries within the region (also caught within the Temperate East Marine Region) are currently regarded to be western and central Pacific Ocean stocks. These species are assessed at a regional level across the western and central Pacific Ocean. Most species are in good condition and not overfished, except for bigeye tuna (*Thunnus obesus*), which is currently considered to be overfished (Harley et al. 2014), and broadbill swordfish (*Xiphias gladius*), which is currently likely to be subject to overfishing but not currently overfished. However, uncertainties associated with the biology of broadbill swordfish mean that this assessment is highly uncertain (Davies et al. 2013). Recent research quantifying the age and growth rates of the species (Farley & Clear 2015) will reduce uncertainty when the species is next assessed in 2017.

Temperate East Marine Region

Overall, populations of species groups are in good condition in the Temperate East Marine Region, although—as with other marine regions—populations demonstrate species-specific state and trends. Long-term monitoring of populations found within, and using, the marine region—other than those subject to commercial fishing—is sparse. As a result, identified trends in populations are few (see Box MAR7). Several species that use the area (e.g. marine turtles, whales, seabirds, tunas, billfish, sharks, rays) demonstrate connectivity with regions to the north and east of the region, and some populations are impacted by pressures (e.g. high fishing effort, high bycatch rates) in areas external to the Australian EEZ; these include bigeye tuna, hawksbill turtles, some species of shearwaters and many shark species.

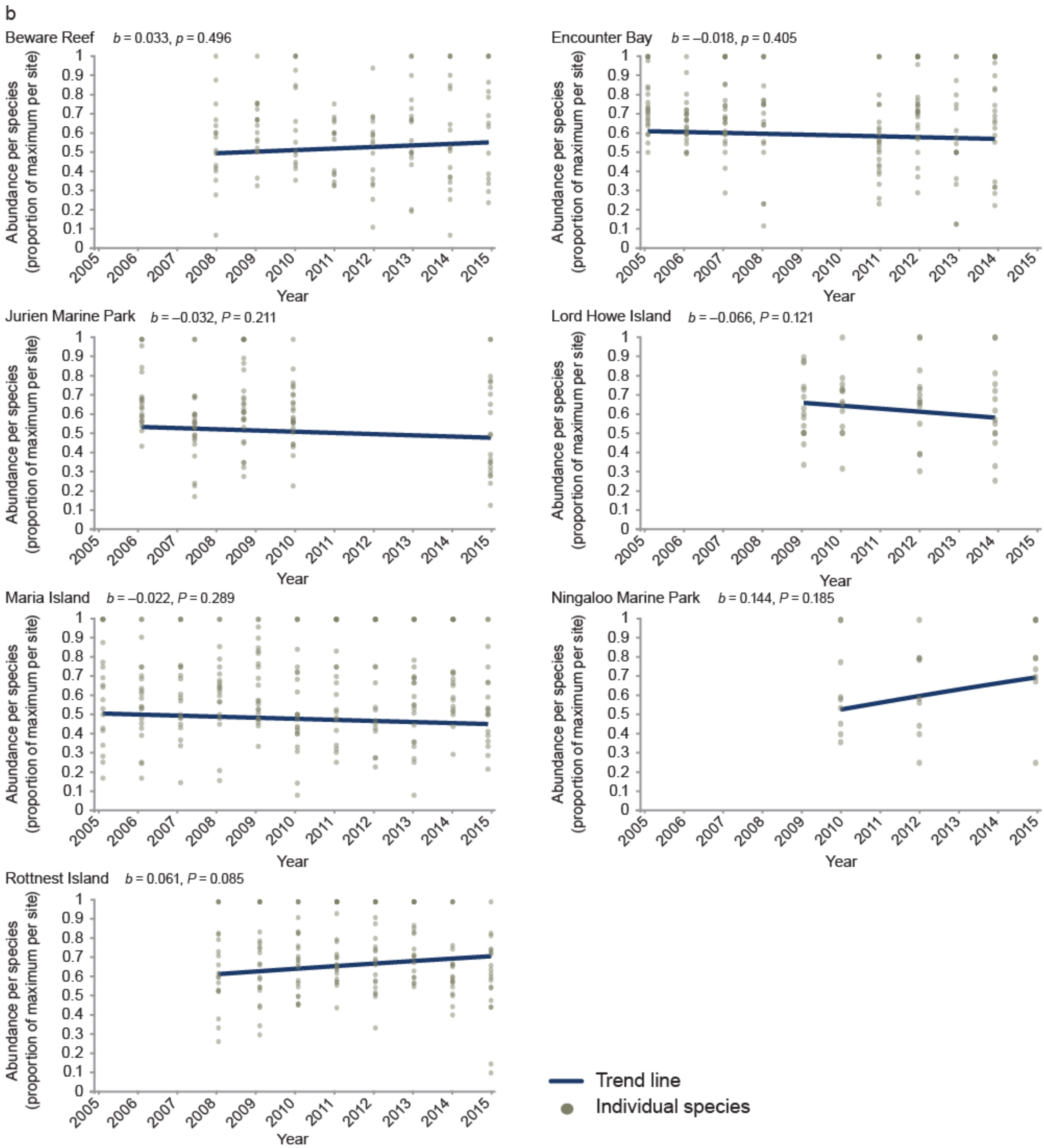
Populations of inner reef fish and invertebrate populations demonstrate varying trends, with most invertebrate populations stable. There is some indication that populations of fish species in marine reserves are in better condition than those in areas that are not protected (Figure MAR27).

Humpback whales, which seasonally migrate through the region to breed and calve each winter on the Great Barrier Reef (see also the *Antarctic environment* report for details of baleen whales that seasonally feed in Antarctic and subantarctic waters), are increasing at close to their maximum rate and are considered to be close to carrying capacity (Noad et al. 2011). Trends for all other marine mammals are uncertain because they are only irregularly monitored or not monitored at all. State and trends of most sharks and rays are also uncertain for the same reasons. The only eastern population of flesh-footed shearwaters occurs in the Temperate East Marine Region on Lord Howe Island. The population has steadily declined because of high fisheries bycatch by Australian and international fisheries, degradation of nesting habitat, and potential marine debris ingestion (Priddel et al. 2006, Lavers 2015). Small pelagic (epipelagic and mesopelagic) fish species are in good condition, with those subject to fishing being sustainably fished (Moore & Mazur 2015). Fisheries management measures limiting catches of some species have stopped the overfishing of some species groups. However, no signs of recovery have been observed to date for some species, such as eastern gemfish (*Rexea solandri*), blue warehou (*Seriolella brama*) and redfish (*Centroberyx affinis*)—the reasons are currently unclear (Georgeson et al. 2015b). Since 2011, blue warehou has been listed as conservation dependent under the EPBC Act. Changing environmental conditions because of the southern extension of the East Australian



Note: The y axis represents the mean indicator value for reef sites in that year relative to the highest value at each site across years. Trends that are significant for all species pooled are identified by a solid trend line.
Source: Data from the Reef Life Survey, the Long-Term Temperate Reef Monitoring Program (Barrett et al. 2009) and the Australian Institute of Marine Science Long-term Reef Monitoring Program

Figure MAR27a Trends in the abundance of all shallow reef fish at long-term reef biodiversity monitoring locations around Australia



Note: The y axis represents the mean indicator value for reef sites in that year relative to the highest value at each site across years. Trends that are significant for all species pooled are identified by a solid trend line.

Source: Data from the Reef Life Survey, the Long-Term Temperate Reef Monitoring Program (Barrett et al. 2009) and the Australian Institute of Marine Science Long-term Reef Monitoring Program

Figure MAR27b Trends in the abundance of invertebrate species at long-term reef biodiversity monitoring locations around Australia

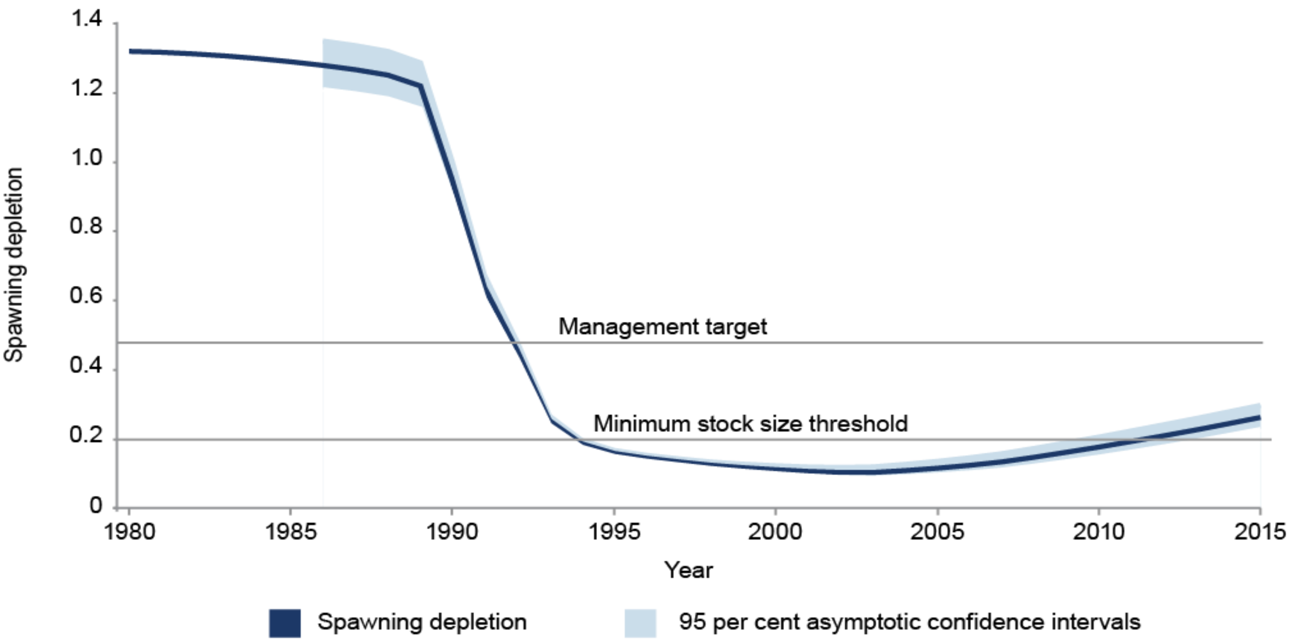
Current (EAC) separation and associated eddies may be a component of this lack of recovery. Recent assessments of species currently targeted by fisheries in the region (noting that some also occur in the Coral Sea and South-east marine regions; Flood et al. 2014 and references therein) have classified:

- 20 species or species stocks in good condition and sustainably fished
- 1 species or species stock recovering from past depletion
- 4 species or species stocks in poor condition and currently overfished
- 11 species or species stocks undefined (not enough data to determine state).

South-east Marine Region

Of all marine regions, the species and species groups of the South-east Marine Region can be considered to be the most affected by past exploitation, declining habitat conditions and, in some areas, lack of recovery of habitats. As with other marine regions, populations of species vary in their state, and, because many populations are not monitored routinely, many trends are unclear. Fisheries management measures reducing capacity, and therefore catches, and the closure of particular areas have helped to reduce overfishing and led to improvements in the population abundances of some species throughout the region. The clearest example of this improving trend is the recovery of the eastern zone stock of orange roughy. Since the closure of the fishery in 2006 because of a low biomass of mature fish, sufficient juveniles have recruited to the mature population to permit a limited commercial fishery to recommence in 2015 (Upston et al. 2014; Figure MAR28). The impacts of the broader fishery on future recruitment of the species remain unknown.

Populations of inner reef fish and invertebrate populations demonstrate varying trends, with most largely stable (Figure MAR27). There is a likelihood that some invertebrate species have deteriorated, such as rock lobster (*Jasus edwardsii*), which has been heavily exploited but is not currently considered as overfished (Hartmann K et al. 2013, Flood et al. 2014, Lyle & Tracey 2014, Linnane et al. 2015a,b). Catches of giant crab (*Pseudocarcinus gigas*) in Victoria are currently less than 5 per cent of their peak (Linnane et al. 2015b), suggesting that this stock is in poor condition. Small



Source: Upston et al. (2014)

Figure MAR28 Spawning biomass of the east coast population of orange roughy, 1980–2015

pelagic (epipelagic and mesopelagic) fish species are in good condition, with those subject to fishing being sustainably fished. Most stocks of demersal and benthopelagic species are similarly considered to be in good condition, although gulper sharks (*Centrophorus* spp.) within the Commonwealth Southern and Eastern Scalefish and Shark Fishery are assessed as being in an overfished state (Georgeson et al. 2015b). Since SoE 2011, Harrisson's dogfish (*C. harrissoni*) and southern dogfish (*C. zeehani*) have been listed as conservation dependent under the EPBC Act, spotted handfish (*Brachionichthys hirsutus*) has been uplisted from endangered to critically endangered, and red handfish (*Thymichthys politus*) has been uplisted from vulnerable to critically endangered. Recent assessments of species currently targeted by fisheries in the region (noting that some also occur in the Temperate East and South-west marine regions; Flood et al. 2014 and references therein) have classified:

- 24 species or species stocks in good condition and sustainably fished
- 2 species or species stocks recovering from past depletion
- 11 species or species stocks subject to overfishing, but not yet in a state of being overfished
- 6 species or species stocks in poor condition and currently overfished
- 18 species or species stocks undefined (not enough data to determine state).

The only albatross species to breed in continental Australia, the shy albatross, occurs in this marine region. Although demonstrating recovery from past exploitation in recent decades, it appears to have plateaued at around half its original population size as a result of high juvenile mortality associated with bycatch in commercial fisheries (Alderman et al. 2011). Kelp (*Larus dominicanus*), silver gull (*Chroicocephalus novaehollandiae*) and Australasian gannet (*Morus serrator*) populations have been observed to be increasing (e.g. Pyk et al. 2013, Woehler et al. 2014). The state and trend of most marine mammals that are either resident in the region (e.g. Australian fur seals—*Arctocephalus pusillus doriferus*, inshore bottlenose dolphins—*Tursiops aduncus*) or seasonally migrate to the region (e.g. pygmy blue whales—*Balaenoptera musculus intermedia*, the eastern population of southern right whales—*Eubalaena australis*) are unclear, although populations of long-nosed fur seals are reported to be increasing (McIntosh et al. 2014).

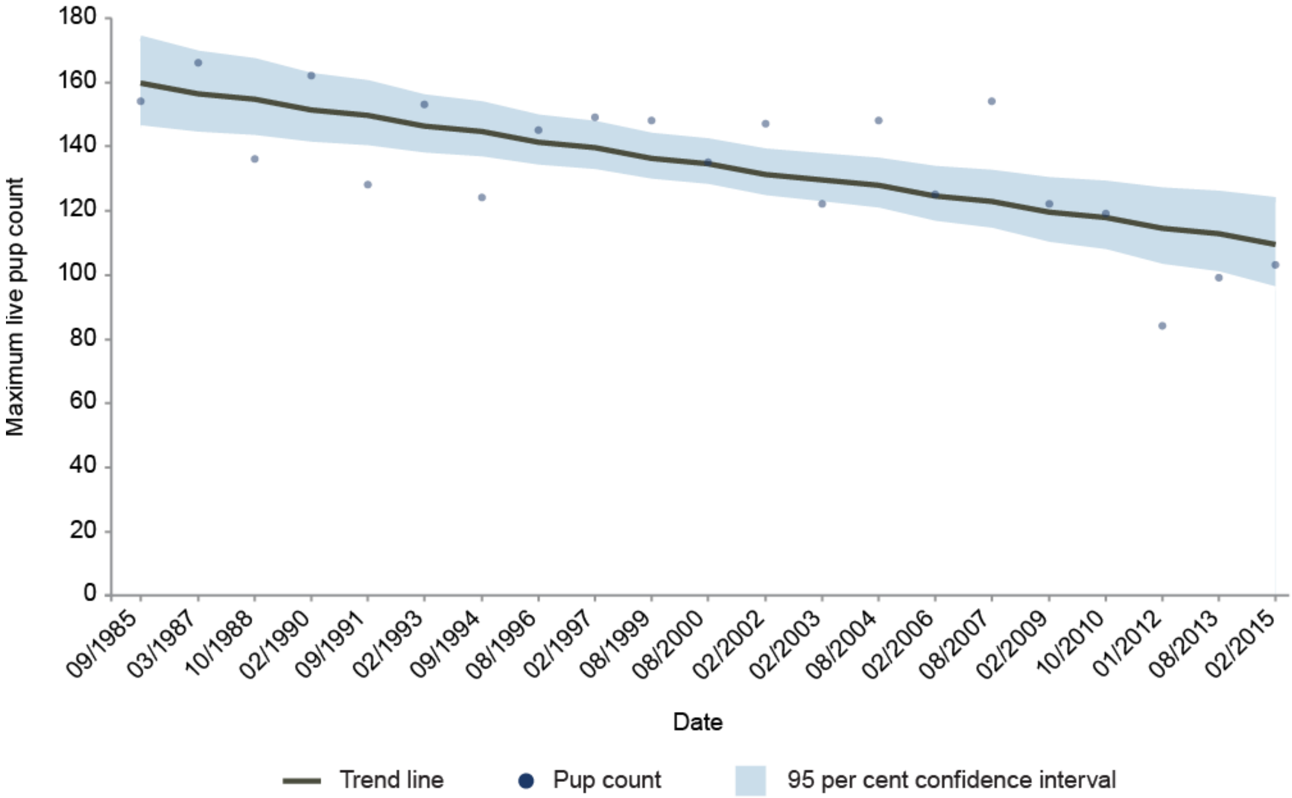
South-west Marine Region

Species and species groups within the South-west Marine Region are in poor to good condition. Those in poor condition are largely associated with past exploitation of populations of species, declining habitat conditions and, in some areas, lack of habitat recovery. Recent assessments of species targeted by fisheries (noting that some also occur in the South-east and North-west marine regions; Flood et al. 2014 and references therein) have classified:

- 28 species or species stocks in good condition and sustainably fished, although Indian Ocean yellowfin tuna (*Thunnus albacares*) has since been classified as overfished by the Indian Ocean Tuna Commission
- 2 species or species stocks recovering from past depletion
- 11 species or species stocks subject to overfishing but not yet overfished
- 2 species or species stocks in poor condition and currently overfished
- 12 species or species stocks undefined (not enough data to determine state).

A further 2 species or species stocks are considered to have been reduced to the point where average recruitment levels are significantly reduced, primarily because of substantial environmental changes or disease outbreaks (rather than overfishing).

Several Australian Government, state and international management measures aimed at recovering populations have been put in place across the region, reducing overfishing (see Box MAR6). Observations of inner reef fish and invertebrate species suggest that, in general, populations are stable (Figure MAR27). Western populations of southern right whales and long-nosed fur seals are increasing from past exploitation (Campbell et al. 2014, Bannister 2015, Shaughnessy et al. 2015). Overall numbers of Australian sea lions remain low after past exploitation, and pup abundance has decreased at 82 per cent of sites in South Australia that have been regularly monitored (e.g. Goldsworthy et al. 2015b; Figure MAR29), despite fishery bycatch management measures implemented in Commonwealth and state fisheries. Information on population numbers and recent trends for most cetaceans, seabirds and sharks is lacking (see Box MAR7). However, active programs focused on coastal dolphins in particular locations are beginning to



Source: Goldsworthy et al. (2015a)

Figure MAR29 Abundance of Australian sea lion pups at Seal Bay (Kangaroo Island), based on maximum live pup counts, 1985–2015

provide information that will enable future assessment of trends in these populations (e.g. Smith et al. 2013). Recent surveys of flesh-footed shearwaters across the region have identified populations that are substantially lower than previously reported (Lavers 2015).

North-west Marine Region

Species and species groups in the North-west Marine Region are largely assumed to be in good condition because of the relatively lower use of the marine environment and the remoteness of much of the northern parts (i.e. north of Broome) of the region. Because of this remoteness, however, long-term monitoring of many marine populations is sparse, and trends in populations are poorly understood. This precludes determination of the status of many species throughout the region. Inner shelf reef fish are in good condition, particularly in northern regions. However, within the Ningaloo region, increasing numbers of some reef fish species are also associated with declining overall community biomass, so care must be taken in interpreting trends, as they may not always be associated with improving conditions. The western population of humpback whales, which breeds in the region, is continuing to increase following past exploitation (Salgado-Kent et al. 2012). The state and trend of most marine mammals that are resident in the region (e.g. snubfin dolphin—*Orcaella heinsohni*) or seasonally migrate to the region (e.g. Brydes whales—*Balaenoptera edeni*) are unclear (e.g. Ross 2006, DoE 2015c). Research programs focused on coastal dolphins are beginning to provide information that will enable assessment of trends in these populations in the future (e.g. Brown et al. 2016).

Box MAR6 Southern bluefin tuna

Southern bluefin tuna is an important apex predator (at the top of the food chain) in Australia's marine environment. Juveniles aggregate in the Great Australian Bight during the summer, and subadults and adults use southern and south-eastern waters primarily during winter. Adults aggregate in an area to the north-west of Australia and south of Indonesia to breed, primarily during the spring and summer months; this is the only spawning ground for the species (Basson et al. 2012).

Southern bluefin tuna is a highly prized target species for international commercial fisheries, and national commercial and recreational fisheries. Within Australian waters, a purse-seine fishery catches juvenile (2–4-year-old) tuna in the waters of the Great Australian Bight during summer for ranching operations, and is of significant value to the regional economy (worth around $150 million each year). A longline fishery targeting large individuals off the eastern Australian seaboard during winter and early spring catches a smaller amount of Australia's commercial allocation (Patterson et al. 2015b). This fishery is one of few in the world where catches of southern bluefin tuna are managed spatially to ensure that bycatch of the species by fishers without allocated quota is minimised (Hobday et al. 2010).

Issues of importance

The southern bluefin tuna spawning biomass (a measure of the adult population) is estimated to have been depleted by fishing to a low fraction of its original size (CCSBT 2014). This low state of the population led to the listing of the species as conservation dependent under the *Environment Protection and Biodiversity Conservation Act 1999* and critically endangered by the International Union for Conservation of Nature (Collette et al. 2011).

Current state

The status of the southern bluefin tuna population and the development of a management plan incorporating a rebuilding program have led to the advancement of new fishery-independent methods for monitoring the population in recent years (Bravington et al. 2016). The data provided by these monitoring methods are highly informative and have been integrated into the internationally agreed stock assessment frameworks (Preece et al. 2015). These methods are being applied more broadly, and are leading to improved methods for estimating the abundance and trends of populations of other listed species (see Box MAR7).

Recent assessment and research results indicate that recruitment (the number of younger fish maturing into the age groups of fish that are commercially fished) has increased from a historical low in 2000 and that the mortality associated with commercial fishing has decreased because of the reduction in global catches since 2006 (CCSBT 2014). The spawning biomass is currently estimated at around 9 per cent of its initial size (CCSBT 2015a).

Management measures

Management of the international commercial fishery is overseen by the Commission for the Conservation of Southern Bluefin Tuna, with global total allowable catches for the species determined by a management procedure since 2011 (Hillary et al. 2015). The management procedure is designed to recover the spawning biomass to 20 per cent of the pre-fishing biomass by 2035 (CCSBT 2014; Figure MAR30). This is the first time such a framework has been introduced to an international tuna fishery. Domestic management of Australia's allocation of the global total allowable catch is the responsibility of the Australian Fisheries Management Authority. Domestic recreational catches of southern bluefin tuna are managed by individual state agencies, largely through daily boat catch limits.

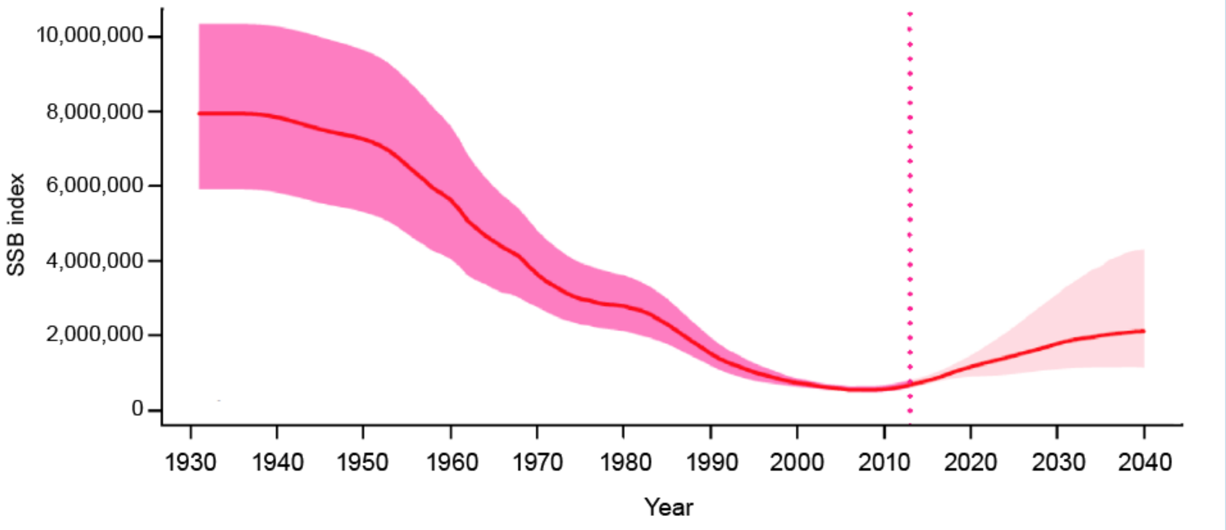
Outlook

The next full assessment for the species is planned for 2017, when current management measures aimed at rebuilding the population can be assessed and the state of the population can be identified. The management procedure will also be reviewed at this time. Initial indications from fishery-independent methods for monitoring the population in recent years suggest that the population is beginning to show positive signs in terms of rebuilding objectives (CCSBT 2015a).

Unaccounted mortalities associated with discards, unreported catches and recreational catches of southern bluefin tuna can affect the achievement of current rebuilding targets set by the Commission (CCSBT 2015a). Urgent efforts to quantify this mortality have been recommended to the Commission. In association with this, Australia has identified that it intends to begin making an allowance for unaccounted catches of southern bluefin tuna that are attributable by 2018 (CCSBT 2015b).

Box MAR6 (continued)

The draft report from a recent inquiry into the regulation of fisheries across Australia highlighted that management of southern bluefin tuna should include catch limits that are applied across all fishery sectors (commercial and recreational), and that day-to-day management of recreational fishers targeting southern bluefin tuna should be negotiated by fishers, and the Australian and state governments (PC 2016). If implemented, this recommendation would result in all catches across sectors within Australian waters being able to be attributed and included in future assessments for the species.



SSB = spawning stock biomass
Note: The red line with the pink region shows the median and 90% confidence intervals of the current base case of biomass. The dotted line demarcates the boundary between the observation-based estimates of biomass and future projected biomass based on management measures implemented.
Source: CCSBT (2015a)

Figure MAR30 Trajectory of spawning stock biomass for southern bluefin tuna under the base case of the operating model used under the management procedure, 1930–2040

Clarks anemone fish, Houtman Abrolhos Marine Area, Western Australia
Photo by Cathy Zwick

Box MAR7 White shark

The white shark (*Carcharodon carcharias*; also known as great white shark or white pointer) is a large, globally distributed apex predator, and one of the few shark species that have been definitively identified as responsible for human fatalities in Australia. It is a target species for ecotourism, with the South Australian industry valued at more than $6 million annually (Bradford & Robbins 2013). In Australian waters, white sharks occur from north-western Western Australia around the south coast to central Queensland as 2 populations, separated east and west by Bass Strait (Blower et al. 2012). Biologically important areas for white sharks occur in all marine regions except the North Marine Region.

A geographically discrete nursery area spanning 65 kilometres of coast is centred on Port Stephens in central New South Wales, and a second more geographically extensive nursery area is situated off Ninety Mile Beach in south-eastern Victoria (Bruce & Bradford 2012). Similar discrete nursery areas have not yet been identified for the western population. Movements are extensive across the range of each population, primarily focused across continental-shelf and continental-slope waters, with occasional open-ocean excursions (Bruce & Bradford 2012, Francis et al. 2015, McAuley et al. 2016).

Current state and trends

The key factor hampering the determination of the current status of white sharks in the marine environment is a lack of information on current population size and trends in populations (Taylor et al. 2016). Recent research has focused on new methodologies to estimate abundance that will allow monitoring of current status and future trends (Bax & Hedge 2015, Bravington et al. 2016).

Although impacts associated with fishing have no doubt decreased since the species was listed as vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), white sharks are still taken as bycatch in commercial shark fisheries. They are also caught under shark control programs and are targeted in response to shark attack or potential hazards. The overall impact of these mortalities on populations is unknown. Although catch rates in the New South Wales shark control meshing program have declined from around 0.3 sharks per 100 net-days to around 0.1 sharks per 100 net-days since the 1950s, there has been a minimal increase in white shark catch per unit effort (a measure of relative species abundance through time) since the mid-1990s (Reid et al. 2011). Whether this reflects overall changes in population size, changes in species distribution or changes in species behaviour is unknown. The impact of shark ecotourism cage-diving operations on white shark physiology is also unknown and subject to current research.

Research since 2011 has improved information on habitat use (Bruce & Bradford 2015, Robbins et al. 2015, McAuley et al. 2016), food-web interactions (Semmens et al. 2013, Pethybridge et al. 2014), and the interactions between white sharks and cage-diving operations (Bradford & Robbins 2013, Bruce & Bradford 2013, Huveneers et al. 2013, Bruce 2015) across the South-west Marine Region.

Management measures

As a result of listing under the EPBC Act, white sharks are subject to a national recovery plan, initially drafted in 2002 and revised in 2013 (EA 2002, DSEWPaC 2013). They are listed under the Convention on International Trade in Endangered Species (Appendix II) and the Convention on Migratory Species (Appendixes I and II), and are listed as vulnerable by the International Union for Conservation of Nature. Recent management changes to the cage-diving industry in South Australia have been implemented to minimise impacts on the species (DENR 2012, Smith & Page 2015). In addition, management changes limiting the use of commercial gillnet gear to target commercial sharks and replacing that effort with longline gear are likely to change the catchability of white sharks in southern Australian waters. In 2014, the Western Australian Government introduced a drumline program to catch and kill sharks that posed a threat to public safety (DPC 2014). This program was subsequently withdrawn, although a catch-and-kill policy remains in relation to sharks perceived as posing a threat.

Outlook

The outlook for white sharks is uncertain because of a lack of reliable data to estimate population size and trend. However, new techniques are currently being developed that may allow these parameters to be estimated and monitored in the future.

Expansion has been observed in populations of roseate (*Sterna dougallii*), crested (*S. bergii*), sooty (*Onychoprion fuscatus*) and bridled (*O. anaethetus*) terns; brown noddys (*Anous stolidus*); and red-tailed tropicbirds (*Phaethon rubricauda*) (Clarke et al. 2011). The Christmas Island frigatebird (*Fregata andrewsi*), which is unique among frigate birds in nesting on only 1 island, has declined and is listed as vulnerable under the EPBC Act (Tirtaningtyas & Hennicke 2015). Also endemic to Christmas Island and undergoing a decline in numbers is the Christmas Island white-tailed tropicbird (*Phaethon lepturus fulvus*), which the EPBC Act lists as endangered (CIEWG 2010).

Several species that use the area (e.g. marine turtles, whales, seabirds, tunas, billfish, sharks) demonstrate connectivity with regions to the north and west of the region, and some populations are impacted by pressures (e.g. high fishing effort, high bycatch rates) in areas external to the Australian EEZ; these include Christmas Island frigatebirds, yellowfin tuna and whale sharks. Recent assessments of species targeted by fisheries (noting that some also occur in the South-west and North marine regions; Flood et al. 2014 and references therein) have classified:

- 26 species or species stocks in good condition and sustainably fished, although Indian Ocean yellowfin tuna has since been classified as overfished by the Indian Ocean Tuna Commission
- 3 species or species stocks recovering from past depletion
- 7 species or species stocks undefined (not enough data to determine state).

Populations of Shark Bay saucer scallops (*Amusium balloti*) and blue swimmer crabs (*Portunus armatus*) are considered to have recruitment levels that are significantly reduced, primarily because of substantial environmental changes or disease outbreaks (rather than overfishing). These declines have been associated with the marine heatwave of 2010–11 (see Interannual and subdecadal variability). Sea snake populations at Ashmore Reef, an isolated and remote Commonwealth marine reserve (see Environment protection systems), have declined, with observations dropping sharply from more than 45 sea snakes per day from 9 species to 1–7 sea snakes per day from 1 or 2 species. The cause of this decline remains unexplained, and there is insufficient information to distinguish population decline from population redistribution (Lukoschek et al. 2013). Since SoE 2011, short-nosed (*Aipysurus apraefrontalis*) and leaf-scaled (*A. foliosquama*) seasnakes have been listed as critically endangered under the EPBC Act. Research aiming to establish the status of these species has been initiated since SoE 2011.

Assessment summary 3
State and trends of species and taxa groups

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Sharks and rays	Status and trends are largely unknown and assumed to be good, but are likely to vary between species and regions. The Temperate East, South-east and South-west marine regions are in poorer condition than the national state	?			
Tuna and billfish	Individual species have differing status and trends, with most formally assessed as in good condition, but some overfished at the regional level. Status is calculated at regional fisheries management scales rather than national or bioregional scales	—			
Shelf (0–250 metres)—demersal and benthopelagic fish species	Although most populations are improving, there are persistent, substantial effects on some populations	↗			
Slope (>250 metres)—demersal and benthopelagic fish species	The South-east Marine Region is in poorer condition than other regions	↗			
Epipelagic fish species	Assessments are restricted to the Temperate East, South-east and South-west marine regions. Fishing pressure has lessened, and biomass information is improving	—			
Mesopelagic fish species	Data from only the South-east Marine Region were assessed	—			
Inner shelf (0–25 metres)—reef fish species	Trend data are lacking for the North and North-west marine regions. Populations vary across regions, with some increasing, some stable and some decreasing	?			

Assessment summary 3 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Inner shelf (0–25 metres)—invertebrate species	State and trends are likely to be regionally variable, with timeseries lacking for most of Australia. Some localised improvements are likely, but some areas have worsened as a result of extreme climate events and climate change–induced range expansions	?			
Outer shelf (25–250 metres)—invertebrate species	There are limited temporal data and historical baselines to determine status and trend. Trawling effort pressures are decreasing in the long term, but pressures associated with climate change are increasing	—			
Seabirds	Population status and trends for species are mixed, with some increasing, some decreasing, some stable and some unknown	?			
Turtles	Population status and trends for species are mixed, with monitoring of populations varying; some populations are increasing, some are decreasing, and some are unknown. There are few quantitative data on marine habitats and pressures on populations at sea	?			
Sea snakes	Status and trends are largely unknown but likely to vary between species and bioregions. Species have almost disappeared from Ashmore Reef in the Timor Sea; the reasons are unknown	↙			
Dolphins and porpoises	Population status for most species is unknown because of lack of data but is assumed to be good; trends are unclear	?			

Assessment summary 3 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Whales	Population status and trends for many species are unknown. Most are assumed to be in good condition, with trends unclear; humpback whales and the western population of southern right whales are demonstrating clear increasing trends	?			
Fur seals and sea lions	Fur seal populations are considered to be in good condition, although trends for Australian fur seals are unclear. Australian sea lion populations in South Australia are deteriorating, and trends for populations in Western Australia are unclear	?			

Recent trends

- Improving
- Deteriorating
- Stable
- Unclear

Grades

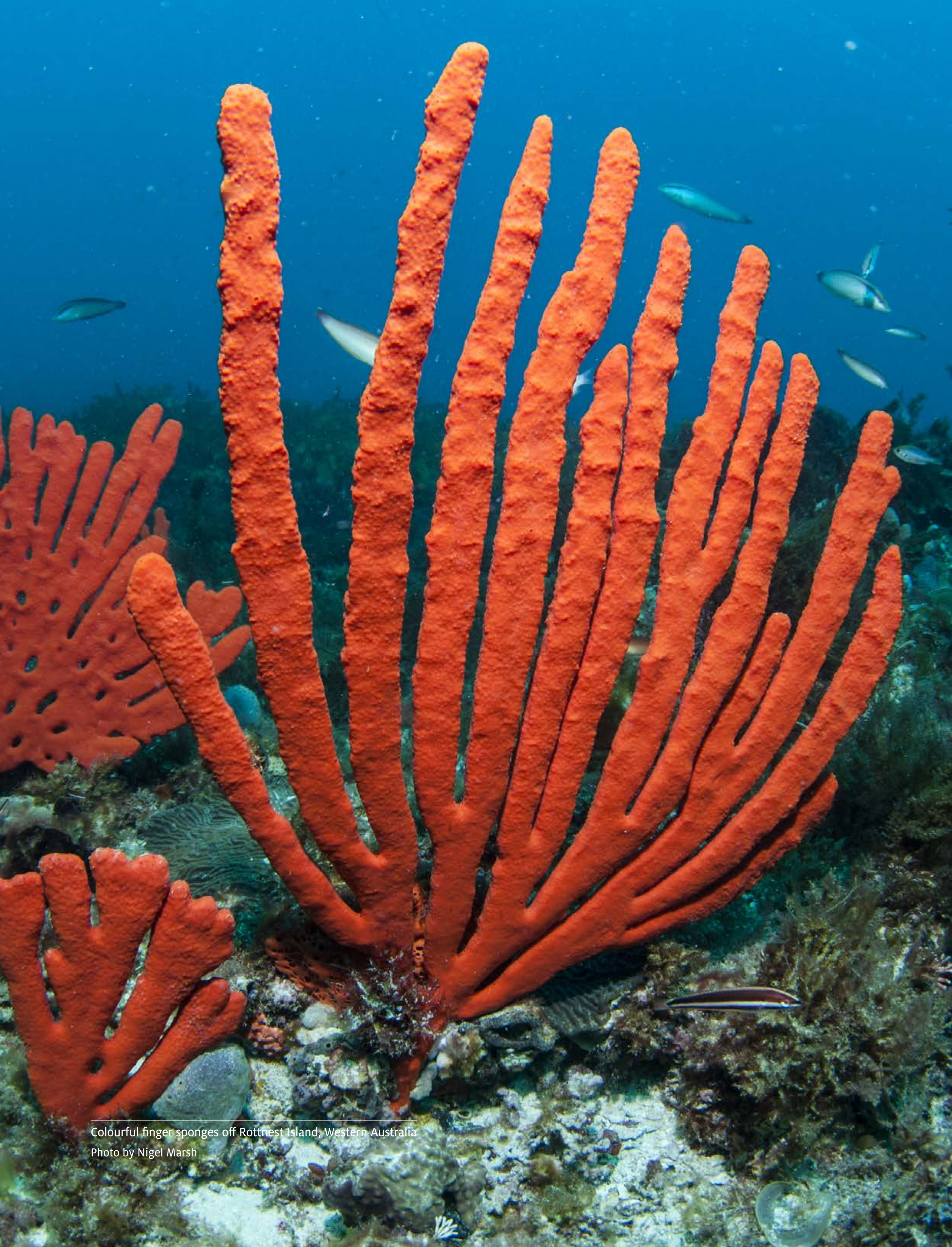
- **Very good:** Very few, if any, populations of species have declined as a result of human activities or declining environmental conditions
- **Good:** Populations of some species (but no species groups) have declined significantly as a result of human activities or declining environmental conditions
- **Poor:** Populations of some species or species groups have declined significantly as a result of human activities or declining environmental conditions
- **Very poor:** Populations of a large number of species or species groups have declined significantly as a result of human activities or declining environmental conditions

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**



Colourful finger sponges off Rottnest Island, Western Australia
Photo by Nigel Marsh

State and trends of indicators of marine ecosystem health

Physical, biogeochemical, biological and ecological processes are important components of marine ecosystem function. Together with the status and trends of marine habitats, communities and species groups, they provide an indication of the health of the marine ecosystem (e.g. Rombouts et al. 2013). Ecosystem health affects the services provided by the environment, and the industries and societies that use the marine environment, either directly (e.g. fishing) or indirectly (e.g. carbon sequestration and climate).

Several initiatives at local, regional and international levels recognise that monitoring key processes as indicators of marine ecosystem health is required to assess, adapt and revise management actions. As a result, there has been considerable discussion in the scientific and management community about the appropriate variables to measure and monitor. They include identifying the processes and components of the marine environment that managers and society value, such as those that support ecosystem services. Examples include 'key biological areas' (Eken et al. 2004), 'key ecological features' (Dambacher et al. 2012), 'ecologically or biologically significant marine areas' (Dunn et al. 2014, Bax et al. 2015) and the 'key environmental variables of the Global Ocean Observing System' (see Sustained ocean monitoring). Processes for identifying measurable variables also vary; they include simple selection criteria–based and more complex model-based frameworks (e.g. Hayes et al. 2015).

Within the Australian marine environment, the identification of key ecological features has been central to the marine bioregional planning process (see Box MAR10). Considerable effort has gone into identifying important ecosystem components and processes associated with each key ecological feature, and the biological variables that have high commonality across the features, which could therefore comprise essential variables for measurement and monitoring (Hayes et al. 2015). To date, this process has been completed for 32 of the 53 key ecological features. For pelagic key ecological features, identified indicators include biogeochemical (nutrients) and biological (phytoplankton) indicators at the bottom of the food web, and predators (large pelagic predatory fish and seabirds) at the top of the food web. In shelf systems, identified indicators include those that are habitat forming (macroalgae and coral; see Hayes et al. 2015). Further detail on Australian and global efforts to identify key indicators for measurement and monitoring is provided in Sustained ocean monitoring.

The biophysical and ecological indicators of marine health discussed here were identified in SoE 2011, and, for comparative purposes, we update them here. These include indicators of physically driven processes (water column turbidity and connectivity), productivity (microbes, phytoplankton and zooplankton), food webs (trophic processes), disease and outbreaks, and invasive species.

Overall, biophysical and ecological indicators of marine health within the Australian marine environment are in good condition, although several indicators are highly spatially and temporally variable. The methods used to measure each indicator are also variable. Current monitoring of many indicators is not spatially and temporally comprehensive enough to capture such dynamics in a robust manner. Therefore, assessment at a national scale and determination of trends for these indicators are difficult. Where indicators are highly dynamic (i.e. there is high variability), it is often difficult to distinguish trends from variability (i.e. the signal from the noise). Care must be taken in deriving trends across short timeseries, because these may capture only a portion of a highly variable signal and may not be indicative of longer-term trends (Hobday & Evans 2013, Harrison & Chiodi 2015). In addition, interpreting any observed trends requires identifying and understanding the relevant components of ecosystem structure, which can vary depending on interpretation, and between different areas or systems. Given the limited spatial and temporal extent of most information and data available, state and trends of these processes will be provided more generally for the Australian region rather than for each marine region.

Physical, biogeochemical and biological processes

Water column turbidity and transparency

Australian marine waters are generally low in turbidity and colour, and high in transparency (Shi & Wang 2010). In oceanic and outer continental-shelf waters, the major determinant of turbidity, transparency and colour is the biomass of phytoplankton, whereas, in inshore regions, sediment flows from river systems or land run-off and high tidal flows have the most influence. Observations from the network of IMOS National Reference Stations show low suspended solids across all stations except Darwin (Figure MAR31).

Although spatially and temporally variable overall, the transparency of the water column in open-water environments has significantly increased since 1997, largely associated with improved wastewater treatment, reduced nutrient inputs, and improved management of agricultural practices and associated run-off (see the *Coasts* report for further detail on inshore, embayment and estuarine regions, and see GBRMPA [2014a] for an assessment of waters associated with the Great Barrier Reef). In regions not greatly affected by these processes, transparency has remained stable (Figure MAR31), with this stability reflected in the generally comparable grade and trend of SoE 2016 to SoE 2011.

Microbial processes and ocean productivity

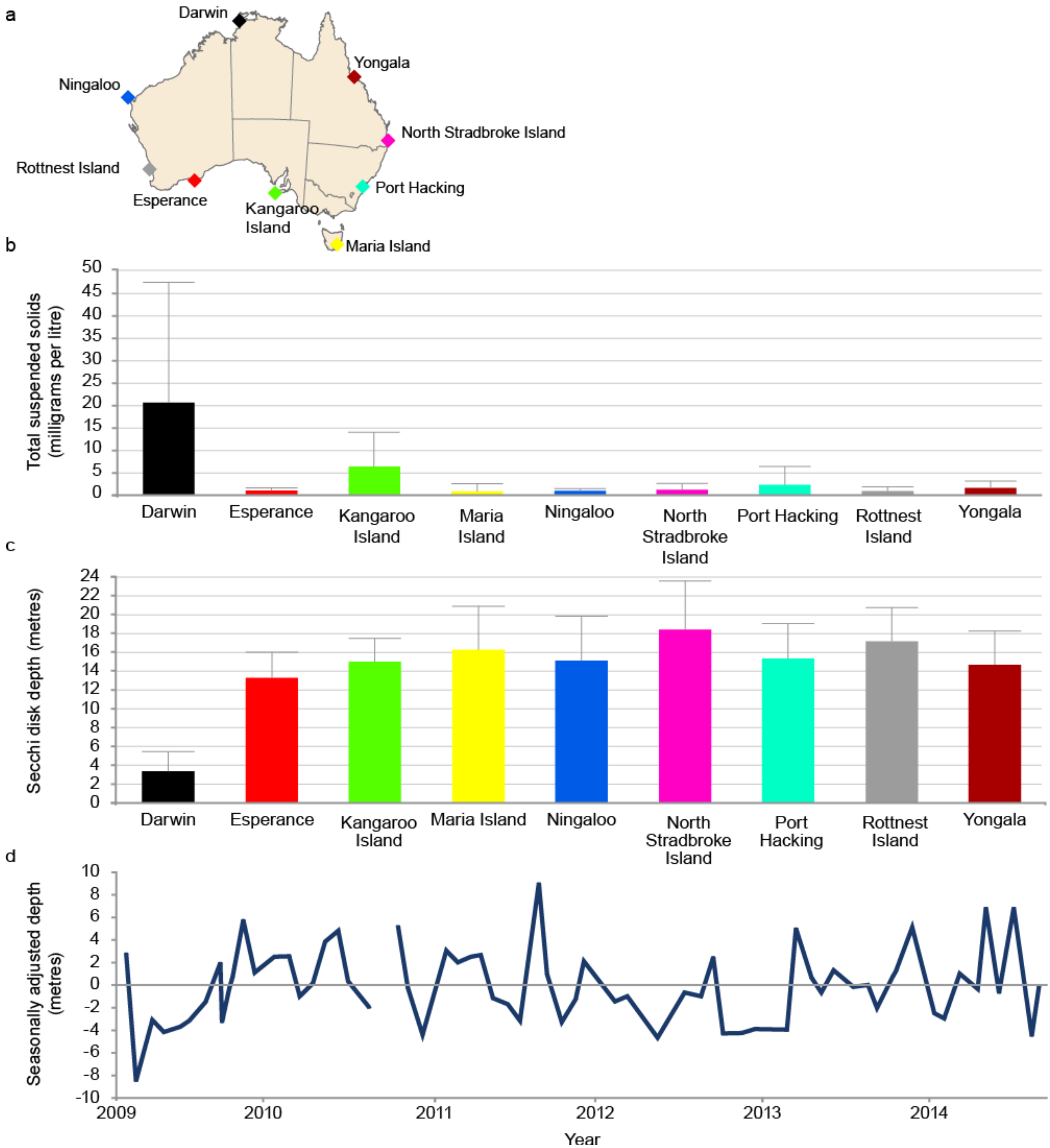
Marine waters typically contain 10,000–1,000,000 microbial (bacteria, archaea and unicellular algae) cells per millilitre, belonging to hundreds to thousands of different species (Fuhrman et al. 1989, Morris et al. 2002). This highly diverse and abundant community has an intimate connection with its environment. Marine microbial assemblages are the first to respond to changes in the chemical and physical properties of the surrounding water. Microbes also shape the marine environment by:

- driving most of the biogeochemical cycles
- supporting phytoplankton and primary productivity
- contributing to the ocean carbon pump (the uptake of carbon by phytoplankton through photosynthesis in the upper ocean and transfer of this carbon to the ocean's interior)
- sequestering carbon in 'recalcitrant' forms (i.e. resistant to decomposition)
- removing a wide range of organics and pollutants (e.g. Follows & Dutkiewicz 2011, Kujawinski 2011).

Understanding of marine microbial communities in Australia's waters is an emerging field. The high throughput genomic methods that allow assessment of communities at relevant spatial and temporal scales have only been available for the past 4–5 years. Because of the emerging nature of this field, generation of baseline databases of microbial community compositions linked to physical, chemical and higher-level biological parameters in the Australian environment has only just started. Therefore, an assessment of microbial communities is not possible at this time, and it is not clear how the assessment in 2011 was achieved. Once generated, these baselines will provide an in-depth understanding of how the state of the marine environment is reflected in the microbial community structure and allow more definitive assessments in future SoE reports.

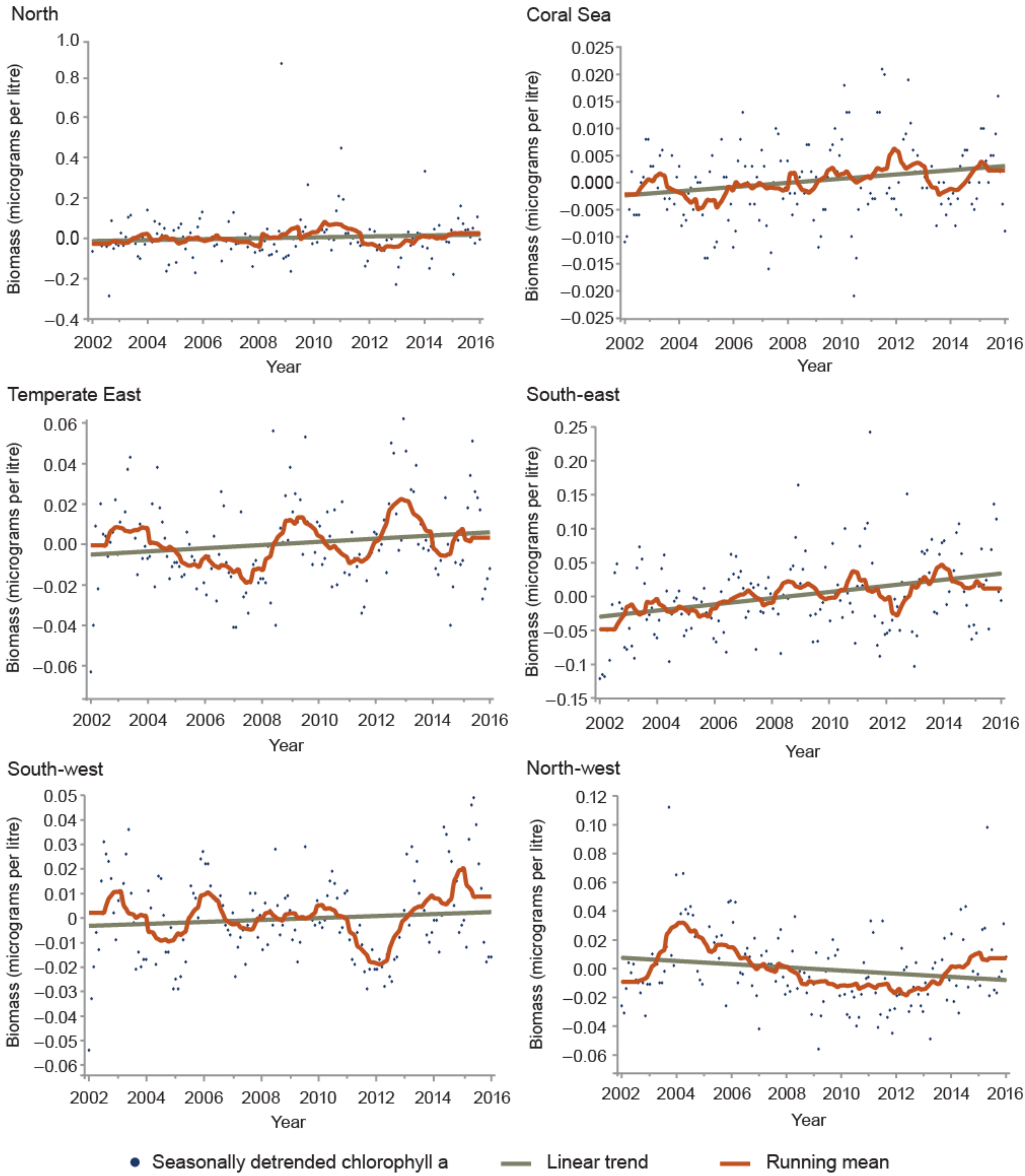
Within Australian waters, trends of primary production are variable. As warm waters extend further south, tropical phytoplankton species that are lower in productivity are also moving south (Thompson et al. 2015a). Regions of declining primary productivity include most oceanic waters north of 35°S, especially the North West Shelf (Figure MAR32) and the Great Australian Bight (Thompson et al. 2015a). Conversely, areas of increasing primary productivity have been observed, including the continental shelf off the east coast of Australia, the Coral Sea and the southern Tasman Sea, potentially because of increased eddy activity and southwards extension of EAC eddies in the region (Kelly et al. 2015). Above average rainfall across various parts of northern and north-eastern regions in 2010–15 contributed to localised increases in nutrients, phytoplankton biomass and primary productivity across the region (Figure MAR32). Globally, ocean warming is expected to result in overall decreases in primary production and phytoplankton biomass in pelagic waters, largely because of increasing stratification of oceanic waters and an associated reduction in the supply of nutrients from deep water to surface light-filled waters (Chavez et al. 2011).

Zooplankton biomass (an indicator of secondary productivity), similarly to phytoplankton biomass, is highly dynamic through space and time. No general trends of zooplankton biomass have been recorded from the IMOS National Reference Stations or the Australian Continuous Plankton Recorder Survey (Richardson et al. 2015). It must be noted, however, that observations are from a limited number of coastal stations, with the majority from the south and east of Australia, where primary production was observed to increase in the past 5 years.



Source: Data from the Australian Ocean Data Network

Figure MAR31 (a) Map showing the locations of the Integrated Marine Observing System (IMOS) 9 National Reference Stations; (b) average concentration of total suspended solids from the 9 IMOS National Reference Stations; (c) average Secchi disk depths at the 9 IMOS National Reference Stations; (d) seasonally detrended Secchi disk depths at Port Hacking (no significant trend; *P* = 0.44), 2009–14



Source: CSIRO, created from Australian Ocean Data Network data

Figure MAR32 Regional trends in phytoplankton biomass from chlorophyll a, as measured by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite for each marine region, 2002–16

Ecological processes

Ecological processes in the marine environment are highly spatially and temporally variable. They are often specific to habitats, communities and biogeographic regions, and incorporate highly complex interactions between biophysical parameters and species groups. Measuring many processes can be challenging because of their complexity and highly dynamic nature (Griffith & Fulton 2014, Kool & Nichol 2015).

Connectivity and trophic structure

Defining connectivity of marine populations is highly complex, and can vary depending on the systems and processes being focused on. Definitions of connectivity include source–sink relationships[7] between populations; key pathways for movement (migration or general movement) between habitats; mixing of multiple populations or stocks of a particular species within a defined region; or fidelity and lack of mixing of breeding populations, resulting in genetic structuring of populations (Cowen et al. 2000, 2006; Figure MAR33). Ultimately, the concept of connectivity can be regarded as relating to the rates, scale and spatial structure of exchange between populations (Cowen et al. 2006).

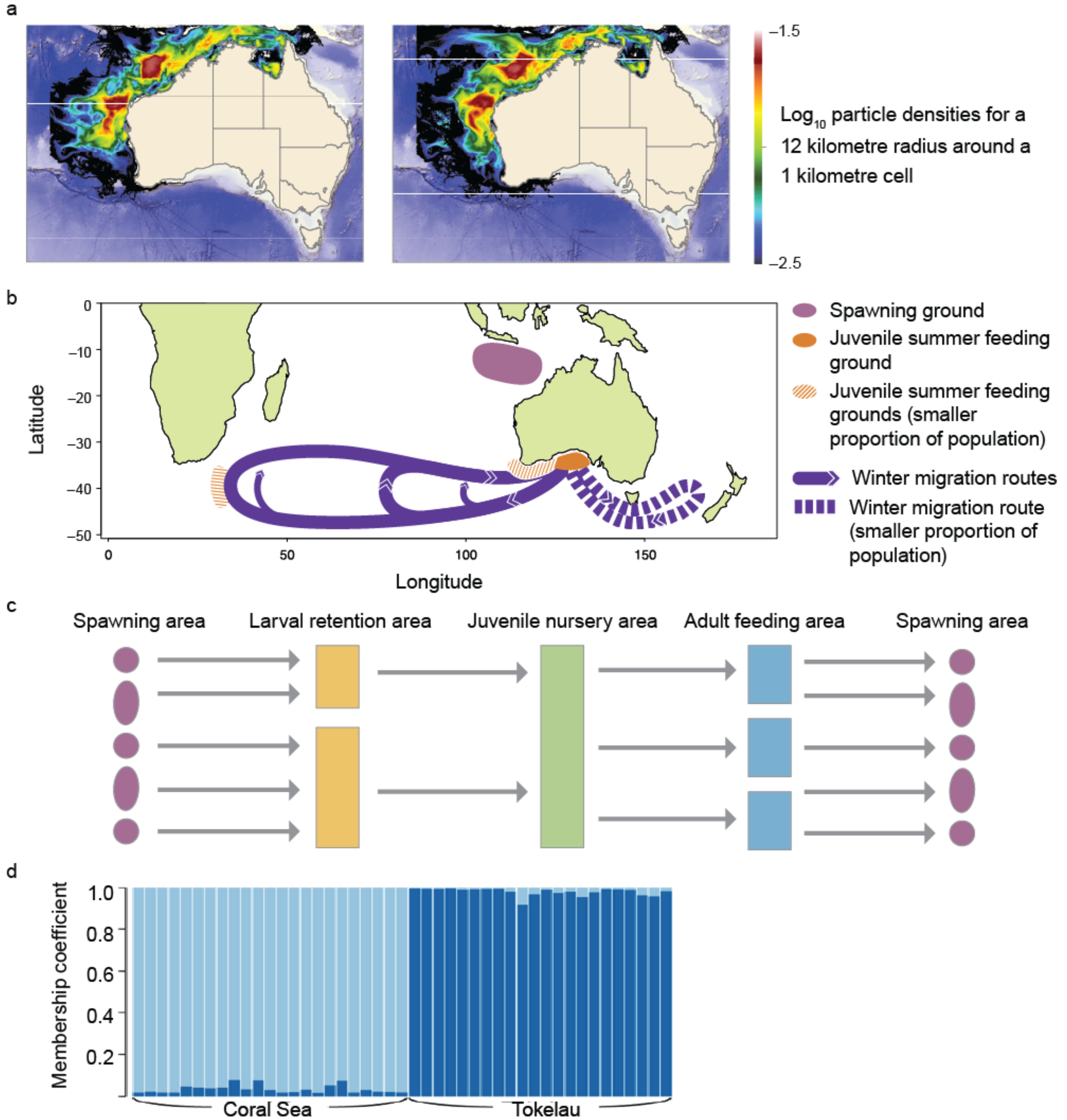
A large proportion of connectivity within the marine environment is driven by the dispersal of larval stages of species by physical processes such as winds, waves, tides and currents, modified by relatively small larval movements and behaviours (Kool & Nichol 2015). High connectivity can have positive or negative influences on ecosystem components, depending on the circumstances, as can low connectivity (i.e. high retention). For example, transport of eggs and larvae from spawning grounds to nursery areas may be critical to successful survival, but may also contribute to the spread of harmful species and diseases. An increase or decrease in connectivity may not be directly indicative of a better or worse state, and the consequences are dependent on the system and processes within the relevant ecosystem.

If we assume that changes in physical processes such as boundary currents provide an indication of the state and trends of connectivity, observations of a weakening Leeuwin Current (Feng et al. 2012) suggest that connectivity of populations in waters off Western Australia has decreased. Conversely, with strengthening of the polewards extension of EAC eddies (Cetina-Heredia et al. 2014), connectivity of populations in waters off eastern Australia could be assumed to have increased. Across habitats such as coral reefs, connectivity based on physical processes occurs on much finer scales (e.g. Hock et al. 2014). Investigation of such connectivity requires fine-scale modelling of ocean processes across large-scale regions. Changes in physical processes associated with climate change are assumed to be affecting connectivity, with varying effects on marine populations, including both limiting and expanding habitat (Hartog et al. 2011, Johnson et al. 2011), and altering larval dispersion (Cetina-Heredia et al. 2015). Progress on modelling approaches through initiatives such as eReefs is allowing the connectivity to be modelled (Cetina-Heredia et al. 2015, Schiller et al. 2015), and impacts of changes to physical processes on connectivity within and across ecosystems to be determined.

Connectivity and trophic processes are linked on evolutionary scales. Colonisation history influences food-web structure and food-chain length. As new colonisers move into habitats, they alter the food web, modifying trophic structures within the habitat (Post 2002), and can alter habitat structure and associated biological communities (e.g. the southerly extension of the sea urchin *Centrostephanus rodgersii* from the mainland to Tasmania; Ling et al. 2009). Selective mortality on specific ecosystem components—for example, the removal of large predators by fishing (see Box MAR5)—will also affect trophic structure. The removal of larger predatory lobsters by commercial and recreational fishers off eastern Tasmania is implicated in the successful climate-mediated colonisation by *C. rodgersii*, which has, in turn, reduced the resilience of kelp forests, contributing to the listing of giant kelp forests in south-eastern Australia as Australia's first threatened marine community (Ling et al. 2009).

Much of our understanding of trophic processes is based on dietary studies, whereas shifts in trophic structure are typically inferred from observations of changing species distributions (e.g. Hobday et al. 2008, Last et al. 2011a), or from modelling studies that also incorporate changes in species abundance (e.g. Fulton et al. 2005, Bulman et al. 2012, Dichmont et al. 2013). Modelling studies

7 Source–sink relationships are where habitats with varying demographic rates can support population groups, allowing populations to persist across habitats. Dispersal of populations from the source habitat maintains populations in the sink habitat (Pulliam 1988).



Note: Membership coefficient in (d) is the frequency of alleles (components of an individual's genome) identified as having ancestory within a group.
Sources: (a) Kool & Nicol (2015); (b) Basson et al. (2012); (c) Stephenson et al. (2001), adapted in Cadrin & Secor (2009); (d) Grewe et al. (2015)

Figure MAR33 Four examples of connectivity: (a) connectivity of habitats for marine larvae via source–sink pathways; (b) connectivity of habitats via migration pathways of southern bluefin tuna; (c) mixing of populations within and between particular habitats for a marine fish with multiple spawning sites and a single juvenile nursery area; (d) genetic structure of yellowfin tuna populations between 2 sites in the Pacific Ocean

(Fulton et al. 2005, Klaer 2005) suggest that some food webs in south-eastern Australia have been restructured during the past century, particularly as a result of the intensification of commercial fisheries up to the 1990s. Eastern Australian ecosystems, including the Great Barrier Reef, are also known to be highly modified (Butler & Jernakoff 1999, GBRMPA 2014a). Reduced fishing pressure, particularly in the past 5–10 years (Flood et al. 2014, Patterson et al. 2015a), should support the recovery of trophic structures across these ecosystems. However, complete recovery is unlikely, given ongoing pressures (e.g. remaining recreational and commercial fishing, habitat modification, pollution), because some highly depleted species (e.g. eastern gemfish) may not recover fully from past overexploitation, and climate-related changes in connectivity are changing the underlying structure of the physical environment. Trends of the state of trophic processes are currently unclear.

The ecosystems in the north, west, south-west and south of Australia see less direct, and spatially more variable, pressures than those in the east and south-east, and, as a result, are likely to have trophic structures that are not as highly modified. However, there are little or no data for deeper-water habitats and more remote locations, and changes to trophic structure are unlikely to be recognised if these were to occur. Areas closed to local pressures, including marine protected areas and reserves (IUCN categories I and II), and fishery closures, provide an opportunity to recognise what (locally) undisturbed trophic structures could look like.

Diseases, outbreaks and blooms

Connectivity influences the spread of diseases and parasitic infestations. It can transport and sustain harmful algal blooms that can suffocate organisms (particularly in semi-enclosed areas; see also the *Coasts* report) by reducing dissolved oxygen concentrations, or poison organisms directly.

Australia has a reporting system for aquatic animal diseases of national significance. All the diseases currently reportable to the World Organisation for Animal Health and any other aquatic animal diseases of national significance are included on Australia's National List of Reportable Diseases of Aquatic Animals.

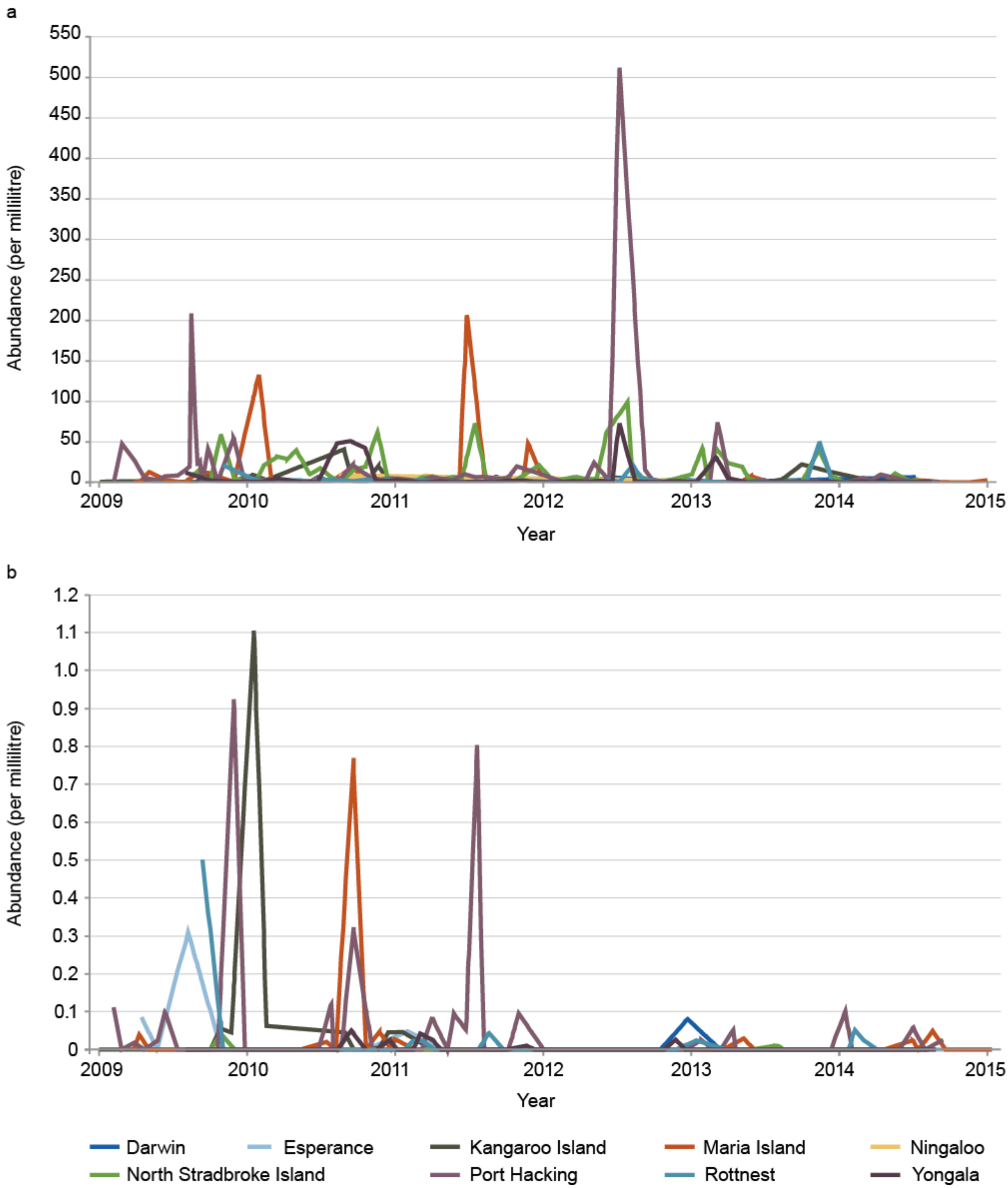
Based on reporting of events, there are currently no regionally or nationally significant changes to marine ecosystems because of diseases, parasitic infestations or mass die-offs. Recent trends appear to be stable, with only 2 major fish die-offs reported in 2011–15: 1 in South Australia in 2014 and 1 in Western Australia in 2015. This suggests that conditions have not changed since SoE 2011.

During 2011–16, blooms of the alga *Karenia mikimotoi* resulted in major fish kills in South Australia in 2014, and the alga *Chaetoceros* sp. bloomed in 2015 in Western Australia with similar results. A prolonged and extensive bloom of *Alexandrium tamarense* along the east coast of Tasmania in 2015–16 contaminated mussels, oysters, scallops and, ultimately, rock lobsters. Shellfish harvest areas were closed from late July to late November 2015, and some wild fisheries blocks remain closed. This followed a harmful algal bloom in Tasmanian waters in 2012, which cost $23 million in lost fishery and aquaculture production (Campbell et al. 2013; see also the *Coasts* report).

Based on observations of concentrations of harmful algal species from the IMOS National Reference Stations, there is no evidence of an increase in the frequency of harmful algal blooms since 2011 (Figure MAR34). Although not specifically designed to monitor harmful algal species, the network of stations provides one of a limited number of datasets from areas outside estuaries, embayments and near-coastal regions that can currently be used to investigate algal blooms. Large-scale algal blooms can also be monitored via satellite imagery; however, these datasets are limited by cloud cover, and algal blooms have to be large enough to be identifiable.

Similarly to harmful algal species, many marine animals associated with 'outbreaks' occur naturally within the marine environment. It is only when spawning coincides with favourable conditions that these species reach outbreak densities and can affect marine ecosystems, marine industries and, in some cases, humans. Examples of these are the crown-of-thorns starfish and jellyfish blooms.

The high fecundity of crown-of-thorns starfish means that, when spawning coincides with favourable conditions, resulting recruitment can lead to outbreak densities of large starfish that can deplete local coral cover within 3–5 years (Kayal et al. 2012). Populations then collapse through starvation and disease, but not before they spawn abundant planktonic offspring, which can form secondary outbreaks on downstream reefs. There have been 4 synchronised eruptions of



Source: Richardson et al. (2015)

Figure MAR34 Timeseries of the abundance of harmful algae (a) *Pseudo-nitzschia* spp. and (b) *Dinophysis* spp. at the Integrated Marine Observing System National Reference Stations, 2009–15 secondary outbreaks of crown-of-thorns starfish in the highly connected Great Barrier Reef since 1960. From 1990 to 2012, crown-of-thorns starfish have contributed to approximately 40 per cent of the overall decline in coral cover on the Great Barrier Reef (GBRMPA 2014a). Outbreaks have also been recorded in all other parts of the starfish's Australian range (far northern Great Barrier Reef, Torres Strait, north-western Western Australia), but their significance is uncertain because systematic monitoring was only recently implemented or is non-existent (see Box MAR5). Trends in crown-of-thorns starfish numbers in other regions of northern Australia are less certain because of lack of observations, but numbers appear to have increased since 2011 on both coasts. The state of the environment in relation to crown-of-thorns starfish is regarded as poor and deteriorating. Although outbreaks are difficult to predict, both the dynamics of previous outbreaks and population models suggest that the central Great Barrier Reef may experience another wave of crown-of-thorns starfish outbreaks in the next decade, with negative impacts on the abundance of coral within the Reef (Mumby & Anthony 2015).

Jellyfish blooms affect marine industries by stinging humans (potentially leading to fatalities), clogging intake pipes and fishing nets, killing fish, and reducing the abundance of commercial fish through competition and predation (Richardson et al. 2009). No systematic monitoring of jellyfish currently exists for areas outside estuaries, enclosed embayments and near-coastal regions. Given a lack of reporting of large blooms of jellyfish in the marine environment, it is assumed that the current state is good, with trends currently unclear.

Outbreaks of crown-of-thorns starfish and jellyfish blooms have been associated with high run-off events that increase nutrients in the marine environment and thereby increase phytoplankton abundance—a food source for crown-of-thorns starfish and jellyfish larvae (Richardson et al. 2009, Fabricius et al. 2010). Direct drivers and processes for these outbreaks are still uncertain, and, as a result, projections of outbreaks are also highly uncertain.

Introduced species

More than 250 introduced marine plants and animals are established in Australian waters (NSPMMPI 2014). Some have hitchhiked to Australian waters on the hulls of vessels of all types, from yachts to commercial cargo vessels, or in their ballast water. Others have been introduced to support local aquaculture, or through the aquarium industry. Some have displaced our native species from their habitats, modifying ecosystems and affecting marine industries (Bax et al. 2002, Ross et al. 2003, Hayes & Sliwa 2003; see also the *Coasts* report).

Many of the species introduced to Australia, however, do not become established (i.e. survive long enough to reproduce, complete a full lifecycle and establish a population), and most established species do not become widespread or invasive in terms of their distribution and numbers. This is largely because environmental conditions at introduction sites are not suitable, and/or native species outcompete species before they can become established and invasive. Many species will remain restricted to areas in ports or other semi-enclosed areas close to their point(s) of introduction. Introduced species in these environments are discussed in the *Coasts* report.

Several species are more widespread in the marine environment. The New Zealand screw shell (*Maoricolpus roseus*) was introduced to southern Tasmania in the 1920s, probably as part of rock ballast discharged by ships taking timber to New Zealand, and is now widespread across the continental shelf (Gunasekera et al. 2005). The northern Pacific seastar (*Asterias amurensis*), originally from Japan, was first established in the Derwent River estuary in the early 1980s, through either hull fouling or ballast water discharge, although it was not detected for 10 years. It has now spread along the eastern Tasmanian coastline to Banks Strait and was detected in Port Phillip Bay in 1995, where it increased to approximately 30 million individuals within 2 years (Ross et al. 2003). Japanese seaweed, or wakame (*Undaria pinnatifida*), was found in 1988 near Triabunna on Tasmania's east coast, probably introduced in ballast water or as biofouling, and was subsequently spread along the coast by fishing and recreational boats, where its establishment was aided by dieback of the native macroalgae canopy (Valentine & Johnson 2004).

Once introduced species have become widespread in the marine environment, control can be prohibitively expensive or unfeasible. An exception occurred in 1999 when Australia became the first country to eradicate an established introduced species, the black-striped mussel (*Mytilopsis sallei*), from 3 marinas in Darwin (Bax et al. 2002).

Under the EPBC Act, introduced species that threaten, or may pose threats to, native species or ecological communities can be listed as key threatening processes, and a subsequent threat abatement plan developed. To date, no introduced species has been listed.

Fortunately, the establishment and spread of introduced species remain rare events, with no change in the state and recent trends of invasive species in the marine environment since 2011. Many species have been in Australia for a significant period, and many have potentially reached an equilibrium state. If this is the case, and given that the major vectors for most introduced species (hull fouling, ballast water, the aquarium trade) have existed for some time, it could be assumed that, if translocation of additional introduced species could occur, it would have done so already. However, changes in international trade routes and a changing receiving environment can provide new opportunities.

Biosecurity measures are in place to manage several major vectors for introduction of species (ballast water and the international aquarium trade), and are under development to manage biofouling on international vessels. These biosecurity measures are designed to minimise new incursions, which are inherently difficult to predict. The history of introductions is replete with unexpected events that establish a species at one location, with the spread of the species then occurring decades later when changed environmental conditions facilitate it. This highlights the need for early detection; some states have developed programs that encourage the public to report unknown species that may potentially be introduced and invasive. Ongoing monitoring for introduced species is cost and labour intensive. Monitoring effort has varied considerably between jurisdictions and is mostly limited, despite concentrated efforts to develop monitoring systems (DAWR 2015). As a result, any limitations to Australia's national and local prevention arrangements are likely to be identified through the establishment of an introduced species. The development of new technologies may provide more viable monitoring options in the future, which are likely to not only allow early detection but also inform regulation development.

The fan worm (*Sabella spallanzanii*), an introduced marine pest species
Photo by CSIRO

Assessment summary 4
State and trends of indicators of marine ecosystem health

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Water turbidity, transparency and colour	There are relatively limited areas of naturally high turbidity				
Connectivity based on physical processes	Connectivity between regions is influenced by physical processes and is highly dynamic. Changes in physical processes associated with climate change are assumed to be affecting connectivity, with flow-on biological impacts	Not assessed			
Trophic structures and relationships	Current state is highly variable. Locations highly impacted by climate or cumulative pressures are in poor condition, whereas other locations are stable and in good condition	?			
Marine microbial communities and processes	Methods for assessment of communities have only recently become available, and development of baselines has only just started, so an assessment of status and trends is not possible	Not assessed			
Primary productivity	Trends are regionally variable, and depend on the magnitude and timing of nutrient supply				
Secondary productivity	Grade and trend based on inshore and offshore areas in all marine regions				
Benthic productivity	Unable to be assessed at a regional or national scale because of lack of data	Not assessed			
Herbivory processes	Unable to be assessed at a regional or national scale because of lack of data	Not assessed			
Viral diseases, parasitic infestations and mass die-offs	No major disease outbreaks have occurred outside coastal areas; national conditions remain stable				

Assessment summary 4 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Algal and jellyfish blooms	Assessment based on a limited number of sites in each marine region	—			
Crown-of-thorns starfish	Outbreaks have been highly cyclical in the past 50 years, but long-term trends are unclear. Outbreak populations are higher in the north-east than in the north-west	?			
Number and abundance of National Introduced Marine Pest Information System–listed species	There have been no reports of significant changes in the distribution and impacts of National Introduced Marine Pest Information System–listed pests	—			
Number and abundance of introduced species	The number of introduced pests has increased over time, but information on their abundance (and any changes in abundance) is lacking, and associated impacts are highly uncertain	?			

Recent trends

- Improving
- Deteriorating
- Stable
- ? Unclear

Grades

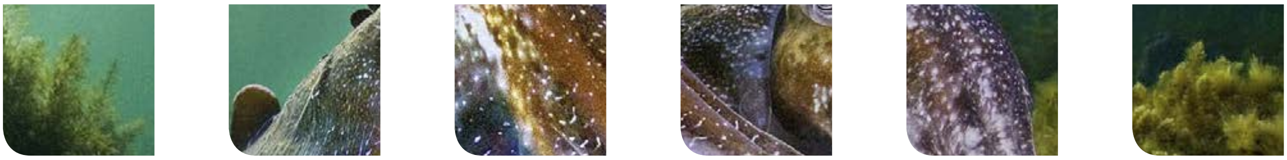
- **Very good:** Very few, if any, changes in physical, chemical or biological processes have occurred as a result of human activities or declining environmental conditions
- **Good:** Some changes in physical, chemical or biological processes have occurred as a result of human activities or declining environmental conditions in some areas, but these are not significantly affecting ecosystem functions
- **Poor:** Substantial changes in physical, chemical or biological processes have occurred as a result of human activities or declining environmental conditions, and these are significantly affecting ecosystem functions in some areas
- **Very poor:** Substantial changes in physical, chemical or biological processes have occurred as a result of human activities or declining environmental conditions, and these are significantly affecting ecosystem functions across widespread areas

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 marine management

At a glance

The diversity of anthropogenic pressures on marine habitats and communities by different industries and sectors is a challenge for managers. Some pressures are increasing, others have declined following implementation of management frameworks, and new pressures and new sectors are developing. Managing the marine environment increasingly requires an understanding of how these different pressures interact and how management frameworks will interact across the different sectors, and sufficient monitoring to fill gaps in knowledge and provide an early warning of unexpected or infrequent disruptive events.

Many improvements to management frameworks across Australian Government, and state and territory jurisdictions, including the implementation of new national regulators, have had beneficial outcomes for the marine environment. However, efforts continue to be poorly coordinated across jurisdictions within sectors, although improvements have occurred in some sectors, such as fisheries and management of commercial vessels. Several strategies focused on conservation, biodiversity protection and sustainable development of Australia's environment have been released, providing frameworks for the coordination of management of the marine environment. Overall, however, coordination between sectors sharing common resources remains lacking, resulting in inadequate accounting for all pressures on a resource, and inconsistent collection and recording of data, which inhibits regional and national oversight. The lack of recognition of the cumulative effects of multiple pressures on marine resources and coordinated approaches to assessing and managing those pressures has the potential to result in gradual declines, despite appropriate management at the level of the individual pressure, sector or jurisdiction.

Mapping cumulative impacts requires spatially explicit information on habitats, communities and species groups; human uses and the pressures generated by human uses; and any feedbacks within the system—information that is frequently unavailable. As a result, assessments of cumulative impacts on the marine environment in Australia to date have been sparse. Modelling frameworks are now starting to provide the means to predict the impact of multiple environmental and anthropogenic pressures. Uptake of integrated approaches to the management of marine natural resources has been slow, and, although approaches such as ecosystem-based management may have been adopted at a policy level, practical implementation has been limited.

Outcomes of environmental protection for marine species and communities under the *Environment Protection and Biodiversity Conservation Act 1999* are mixed. Since the state of the environment 2011 report, no species have been removed from the list, and further species have been added to the list. Some species have been reclassified because of increasing threats, and ineffective management and mitigation of pressures and associated identified threats. There is a clear gap between identification of pressures and issues associated with threats in recovery plans, and implementation of activities that might mitigate pressures and assist the recovery of species or communities that are the focus of plans.

At a glance (continued)

Although the likely effects of climate variability and climate change are understood and some planning is under way, activities resulting from this planning are considered to lack effectiveness in addressing pressures, resulting in an anticipated lack of impact on outputs and outcomes. Continued development of management frameworks for commercial fishing, oil and gas extraction, and commercial vessels have improved their effectiveness, although some components of each and the spatial overlap between jurisdictions still need to be addressed. A risk-based management plan for international and domestic translocations of introduced species implemented under the Intergovernmental Agreement on Biosecurity came into effect in 2012. The acute impacts of anthropogenic noise are considered to be generally effectively managed; however, understanding of the impacts and management of increasing chronic impacts are lacking. Management frameworks considered to be currently only partially effective include those focused on recreational fishing and traditional resource use, although management of both is improving. The understanding of pressures associated with marine debris is improving from a low base, but planning, actions and outcomes are currently considered to lack effectiveness. Management of emerging industries such as marine mining remains partially effective, with little development of frameworks that might address future pressures.

The National Representative System of Marine Protected Areas is developing steadily, with 40 Commonwealth marine reserves added to those already proclaimed in the South-east Marine Region. Management plans for the marine reserves in the South-east Marine Region have been implemented, and those developed for the remaining reserves have recently been reviewed and are currently under consideration by the Australian Government. Marine parks and reserves now cover approximately 40 per cent of the Commonwealth marine area, and approximately 5–50 per cent of the area of state and territory waters.

Social licence to operate (SLO) is becoming more prominent across sectors. There has been a shift towards government regulation of company–community interactions, and incorporation of SLOs into environmental licensing systems. Many fisheries are now adopting third-party certification schemes through independent bodies such as the Marine Stewardship Council.

Prioritising the use of research and management resources continues to be an issue, because investment of funds and effort is finite. Targeting resources to areas where clear, cost-effective management actions have been identified, preferably as part of an adaptive management cycle, provides one approach to maximise investment returns.

Habitats are the natural capital that support the communities and species that provide ecosystem services and maintain ecosystem functioning. Many initiatives across jurisdictions have prioritised the protection and improvement of healthy marine habitats (e.g. the national strategy for research, development and extension for fisheries and aquaculture [FRDC 2010]; the Australian Fisheries Management Forum's national statement of intent on fisheries and aquaculture).

The diversity of anthropogenic pressures on marine habitats and communities by different industry and public sectors is a challenge for managers. Some pressures are increasing, others have declined following the implementation of active management frameworks, and new pressures and new industry sectors are developing. Managing the marine environment increasingly requires an understanding of how different pressures interact and how management frameworks might interact across different sectors, and sufficient monitoring to fill gaps in knowledge and provide an early warning of unexpected or infrequent disruptive events.

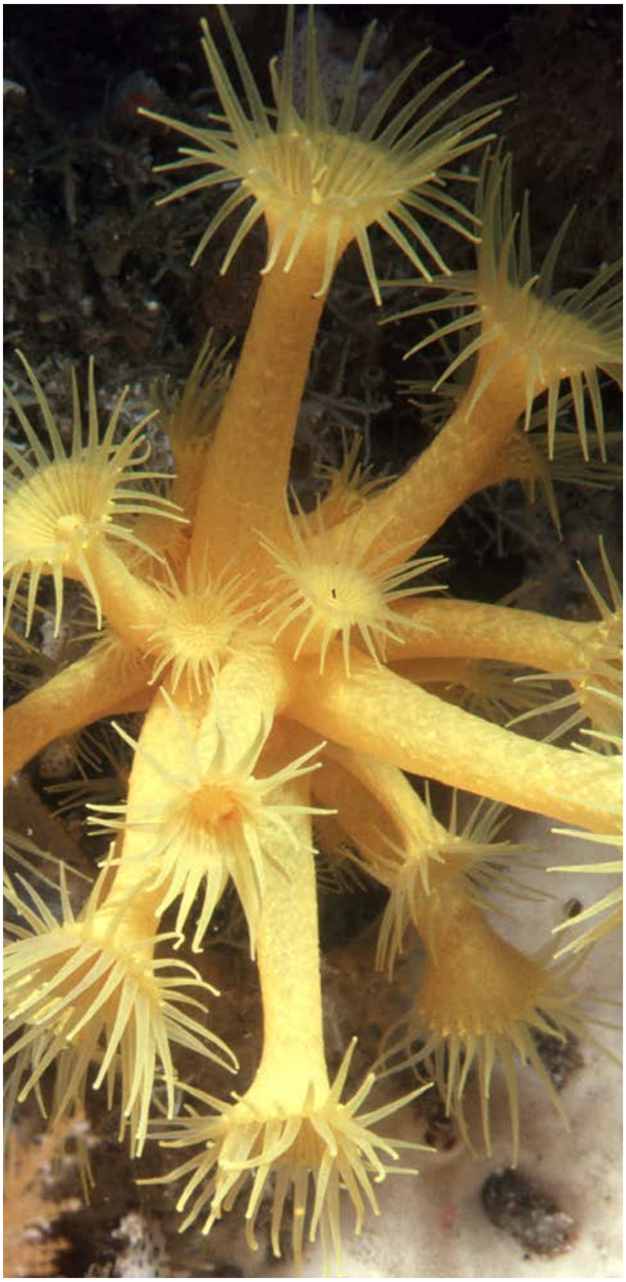
Varying approaches to the management of the marine environment are implemented around the world. Approaches range from simple controls on what can enter the marine environment and what can be taken from it, to active interventions such as restoration and restocking (Spalding et al. 2013).

Monitoring, evaluation, reporting and management frameworks designed to adapt to new information and changing circumstances are widely recognised as the foundations for effective management (Walters & Hilborn 1978). Widespread engagement of stakeholders helps to ensure that planning is transparent, frameworks are credible and stakeholders have some custodianship in achieving management objectives (Ehler 2014). A clear governance structure, based on sound policy with agreed and measurable management objectives, will support decision-making and provide identifiable indicators against which the implementation of the management system and its impact on target and nontarget resources can be evaluated (Dichmont et al. 2016).

One of the key gaps identified in previous SoE reports, similar reports produced at the state level and numerous other reports reporting on management of the marine environment has been coordination of management systems across jurisdictions. Marine management is required to address global and local pressures, and pressures that originate at a distance from their place of impact, including on land. Management measures should therefore be implemented across multiple scales and multiple jurisdictions, from local, and state or territory, to national and international. Poor coordination across sectors and jurisdictions sharing a common resource can result in redundancy of efforts. More importantly, a jurisdictional inability or failure to account for all pressures on a resource can result in its gradual decline, despite appropriate management at the level of the individual sector or jurisdiction.

Cross-jurisdictional management of Australia's marine environment remains under the control of the Offshore Constitutional Settlement, adopted in 1979. Under the settlement, each sector's issues are dealt with separately within agreed arrangements, which include a legislative package, an offshore petroleum package, an offshore fisheries package, a Great Barrier Reef package and new ancillary arrangements (Haward & Vince 2008). Although jurisdictional issues have been addressed within each of these sectors, coordination between sectors remains lacking.

Some progress has been made in implementing systems for reporting and assessing several activities by sectors across jurisdictions. In the fisheries sector, national assessment and reporting of key Australian fish stocks is occurring through a collaboration across all government fisheries agencies. Additionally, a national strategy for research, development and extension for fisheries and aquaculture (FRDC 2010) is in place under the broader National Primary Industries Research, Development and Extension Framework, which is a collaboration between Australian Government and state and territory agencies, and key research providers (see Commercial fishing). The formation of NOPSEMA now provides for national regulation of safety, well integrity, and environmental management of oil and gas operations in Australian waters, and in coastal waters where powers have been conferred by the state or territory (see Marine oil and gas exploration and production). The revised National Plan for Maritime Environmental Emergencies (AMSA 2015) provides a single, national, comprehensive and integrated response arrangement for management of maritime emergencies (see Marine vessel activity).



Yellow zoanthid soft coral (*Parazoanthus* sp.), found in rocky reefs
Photo by Graham Blight

Several strategies focusing on conservation, biodiversity protection and sustainable development of Australia's environment have been released, including Australia's Biodiversity Conservation Strategy 2010–2030 (NRMMC 2010), the Great Barrier Reef Marine Park Authority *Science strategy and information needs 2014–2019* (GBRMPA 2014b) and the National Marine Science Plan 2015–2025 (NMSC 2015). The National Representative System of Marine Protected Areas (NRSMPA) has been established, and the management plan for the first Commonwealth marine reserve network in the South-east Marine Region has been implemented (see Environment protection systems).

At the same time, however, several formal frameworks that facilitated national coordination between the Australian Government, and the states and Northern Territory on marine science strategy and investment have been devolved. These include the National Oceans Advisory Group, the Marine and Coastal Committee of the Natural Resource Management Ministerial Council and the supporting National Marine Protected Area Working Group.

A comprehensive assessment of the management arrangements for the Great Barrier Reef Marine Park and their effectiveness is provided in the *Great Barrier Reef outlook report 2014* (GBRMPA 2014a) and reviewed in Hockings et al. (2014), and will not be presented here.

Environment protection systems

Australia has more than 100 laws and policy instruments addressing aspects of management of the marine environment, and many incorporate principles such as sustainable development (Haward & Vince 2008). Managing the marine environment involves Australian Government, and state and territory jurisdictions, with separate but overlapping legislation, policies and environmental programs.

Australia's Oceans Policy, initiated in 1998, lacked agreement between the Australian Government and states and territories, and the first regional marine plan considered under this umbrella proved difficult to develop. The policy was reviewed in 2002 and effectively disbanded in 2005 (Haward & Vince 2008, Vince et al. 2015). However, it did lay the foundation for the regional marine plans, which were subsequently carried out under the EPBC Act.

Australian Government

The key piece of legislation that upholds protection of Australia's biodiversity and environment is the EPBC Act. The EPBC Act provides a national scheme under which matters of national environmental significance are directed to the Australian Government; the states and territories are responsible for environmental matters of state and local significance.

There are 9 matters of national environmental significance, 6 of which are relevant to the marine environment:

- World Heritage properties
- National Heritage places
- listed threatened species and ecological communities
- migratory species protected under international agreements
- Commonwealth marine areas
- the Great Barrier Reef Marine Park.

Approval under the EPBC Act is required if an activity is likely to have a significant impact on any of these. Key criteria are identified in determining what a significant impact is in relation to each of the matters of national environmental significance, and a precautionary approach is taken when determining whether a significant impact is 'likely' (DoE 2013). Activities carried out under the EPBC Act include:

- protection of listed threatened species and communities
- protection of species under international agreements to which Australia is party
- assessment of activities that are likely to have a significant impact on the environment, such as fisheries, energy production and defence activities
- marine bioregional planning and, in association, implementation and management of Australian marine areas
- management of World Heritage places.

A wide range of species and species groups are protected under the EPBC Act (Table MAR4). In some cases, this is because their populations are identified as being threatened and requiring protection, whereas, in others, it is because they are listed under international agreements to which Australia is a signatory. For example, under the EPBC Act, all marine mammals in Australian waters are listed as either cetaceans or marine species, and several species identified as being migratory (e.g. seabirds, sharks, rays, marine turtles) are also listed. Since 2011, no species has been removed from the list; 2 sea snakes, 2 seabirds, 2 sharks, 1 sawfish and 1 fish have been listed; and 2 fish species have been reclassified as critically endangered. The east coast and west coast Australian populations of humpback whales remain listed as vulnerable under the EPBC Act, although they have increased substantially from pre-whaling levels, with the eastern population considered to be close to carrying capacity (Noad et al. 2011) and no longer at risk of extinction. Their reclassification under the EPBC Act to reflect the increase in populations would highlight a conservation success (Bejder et al. 2016).

In response to the listing of species, conservation advice is developed that provides guidance on immediate recovery and threat abatement activities that can be undertaken to ensure the conservation of a newly listed species or ecological community. For some species and ecological communities, recovery plans may also be developed, although they do not provide a mechanism for subsequent implementation. Adopted recovery plans generally span 5 years, but this may be shorter or longer, depending on the requirements of the species or ecological community. At the end of the period of the plan, progress against the plan's objectives is reviewed. Further recovery plans may be put in place following the review. Recovery or management plans are in place for 42 species, and a further 8 have been identified as requiring plans to be prepared. A recovery plan for giant kelp forests of south-eastern Australia is yet to be prepared.

The EPBC Act identifies a number of key threatening processes to the environment and coordinates responses to these through threat abatement plans. In the marine environment, 3 key threatening processes have been identified:

- incidental catch of marine turtles by trawling operations
- incidental catch of seabirds by longline operations
- entanglement or ingestion of marine debris by marine vertebrates.

Table MAR4 Number of marine threatened species listed under the categories of the EPBC Act in the marine environment jurisdictions covered by this report

Species group	Extinct	Critically endangered	Endangered	Vulnerable	Conservation dependent
Whale, dolphin, porpoise	0	0	2	3	0
Seal, fur seal, sea lion	0	0	0	3	0
Marine turtle	0	0	3	3	0
Sea snake	0	2	0	0	0
Seabird	0	2	10	24	0
Shark, skate, ray	0	2	2	6	3
Fish	0	2	0	2	4
Seastar	0	0	0	1	0
Seaweed	1	0	0	0	0

EPBC Act = *Environment Protection and Biodiversity Conservation Act 1999*
Note: Species do not include shorebirds (refer to the *Coasts* report), or subantarctic or Antarctic species (refer to the *Antarctic environment* report).
Source: EPBC Act List of Threatened Flora and Fauna

Threat abatement plans have been developed for the impacts of marine debris on vertebrate marine life (DEWHA 2009a) and the incidental catch (or bycatch) of seabirds during oceanic longline fishing operations (DoE 2014). The threat abatement plan for the entanglement or ingestion of marine debris by marine vertebrates was recently reviewed (DoE 2015b). The review concluded that, despite progress, particularly in clean-up efforts, it was not possible to state that criteria for success had been met during the life of the plan, and the plan should be revised. In addition, the Australian Senate referred an inquiry into the threat of plastic pollution in Australia and Australian waters to the Environment and Communication References Committee in 2015, and the report detailing the Committee's findings was released in 2016 (ECRC 2016; see also Marine debris).

The EPBC Act provides for the proclamation and management of marine reserves, with reserves managed in accordance with principles prescribed for the International Union for Conservation of Nature's internationally recognised set of protected area management categories. An NRSMPA has been developed for Australian marine waters—it was first identified by the Intergovernmental Agreement on the Environment 1992, and agreed to by the Australian and state and territory governments in 1998. The marine bioregional planning process provides the support framework for implementing the NRSMPA in the Commonwealth marine area, with the aims that the NRSMPA be comprehensive, adequate and representative, and, among other criteria, minimise socio-economic costs arising from displacing activities and resource access (National Principle 9; DEWHA 2009b).

The first network of 14 Commonwealth marine reserves (CMRs) was proclaimed in the South-east Marine Region in 2007, before the start of the marine bioregional planning program. Draft marine bioregional plans and marine reserve network proposals were produced for each of the remaining marine regions in 2011–12. The proposed network was reported to include areas accounting for 1 per cent (by value) of Australia's annual commercial catch, and would have closed 4 per cent of Commonwealth waters within 100 kilometres offshore to recreational fishing. The plans were contentious among stakeholders and the public; after 245 public meetings, involving about 2000 people, an additional 566,377 written submissions were received, most focusing on the draft marine reserves network proposals. A further approximately 80,000 submissions were received focusing on the final network proposals. In November 2012, 40 CMRs were proclaimed in the South-west, North-west, North, Temperate East and Coral Sea marine regions, completing the NRSMPA in the Commonwealth marine area. Following continuing disquiet from some stakeholders, the CMRs were reproclaimed in December 2013, and the management plans for all regions except the South-east were set aside. The 10-year South-east Management Plan came into effect in 2013, with management under the Director of National Parks in accordance with the EPBC Act. A review of the new CMRs and how they are to be managed started in August 2014, with further extensive stakeholder consultation. Two reports (a review by a scientific panel and a review by a bioregional advisory panel) were released in August 2016.

Reviews of the CMRs identified that there was a general lack of coordination across the network, and inconsistencies in zoning and allowable uses, particularly with the remainder of the NRSMPA. These inconsistencies could result in complexities in management across the network, making varying compliance and enforcement across the network difficult for users to understand (Buxton & Cochrane 2015). It was also identified that a robust adaptive management approach based on well-targeted long-term monitoring and evaluation would be required if management of the CMRs was to be effective and efficient. There would need to be significant investment in new infrastructure and capability beyond that currently provided, to provide adequate coverage of the CMRs in support of adaptive management of the CMRs and Australia's marine estate in general (Beeton et al. 2015). Continuing support for IMOS and the Australian Ocean Data Network was identified as a vital part of the monitoring process. Overall lack of clarity around the conservation objectives of the CMRs was highlighted as needing to be addressed, to identify and address potential risks and impacts of activities, and to assist in the development of performance indicators that could be measured (Buxton & Cochrane 2015). Greater consultation of stakeholders in the development, management, monitoring and reporting of the CMRs through the implementation of robust, sustainable and effective mechanisms for engagement was also highlighted as a requirement.

Starfish (*Pentagonaster dubeni*), Houtman Abrolhos Islands, Western Australia
Photo by Institute for Marine and Antarctic Studies

In particular, involvement of Indigenous communities in the planning and management of the CMRs, particularly where land and sea Country rights and responsibilities extend into the CMRs, was needed (Buxton & Cochrane 2015). The recommendations made by the reviews are currently being taken into consideration in the preparation of draft management plans for the CMRs.

The iconic nature of Australia's marine environment and the need to protect the environment is recognised internationally; the Great Barrier Reef, the Lord Howe Island Group, the Ningaloo Coast and Shark Bay have all been listed as World Heritage Areas under the World Heritage Convention. As a party to the convention, Australia has committed to implementing management plans, and a system that ensures the effective protection of each site for present and future generations, with the Australian Government having primary responsibility for these. Management of World Heritage Areas varies—some are managed by the Australian Government and some by relevant state agencies. The Great Barrier Reef is managed by the Great Barrier Reef Marine Park Authority, which is tasked with managing the marine park under the *Great Barrier Reef Marine Park Act 1975*.

A joint monitoring mission by the World Heritage Centre and the IUCN visited the Great Barrier Reef World Heritage Area (GBRWHA) in 2012 amid concerns of increasing impacts from ongoing environmental pressures. In 2015, and following announcement of the Reef 2050 Long-term Sustainability Plan (Australian Government & Queensland Government 2015), the World Heritage Committee determined that it would not list the GBRWHA as 'in danger'. It requested a state of conservation report in 2019 and an update on progress with implementation of the Reef 2050 Long-Term Sustainability Plan to be submitted in December 2016.

Beyond the EPBC Act, the Australian Government has a complex set of policies and legislation in place to regulate and manage use of the marine environment (Table MAR5). Key Acts include:

- the *Fisheries Administration Act 1991* and the *Fisheries Management Act 1991* for the regulation and management of commercial fisheries by AFMA
- the *Offshore Petroleum and Greenhouse Gas Storage Act 2006*, under which offshore petroleum activities are managed by NOPSEMA
- the *Australian Maritime Safety Authority Act 1990*, the *Navigation Act 2012* and the *Shipping Registration Act 1981* for the regulation and management of marine vessels by the Australian Maritime Safety Authority (AMSA), and the Australian Government Department of Infrastructure and Regional Development
- the *Biosecurity Act 2015* for the regulation and management of biosecurity risks associated with goods, people and conveyances entering Australia, including introduced species
- the *Protection of the Sea (Prevention of Pollution from Ships) Act 1983*, the *Protection of the Sea (Harmful Anti-fouling Systems) Act 2006* and the *Environment Protection (Sea Dumping) Act 1981* for the regulation and management of marine pollution, marine debris and wastes; AMSA is responsible for the *Protection of the Sea (Prevention of Pollution from Ships) Act 1983* and the *Protection of the Sea (Harmful Anti-fouling Systems) Act 2006*, and the Australian Government Department of the Environment and Energy is responsible for the *Environment Protection (Sea Dumping) Act 1981*
- the *Offshore Minerals Act 1994* for the regulation and management of marine mining by the Australian Government Department of Industry, Innovation and Science
- the *Renewable Energy (Electricity) Act 2000* for the regulation and management of electricity generation from renewable energy sources by the Clean Energy Regulator.

State and territory governments

The states and the Northern Territory have a complex set of policies and legislation in place to protect, regulate and manage activities in the marine environment (Table MAR5). All have equivalent agencies and responsibilities covering the marine environment in state and territory waters, although they vary in the way that they are structured and operate.

Systems for listing threatened species operate in all states and the Northern Territory (Table MAR6), and some jurisdictions (e.g. New South Wales) have mechanisms for listing key threatening processes. Processes for listing particular species are specific to each state and territory. Species that are listed under state or territory legislation may differ from those

Table MAR5 Legislation for protecting the marine environment and regulating key pressures across Australian jurisdictions

Legislated pressure or item	Australian Government	NSW	NT	Qld	SA	Tas	Vic	WA
Threatened species	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Climate change (greenhouse gas emissions reduction)	No	No	No	No	Yes	Yes	Yes	No
Fishing	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Traditional use of resources[a]	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Oil and gas exploration and production	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Marine mining and industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Marine renewable energy generation[b]	Yes	No	No	No	No	No	Yes	No
Vessel activity	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pollutants, debris and wastes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

NSW = New South Wales; NT = Northern Territory; Qld = Queensland; SA = South Australia; Tas = Tasmania; Vic = Victoria; WA = Western Australia

a In the Northern Territory, the Indigenous Fisheries Development Strategy 2012–14 aims to review and update the definition of 'customary fishing' in the Northern Territory *Fisheries Act 1988*, so customary fishing rights are enshrined in the Act. In NSW, the Aboriginal Cultural Fishing Interim Access is in place until an amendment of the *Fisheries Management Act 1994* is enacted. In Victoria, amendments to fisheries legislation and regulations are being developed to remove inconsistency with the *Native Title Act 1993* under the Victorian Aboriginal Fishing Strategy.

b Most jurisdictions do not have legislation specific to renewable energy; however, electricity generation from renewable sources is incorporated into legislation regulating electricity generation.

species listed under the EPBC Act, and species may be listed under different categories in different jurisdictions. For example, under the EPBC Act, leatherback turtles are listed as endangered, whereas, under the *Territory Parks and Wildlife Conservation Act 2014* (NT), the species is listed as critically endangered. In addition, classifications across jurisdictions can also differ because of differing classification frameworks. For example, species can be classified as extinct, endangered, vulnerable or rare under the *Threatened Species Protection Act 1995* (Tas), whereas, under the *Nature Conservation (Wildlife) Regulation Act 2006* (Qld), they can be classified as extinct in the wild, endangered, vulnerable or near threatened. Some states (e.g. New South Wales, Victoria, South Australia, Western Australia) also list ecological communities.

Systems of marine reserves have been implemented across all states and the Northern Territory (Table MAR7), some of which contribute to the NRSMPA. New marine reserves declared since January 2011 and reported in the 2014 Collaborative Australian Protected Area Database include reserves in the Northern Territory (675 square kilometres), Queensland (256 square kilometres), Tasmania (31 square kilometres) and Western Australia (10,055 square kilometres).

Table MAR6 Number of threatened species (various categories) identified under state and territory legislation in the marine environment jurisdictions covered by this report

Species group	NSW	NT	Qld	SA	Tas	Vic	WA
Whale, dolphin, porpoise	4	0	3	21	4	3	6
Seal, fur seal, sea lion	2	0	0	2	1	1	1
Marine turtle	3	5	6	3	4	1	6
Sea snake	0	0	0	0	0	0	2
Seabird	22	0	12	20	18	19	20
Shark, skate, ray	0	5	2	0	2	1	3
Fish	0	0	0	0	1	0	0
Starfish, sea cucumber	0	0	0	0	0	8	0
Seaweed	0	0	0	0	1	0	0
Other	0	0	0	0	0	3	0

NSW = New South Wales; NT = Northern Territory; Qld = Queensland; SA = South Australia; Tas = Tasmania; Vic = Victoria; WA = Western Australia

Since 2011, several states have introduced strategies, management plans and initiatives relating to marine conservation areas, including:

- *NSW 2021: a plan to make NSW number one* (NSW Government 2011), which sets out goals associated with protecting and conserving biodiversity, including establishing more conservation areas across New South Wales
- South Australia's Strategic Plan (South Australian Government 2011a) and the South Australian natural resources management plan (South Australian Government 2011b), which set out targets for the marine environment, including management, monitoring and evaluation of its marine park network
- drafting and finalisation of the management plans for South Australia's marine parks network
- the Kimberley Science and Conservation Strategy, in which the Western Australian Government is investing in research and monitoring projects, including working with traditional owners in the creation and management of marine parks in the Kimberley region
- various changes to zoning and permitting associated with conservation areas across several states.

The variety of marine planning by Australian jurisdictions leads to a complex spatial management structure. For example, some areas can be subject to specific fishery zoning and spatial biodiversity management plans, while also focusing on management of oil leases, oil wells, vessel activity, commercial fishing and other marine uses (e.g. Figure MAR35). These are all managed independently of each other and, in some cases, are managed separately and independently across jurisdictions. There are, however, some consultative mechanisms either currently in place or being developed across jurisdictions to facilitate consultation and assist with decision-making (e.g. the Australian Fisheries Management Forum and the North East Water Space Management Group, which bring together government agencies from Australian, and state and territory jurisdictions).

Several states (e.g. Queensland, New South Wales, Victoria, South Australia) prepare reports on the status of the environment as a requirement of environmental legislation. Similarly to this national SoE report, they provide regular updates on the current state and key pressures influencing the environment to assist with decision-making in each jurisdiction (see EPA WA 2007, TPC 2009, DEHP 2011, NSW EPA 2012, CESV 2013, EPA SA 2013).

Table MAR8 Area of Australia's marine parks and reserves (km²) by IUCN management category as reported in the 2014 Collaborative Australian Protected Area Database

IUCN category	Australian Government	NT	Qld	NSW	Vic	Tas	SA	WA	Total
IA	2,122	0	411	0	21	1	3,127	3,126	8,808
IB	0	0	0	0	0	0	0	0	0
II	1,075,760	0	16,607	666	533	328	3,100	8,754	1,105,748
III	0	0	0	0	109	0	7	631	745
IV	579,548	0	8,996	1,688	0	13	15,199	4,181	609,625
V	4,326	0	0	0	0	0	0	0	4,373
VI	1,287,733	2,909	17,697	1,134	681	179	8,318	11,543	1,330,194
Total	2,949,489	2,909	43,711	3,488	1,344	568	29,751	28,235	3,059,493
% of total jurisdictional area	40.59	4.05	35.83	39.63	13.16	2.54	49.56	24.40	39.85

IUCN = International Union for Conservation of Nature; NSW = New South Wales; NT = Northern Territory; Qld = Queensland; SA = South Australia; Tas = Tasmania; Vic = Victoria; WA = Western Australia

Note: The table does not include the reserves or that area of the exclusive economic zone (EEZ) surrounding Macquarie Island (reserves: 162,756 km², EEZ: 471,837 km²), and Heard Island and McDonald Islands (reserve: 70,953 km², EEZ: 410,722 km²); see the *Antarctic environment* report for marine parks and reserves in the subantarctic and Antarctic regions. The table does not include marine Indigenous Protected Areas, as they are currently not listed in the Collaborative Australian Protected Area Database. The area of the Australian Government marine parks and reserves includes the Great Barrier Reef Marine Park, of which approximately 77,329 km² is within Queensland state waters. It also includes those parts of the National Representative System of Marine Protected Areas for which management plans are yet to be implemented. The area of the Queensland marine parks and reserves includes a portion that are in Commonwealth waters, the majority associated with the Great Barrier Reef Coast Marine Park (approximately 13,600 km²). Marine areas were derived from the Maritime Boundaries Program, Geoscience Australia. Areas have been rounded to the nearest kilometre.

Source: Collaborative Australian Protected Area Database

Sustainability and sector management

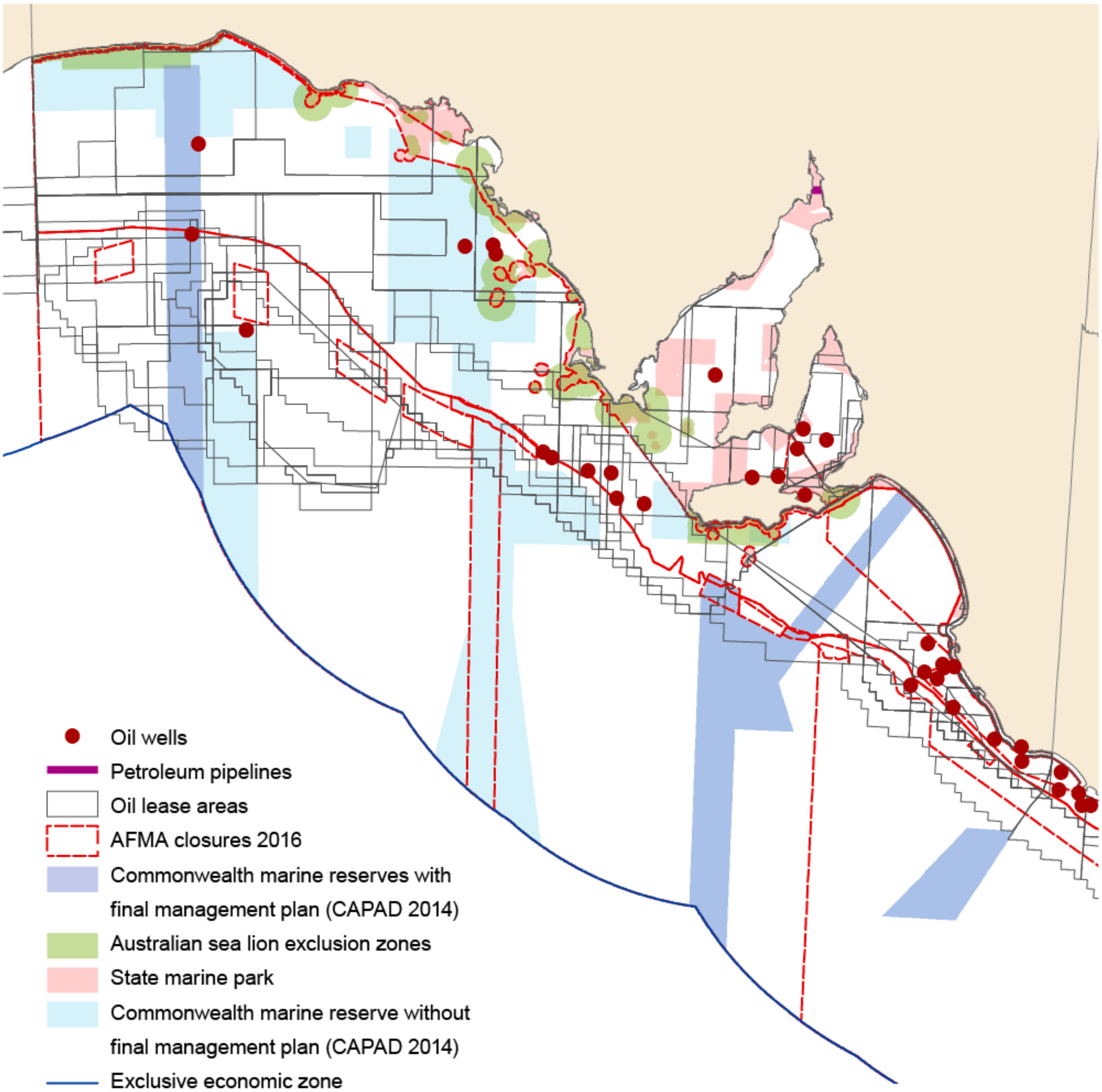
Managing for externalities

Climate variability and longer-term change

Australia is a world leader in the understanding of climate systems and climate change as a result of strong collaborations and partnerships between research institutes and agencies, both nationally and internationally. Changes to marine systems associated with climate variability on seasonal, interannual, decadal and longer timescales are well understood, and the anticipated changes, particularly to physical systems, as a result of ongoing climate change are relatively well known. The effects on biological systems are less well known. The rate of change, interactions between the changing components of the environment and, therefore, the extent of change are dependent on future changes in anthropogenic greenhouse gas emissions (i.e. reduction, no change or increase), which are unknown.

The Climate Change Authority, established by the Australian Government in 2011 under the *Climate Change Authority Act 2011*, is tasked with providing independent advice on climate change policies, and undertaking reviews and making recommendations on:

- emissions reduction targets and carbon budgets
- the Renewable Energy Target
- the Carbon Farming Initiative
- the National Greenhouse and Energy Reporting System.



AFMA = Australian Fisheries Management Authority; CAPAD = Collaborative Australian Protected Area Database
Note: Fishery closures are copyright of AFMA.
Source: National Environmental Science Programme Marine Biodiversity Hub

Figure MAR35 Example of marine spatial management in the Great Australian Bight off South Australia by multiple sectors and jurisdictions

Although the Australian Government is required to respond to reports released by the authority, there is no obligation to follow its recommendations.

Internationally, Australia participates in the United Nations Framework Convention on Climate Change and the Kyoto Protocol that was developed in 1997 under this framework. Australia signed the Kyoto Protocol in 1998, and ratified the protocol 10 years later in 2007. Under the Kyoto Protocol, Australia was required to limit its average annual greenhouse gas emissions in 2008–12 to 108 per cent of its emissions in 1990.

In response to obligations under the Kyoto Protocol, Australia has a framework for reporting of greenhouse gases, and has set goals for the reduction of greenhouse gases to 5 per cent below 2000 levels by 2020, and 26–28 per cent below 2005 levels by 2030. More recently, Australia committed to the global agreement for climate action post-2020, which was concluded at the Conference of the Parties (COP21). The agreement has a global goal to hold average temperature increase to well below 2 °C and pursue efforts to keep warming below 1.5 °C above pre-industrial levels (see also the *Atmosphere* report).

Understanding of the impacts of climate variability and climate change on the economic benefits and cultural values of the marine environment for Australia is limited. Several products have been developed for use in developing processes to manage the impacts of climate variability;[8] however, these are relatively few, and the explicit incorporation of climate variability and climate change into most management frameworks is currently lacking. This is partly because of the complexity of responses of the marine environment to climate variability and climate change (Davidson et al. 2013, Creighton et al. 2015).

Legislation providing frameworks to directly address the impacts of climate variability or climate change are lacking across most jurisdictions, except for Victoria, Tasmania and South Australia. Each of these states has specific legislation aimed at addressing, mitigating or adapting to climate change (or any combination of these). Current assessments of management frameworks in place and their ability to contribute to global efforts to address climate change vary, with many considering that frameworks will need to be redesigned to meet current and any additional targets Australia might commit to in the future (e.g. Wood et al. 2015). Technological change and innovation will be crucial to reducing greenhouse gas emissions in the future (e.g. CSIRO 2015).

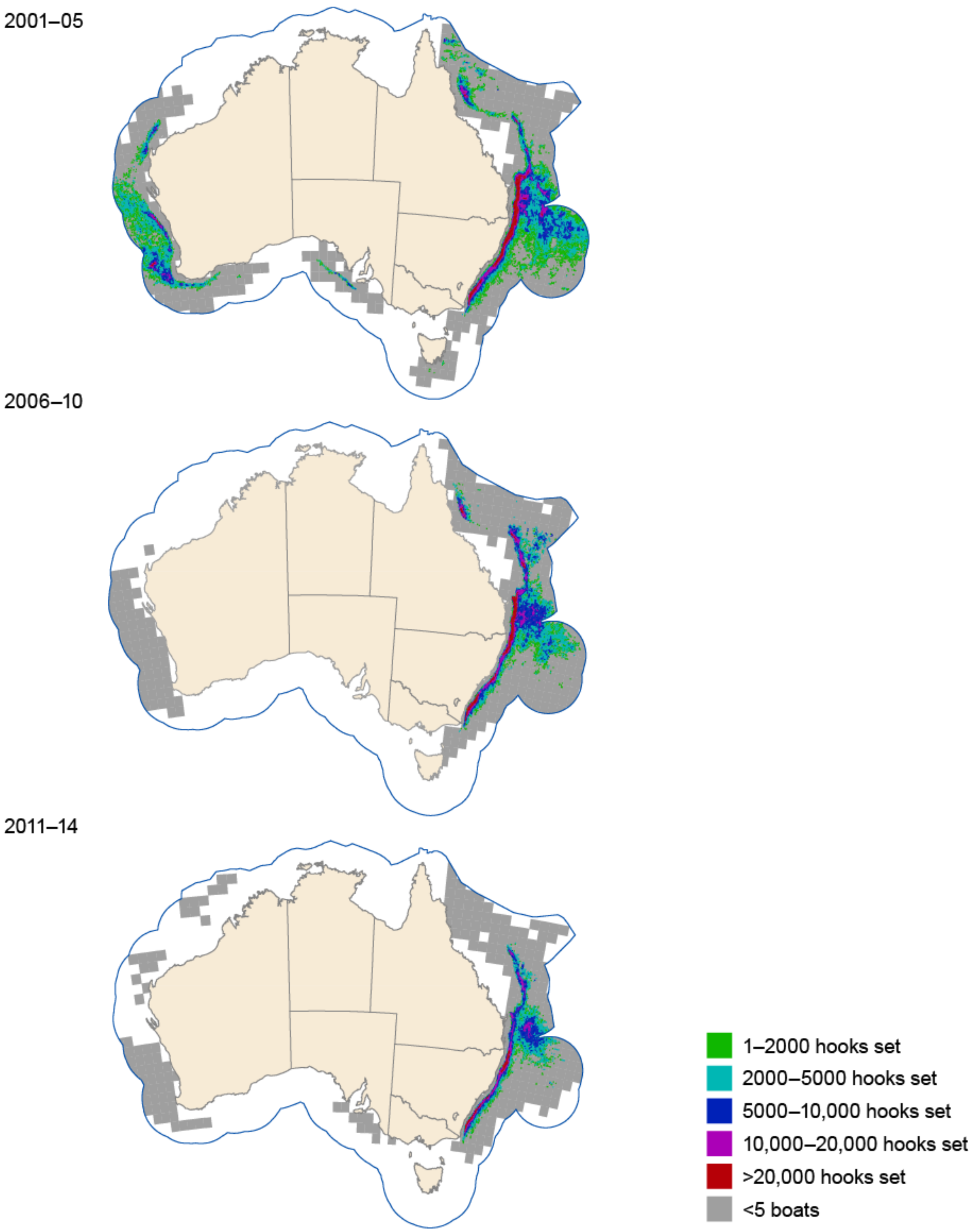
Commercial fishing

With the acknowledgement that development of industries within the marine environment needs to consider the environment and aim to achieve sustainability goals, understanding of the direct pressures on the marine environment from commercial fishing has increased. In response, in the past decade, fisheries management across all jurisdictions has introduced one or more measures to address the pressures that are increasingly based on risk assessment and implement a management response. These include harvest strategies for the main commercial species (see also Box MAR8), adaptive management involving expert judgement for both target and bycatch species, quantitative management strategy evaluation, ecosystem modelling, and broader ecological risk assessments.

In most fisheries, management and policy actions implemented during the past decade have led to industry restructuring and licence buybacks, resulting in progressive effort reduction (e.g. Figure MAR36; see also Box MAR2). Restructuring of fisheries in Australian waters has been associated with productivity increases, primarily because of the departure of less productive vessels, but also because of improvements in the remaining operators' ability to pursue productivity improvements to offset increased input costs (e.g. fuel and business overheads) and reduced competition among the remaining operators because of reductions in fleets (Stephan & Vieira 2013).

Spatial management has been introduced to mitigate the impacts of commercial fishing on vulnerable species and habitats (e.g. gulper shark closures in the Southern and Eastern Scalefish and Shark Fishery [AFMA 2012], the introduction of gillnet zoning closures to limit interactions with the Australian sea lion [AFMA 2015]). Similarly, spatial closures have been implemented that specifically prohibit commercial trawling within seagrass and other sensitive nursery habitats that are often used for many commercial fisheries—for example, the Shark Bay and Exmouth Gulf prawn trawl fisheries in Western Australia.

8 See, for example, Bureau of Meteorology.



Source: National Environmental Science Programme Marine Biodiversity Hub

Figure MAR36 Reduction and shift in pelagic longline fishery effort (number of hooks set) in Australian waters for each 5-year time period from 2001 to 2014

Closures of areas to fisheries have also been implemented in recent years by the Australian Government and the states. Although many of these measures were not specifically intended to reduce commercial fishing effort or the footprint of commercial fisheries (e.g. PIRSA 2013), some have effectively achieved this, and the recovery of affected sensitive fauna is expected as a result.

Of 53 countries (making up 95 per cent of global commercial fisheries catches) assessed, and based on 14 indicators of resource management, Australia's commercial fisheries management was ranked equal fourth overall and second in terms of sustainability (Alder & Pauly 2008).

Management of bycatch species varies across jurisdictions, reflecting inconsistencies in the level of reporting and understanding of the impacts of commercial fishing on bycatch species (see Commercial fishing under Pressures affecting the marine environment). In general, management of bycatch of protected species is more developed than management of species that are not protected. AFMA has developed fishery-specific work plans to address bycatch of high-risk and protected species in commercial fisheries managed by the Australian Government. Some states have developed management strategies that account for bycatch species in state commercial fisheries (e.g. NSW DPI 2006). Specific mitigation measures addressing the bycatch of protected species have been implemented across both Commonwealth, and state and territory commercial fisheries—these include seal and turtle excluder devices, square mesh panels in trawls, tori lines, and other seabird-deterrent devices. Education programs aimed at the commercial fishing industry provide a greater understanding of how to avoid and/or handle protected species (e.g. the code of practice for mitigating operational interactions between the South Australian sardine fishery and dolphins [Hamer et al. 2009], the guide for looking after protected species in Queensland [DEEDI 2010]). Targeted research programs aimed at reducing interactions have also been introduced in some regions (e.g. Fletcher & Santoro 2015).

Risk assessments carried out on commercial fisheries have identified a suite of byproduct and bycatch species that are not currently managed directly as being at risk from commercial fishing across a broad range of habitats (Hobday et al. 2011). Often, management of bycatch is approached on a fishery-by-fishery and jurisdictional basis, rather than being integrated across fisheries and jurisdictions. Species that are captured by several fisheries may be better managed by a single set of arrangements, rather than fishery-specific rules set up across different jurisdictions (Hobday et al. 2011).

The combined improvements through the implementation of the National Fishing and Aquaculture Research, Development and Extension Strategy, sharing of methods for assessing and managing fisheries, and a national approach to regularly reporting commercial fishery performance enable better targeting of limited resources to those areas where commercial fisheries pose the highest risk to the marine environment.

Since 2011, 2 important reviews of commercial fisheries called for by the Australian Government have occurred: the *Review of Commonwealth fisheries: legislation, policy and management* (Borthwick 2012), and an inquiry by the Productivity Commission into the regulatory burden imposed on the Australian marine fisheries and aquaculture sectors under parts 2 and 3 of the *Productivity Commission Act 1998* (PC 2016; see also Recreational fishing and Traditional use of marine resources). In addition, the report on the review of the Commonwealth Policy on Fisheries Bycatch was released (DAFF 2013b).

The review of Commonwealth fisheries management identified that the approach to management had been progressively adapted and refined to address a historical legacy of weak regulation. This resulted in chronic overfishing, which threatened the viability of many fishers and regional communities, and was indifferent to environmental consequences. The management framework was found to be well thought out, with a careful assessment of risks, both commercial and to the marine ecosystem (Borthwick 2012). The review made recommendations targeted at areas of management that needed improvement, including that there be clearer policy settings associated with target species (through the Commonwealth Harvest Strategy Policy), minimising effects on nontarget species (through the bycatch and discards policy) and safeguarding the broader marine ecosystem.

The review of the Commonwealth Policy on Fisheries Bycatch found that management actions on the whole had contributed to good bycatch management; however, it was difficult to assess the performance of the bycatch policy, and associated outcomes and trends. The review recommended that, in revising the policy (DAFF 2013b):

- a new definition of bycatch should be implemented that applies to noncommercial species
- effective monitoring and evaluation protocols should be developed
- the bycatch policy should be integrated with the Harvest Strategy Policy to facilitate seamless management of commercial species, and byproduct and bycatch species
- current policy objectives and implementation guidelines should be strengthened.

To address the issue of cumulative impacts on bycatch species, the identification of approaches to assessing and managing cumulative impacts was recommended as a priority (DAFF 2013b).

The draft report from the Productivity Commission inquiry into the regulation of Australian marine fisheries and aquaculture sectors was released in August 2016 (PC 2016). The report identified that, although fisheries policy had generally been successful in improving the sustainability of fisheries, there were still several issues that management of fisheries (commercial, recreational and Indigenous) across all jurisdictions could improve on. For commercial fisheries, issues included general use of inefficient and outdated management methods, and variable adoption of best-practice management techniques across jurisdictions. These were regarded as inhibiting the introduction of more cost-effective practices and introducing risks to the sustainability of cross-jurisdictional stocks.

Recommendations made by the Productivity Commission in relation to commercial fisheries included:

- movement of management to transferable quota systems, as a default position, which would result in fewer constraints on fishing practice, and provide a more efficient and effective means of adhering to harvest limits
- regular reviews of fishing regulations to ensure that they can continue to meet policy objectives
- accounting for impacts of other sectors on the commercial fishing sector
- reform of the management of cross-jurisdictional fisheries, including regular reviews of management to ensure that they remain fit for purpose
- dissolution of boundaries for cross-jurisdictional stocks through active cooperation
- introduction of clearer regulatory and reporting standards for protected species
- greater delegation of operational decision-making to fishery managers, thereby increasing efficiencies
- clearer policies on co-management of fisheries.

At the time of writing, public submissions of input to the draft were still open, with the final report to be released in December 2016.

It should be noted that clear benefits of developing management systems based on transferable quotas have been identified for many years (Grafton 1996, Squires et al. 1998); however, several reservations have also been raised about the use of such a management tool (e.g. Smith et al. 2009, Parslow 2010). At their essence, individual transferable quotas are an incentive-based fisheries management tool that uses economic self-interest to promote economic efficiencies, but by themselves do not ensure sustainability (Parslow 2010). Careful design of such systems is required if they are to be used as part of a broad ecosystem management framework (Grafton 1996, Sumaila 2010).

Box MAR8 Commercial fisheries managed by the Australian Government

In general, the Australian Government, through the Australian Fisheries Management Authority (AFMA), is responsible for commercial fishing beyond 3 nautical miles from the coast. Some fisheries managed through AFMA target fish stocks that extend into the high seas and the exclusive economic zones of other countries. These are jointly managed with other countries through conventions and agreements.

Key commercial stocks in fisheries are managed under the Commonwealth Fisheries Harvest Strategy Policy (HSP; DAFF 2007). The HSP requires an evidence-based approach to setting catch levels. It prescribes explicit limit and target biomass reference points to ensure that stocks are maintained at ecologically sustainable levels and, within this context, that economic returns to the Australian community are maximised. The key difference from previous forms of management in applying harvest strategies is the adoption of one or more pre-agreed decision rules. This links the management response explicitly to assessments of stocks and provides for adaptive management if there is a change in the status of stocks. A review of the HSP in 2013 (DAFF 2013a) found that the policy and guidelines improved the management of fisheries by the Australian Government. This was further supported in independent assessments of the policy (Smith et al. 2014), which also identified some of the challenges faced.

AFMA aims to implement an ecosystem-based approach to all fisheries, considering their interactions with, and impacts on, bycatch species, habitats, communities and ecosystems. Bycatch species are managed under the Commonwealth Policy on Fisheries Bycatch (DAFF 2000) and in line with requirements under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The policy aims to reduce bycatch and improve protection for vulnerable species through a risk management framework. A new bycatch policy is being developed, which will better align the policy with the HSP.

Reporting on the status of commercially targeted species

Since 1992, the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) has reported on the status of key commercial fishery stocks in Commonwealth fisheries (see Patterson et al. 2015a). Status assessments consider whether the size of a stock is adequate to sustain the stock above the level that would be considered overfished (biomass status) and whether current catch levels allow the stock to remain in that state (fishing mortality status).

In general, the number of stocks classified as not overfished and/or not subject to overfishing has increased since reporting at this resolution began in 2004 (before 2004, 1 status classification was provided). There has been a commensurate decline in the number of stocks for which biomass or fishing mortality status is uncertain, and a gradual decline in stocks that are classified as overfished or subject to overfishing (Figure MAR37). In 2015, of the 92 stocks across 21 fisheries assessed, 66 were classified as not overfished and 77 as not subject to overfishing—of these, 63 stocks were both not subject to overfishing and not overfished (Patterson et al. 2015a). Two stocks were classified as subject to overfishing, and 12 stocks were classified as overfished. For the past 2 years, no stocks managed solely by the Australian Government have been classified as subject to overfishing. However, there has been an increase in the number of stocks classified as uncertain with respect to fishing mortality. Overall, this demonstrates an improvement in the current state of key commercial stocks managed by the Australian Government.

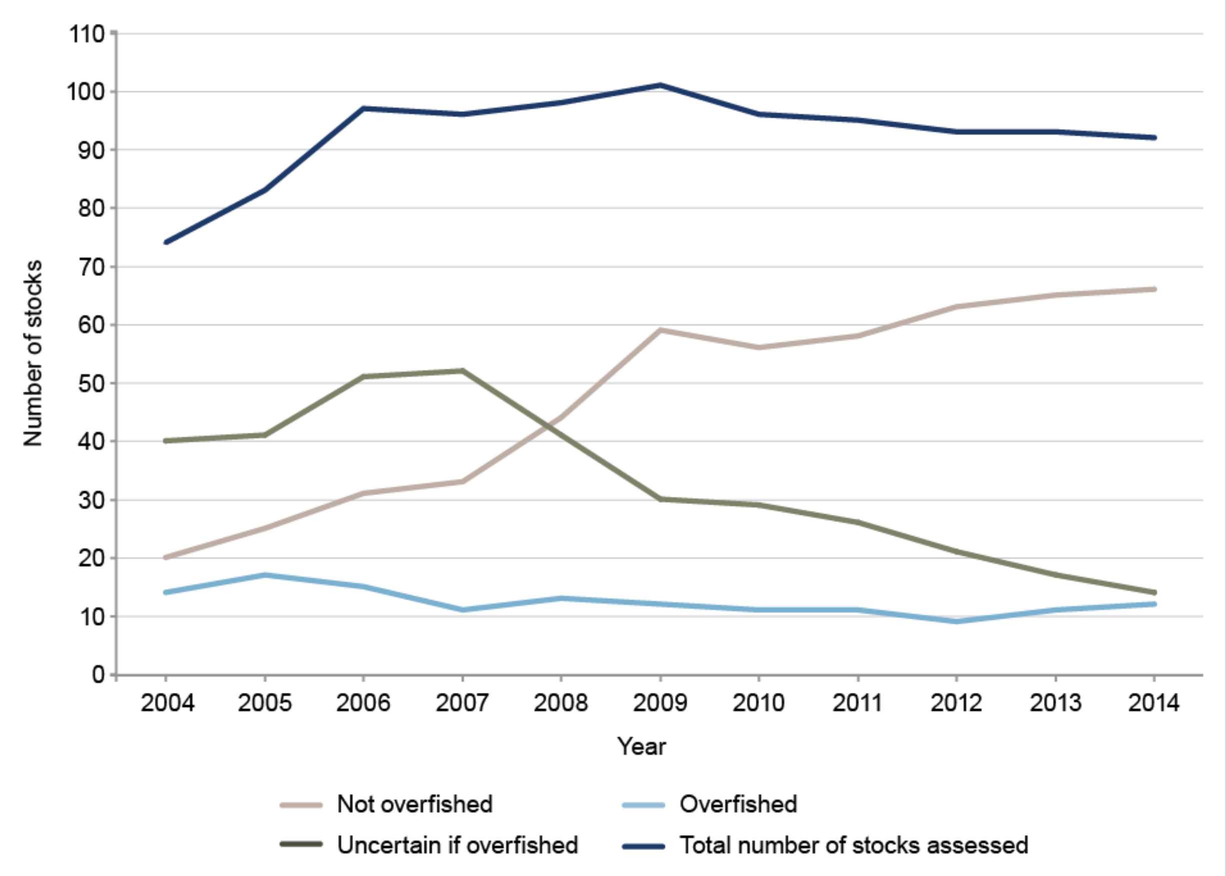
The status reports compiled by ABARES detail some of the broader impacts of fishing on the environment, with information on fishery assessments under the EPBC Act, ecological risk assessments, and the level of interaction with threatened, endangered and protected species. Compulsory use of turtle excluder devices, introduced into the Northern Prawn Fishery in 2001, has been reported to have reduced bycatch of turtles from 5700 per year to approximately 30 per year (Brewer et al. 2004). In response to the bycatch of Australian sea lions by sectors of the Southern and Eastern Shark and Scalefish Fishery, AFMA introduced gillnet fishing closures around known breeding colonies and trigger limits that shut down spatial zones of the fishery if a level of bycatch is exceeded (AFMA 2015).

Box MAR8 (continued)

Issues associated with the management of commercially targeted species

A recent review of the fisheries bycatch policy (DAFF 2013b) highlighted challenges in assessing the effectiveness of implementation of the policy, particularly the limited data on protected species interactions in some fisheries. The often sporadic nature of interactions creates a challenge for obtaining the reliable estimates that are required to determine the potential impact on populations and management effectiveness.

Despite fisheries management measures that do not allow the targeted fishing of some species, some depleted stocks (e.g. eastern gemfish) do not appear to be recovering. The reasons for this are not currently clear.



Source: Patterson et al. (2015a)

Figure MAR37 Biomass classification of fish stocks across the 21 fisheries managed by the Australian Fisheries Management Authority, 2004–14

Recreational fishing

Recreational fisheries catch more than 1160 species, 245 of which are commercially fished within Australian Government–managed fisheries (Griffiths & Pepperell 2006). Currently, a range of controls are used to manage recreational catches of marine species, including combinations of access restrictions, closed areas, closed seasons, restrictions on gear types, daily bag limits, minimum and/or maximum size limits, and possession limits. Varying degrees of licensing of recreational fishing are in place across jurisdictions, which range from general fishing licences to activity-specific or species-specific licences, to none at all. Licensing frameworks, when implemented, provide a database of recreational fishers for targeted surveys to monitor the responses of recreational fishers to changing fisheries management. These databases can also be used to disseminate information to recreational fishers, including information on regulations and changes to those regulations, and for targeted education purposes.

Input controls placed on recreational fishing are known to only weakly control the effort placed into fishing and the overall extent of harvest (Sutinen & Johnson 2003). In some cases, where commercial and recreational fisheries overlap, conflict can be created where there is disparity between the 2 sectors in requirements for reporting of catch, controls on the extent of catch and access to particular species (Brown 2016). Direct approaches to reducing this conflict are sparse, although, recently, defined areas have been closed to commercial fishing with the aim of supporting recreational fishing across Queensland and Victoria. How effective these closures might be in supporting the objectives of providing recreational fishers with 'more and bigger fish' is unclear, because they only close areas to specific types of commercial fisheries, are not integrated within formal spatial management frameworks and are not supported by any monitoring frameworks. Further, by increasing access to recreational fishers, they potentially support higher harvesting rates than had previously occurred, particularly in the case of species for which recreational catches are similar to, or higher than, commercial catches (Brown 2016).

In Western Australia, catches within some fisheries are allocated between the commercial, recreational, aquaculture and traditional-use sectors, with the total harvest level across all groups not exceeding the allowable harvest level. If the harvest level is exceeded, steps are taken to reduce the harvest within each sector. For example, when the stock assessment for the west coast Australian herring indicated low stock abundance resulting from environmental factors and fishing pressure, the daily bag limit of Australian herring for recreational fishers was reduced to assist stock recovery (Ryan et al. 2015).

A National Recreational Fishing Survey was done in 2000–01, which was the first to be conducted across all state and territory jurisdictions (Henry & Lyle 2003). The survey provided regional, jurisdictional and national breakdowns of social, sport and economic components of recreational fishing—invaluable information to guide the management of particular species.

Although a similar nationwide assessment has not been conducted since, several jurisdiction-level surveys of recreational fishing have been conducted (Table MAR8). These have a continued emphasis on collecting catch and effort data, and, to a lesser extent, social, behavioural and economic information. However, although all jurisdictions have a formal focus on recreational fisheries management capacity and planning, there has been little, if any, coordination of surveys between jurisdictions. The result has been a discontinuous dataset in space and time for assessing recreational fishing at the national level.

One of the shortcomings of the National Recreational Fishing Survey was that, given its broadscale nature, it did not provide fine-scale information required for some decision-making processes at the jurisdictional level (Henry & Lyle 2003). In response, appropriate methods for a national approach were assessed for recreational fishing, aggregating available datasets to provide an update to the survey, providing relevant information for jurisdictions and assessing fish stocks, including commercial and recreational catches, across jurisdictions (Griffiths et al. 2014). The assessment found that it was not possible to aggregate jurisdictional datasets in a statistically defensible way to produce reliable national estimates in any given year. Consequently, it was recommended that, to improve recreational fishing data at the national level, another national survey should be undertaken or that coordination between jurisdictions should be improved. Subsequently, further work to identify best-practice methods to conduct national recreational fishing surveys has been performed (Georgeson et al. 2015a).

Kingfish *(Seriola lalandi*), in midwater off Port Stephens, New South Wales
Photo by David Harasti

At the same time, the *Status of key Australian fish stocks reports* released in 2012 (FRDC 2012) (Flood et al. 2014) and 2016 have attempted to include recreational fishing data, where available, in assessments of the status of key wild-caught fish stocks. Additionally, in some jurisdictions (e.g. Western Australia), formal harvest strategy policies have been adopted that specifically include recreational fishing and allocation issues, providing for more comprehensive assessments of relevant stocks both within and across jurisdictions. Other jurisdictions, while progressing management frameworks towards more comprehensive harvest strategies that include recreational catches in stock assessments of target species, are yet to implement such frameworks.

An objective of the Australian Government's Policy for a More Competitive and Sustainable Fisheries Sector (August 2013) is to conduct national recreational fishing surveys every 5 years. The objective is yet to be implemented, and no clear timeline for such a survey has been articulated, nor is it clear who will coordinate such a survey.

Issues relating to the management of recreational fishing were highlighted by the inquiry by the Productivity Commission into the regulation of the Australian marine fisheries and aquaculture sectors (PC 2016). These included:

- a weak understanding of the impacts of essentially unmanaged recreational fishing on high-value fish stocks
- sporadic monitoring of recreational fishing
- lack of accounting of impacts of recreational fishing on stock sustainability in fishery management regimes.

Table MAR8 Timeline of recreational fishing surveys conducted in Australia, 2000–16

Jurisdiction	2000–01	2001–02	2004–05	2006–07	2007–08	2009–10	2010–11	2011–12	2012–13	2013–14	2015–16
National	P-D	–	–	–	–	–	–	–	–	–	–
NSW/ACT	P-D	–	–	–	–	–	–	–	–	P-D	–
NT	P-D	–	–	–	–	P-D	–	–	–	–	–
Qld	P-D	P-D	P-D	–	–	–	P-D	–	–	P-D	–
SA	P-D	–	–	–	P-D	–	–	–	–	P-D	–
Tas	P-D	–	–	–	P-D	–	–	–	P-D	–	–
Vic	P-D	–	–	L	–	–	–	–	–	–	–
WA	P-D	–	–	–	–	–	–	P-D (B)	–	P-D (B)	P-D (B)

– = no survey; ACT = Australian Capital Territory; L = licensed fisher survey; NSW = New South Wales; NT = Northern Territory; P-D = phone-diary survey; P-D (B) = phone-diary (boat-based fishing) survey; Qld = Queensland; SA = South Australia; Tas = Tasmania; Vic = Victoria; WA = Western Australia
Source: Griffiths et al. (2014), Georgeson et al. (2015a)

Recommendations on the management of recreational fishing made by the Productivity Commission in its draft report included:

- expanding licensing systems across the board and making better use of such licensing systems in fisheries management
- implementing harvest tagging systems for at-risk species when conventional management controls are ineffective in achieving sustainability goals
- increasing understanding of postrelease survival rates and associated methods for deepwater fisheries
- strengthening penalty regimes to increase compliance
- implementing regular standardised recreational fishing surveys.

The report also highlighted for consideration (PC 2016):

- greater recognition of recreational fishing catches in fisheries management
- development of a sound evidence base for decisions on restrictions and facilities for recreational fishing
- allocation of access where competition for fisheries resources occurs across commercial, recreational and Indigenous fishing.

Illegal, unreported and unregulated fishing

Australia is a signatory to several international conventions and is a member of several regional fishery management organisations in which illegal, unreported and unregulated (IUU) fishing is a major focus (e.g. Agnew 2000). A *National plan of action to prevent, deter and eliminate illegal, unreported and unregulated fishing* has been developed, which aligns with the *International plan of action to prevent, deter and eliminate illegal, unreported and unregulated fishing* adopted by members of the Food and Agriculture Organization of the United Nations (FAO) in 2001 (FAO 2001). In 2015, the Australian Government ratified the United Nations FAO Port State Measures Agreement. Parties to this agreement are required to act against vessels and operators suspected of IUU fishing, by denying entry into ports and preventing access to markets for illegally caught fish.

All jurisdictions have fishery compliance regulations in place across both commercial and recreational fisheries. They employ fishery officers, or have arrangements with police, to enforce fisheries regulations. Education programs aimed at increasing knowledge of fisheries regulations operate across commercial and recreational fisheries. The National Fisheries Compliance Committee of the Australian Fisheries Management Forum, which brings together Australian Government, state and Northern Territory fisheries agencies, has developed a National Compliance Strategy that outlines objectives for pursuing and promoting voluntary compliance, and creates effective deterrents to illegal fishing activity (NFCC 2010). The strategy aims to achieve collective responsibility and stewardship across the commercial, recreational and Indigenous fishing sectors. AFMA has also done considerable work in response to recommendations made under an external audit to improve and manage noncompliance with commercial fisheries regulations in Australian waters (ANAO 2009, 2013).

The inquiry into the regulation of the Australian marine fisheries and aquaculture sectors highlighted more accessible processes for the sharing of information on illegal fishing and strengthened processes for following up on illegal fishing reports as areas requiring further action (PC 2016).

Traditional use of resources

Because of the dispersed and sporadic nature of traditional harvesting, building community endorsement for long-term monitoring programs is often a complex and sensitive process. Community initiatives for monitoring and managing traditional harvest are highly diverse because of the specific local context for planning, management and conservation. Determining whether traditional harvest is sustainable should be assessed on a case-by-case community basis, given the wider ecological and pressure conditions within an area. It is important to consider the state of the harvested population, the state of supporting habitats, the range of threats, and controls to limit human impacts.

The most effective planning approaches are built from cooperative relationships between Indigenous communities and other stakeholder partners (Hill et al. 2012). The recent inquiry into the regulation of the Australian marine fisheries and aquaculture sectors identified cooperative approaches to the management of customary fishing rights as a key recommendation (PC 2016). Across Australia, a variety of cooperative management and planning processes address Indigenous resource use. Planning approaches include:

- Traditional Use of Marine Resource Agreements, which are a statutory arrangement for establishing partnerships between the Great Barrier Reef Marine Park Authority and Indigenous communities that live adjacent to the marine park (Dobbs 2007)
- the Protected Zone Joint Authority process in Torres Strait (Butler et al. 2012)
- the Nature Conservancy's Conservation Action Planning tool, which uses regular monitoring of specified indicators to inform planning in Indigenous communities (Moorcroft 2012).

In northern Australia, Indigenous-driven planning for the traditional use of marine resources has targeted the development of community plans for the traditional harvest of dugongs and marine turtles (NAILSMA 2009; see also Box MAR10). Marine parks in Western Australia are increasingly being jointly managed by the Western Australian Government and Indigenous communities (R Evans, Department of Parks and Wildlife, pers. comm., 7 July 2016).

In the Great Barrier Reef Marine Park, as part of a Traditional Use of Marine Resource Agreement, traditional owners are required to monitor, record and report traditional harvest activities. Since SoE 2011, the workforce of Indigenous rangers has grown around Australia, which has increased the on-ground capacity for monitoring the traditional take (e.g. GBRMPA 2011, DPIF 2013; see also Box MAR9). In the Northern Territory, Indigenous rangers record information on the loss or return of marine species such as fish, dugong and turtles in their patrol areas (DPIF 2013). Kimberley coastal communities are also developing and implementing monitoring and evaluation frameworks (Jackson et al. 2015), and there is wide-scale involvement of Indigenous rangers in monitoring programs in Torres Strait (Johnson et al. 2015, TSRA 2016).

Coastal Indigenous communities are at very different developmental stages in implementing and evaluating community-based management strategies. Even with increased effort dedicated to Indigenous natural and cultural resource management, results of management strategies put in place have been mixed, with many projects falling well short of both Indigenous and non-Indigenous expectations (Barbour & Schlesinger 2012). A limited number of the initiatives have had an in-depth evaluation. Currently, there is incomplete assessment of the effectiveness of these initiatives for improved sustainable management, since potential change in traditional harvesting practices is not consistently monitored. As such, possible improvements remain poorly described, and management strategies are not updated with monitoring information.

There has been a push towards improved evaluation through assessing performance outcomes in the work plans of Indigenous rangers (DSEWPaC 2012e). More effective input of traditional harvest and involvement of Indigenous contributors in fisheries management systems have been identified as key recommendations by the Productivity Commission in relation to regulation of fisheries across Australia (PC 2016).

Collection of information on traditional catch requires bottom-up consensus, commitment and capacity, and is unlikely to be effective under only top-down rules. Both local communities and policy-makers have aspirations for managing natural resources, and conflict can exist when top-down views are imposed on bottom-up processes. Information on the harvest levels of traditional use is currently unlikely to be shared with the public, because of the sensitive nature of cultural harvesting of protected species and associated confidentiality provisions. A lack of understanding by the public and policy-makers about established cultural rights to traditional use can undermine the collection and sharing of harvest information with broader stakeholders. The Productivity Commission raised this lack of provision of information on traditional harvest as an issue for fisheries management (PC 2016). Recognition of customary fishing by Indigenous Australians in fisheries management regimes, and appropriate allocation of resources in accordance with proven traditional laws and customs were key recommendations from the inquiry (PC 2016).

The Indigenous Reference Group of the Fisheries Research and Development Corporation has developed 11 key research development and extension principles aimed at recognising cultural fisheries and their benefits to communities, supporting access to aquatic resources, developing self-management structures and community roles, increasing commercial opportunities, and reducing environmental impacts associated with traditional harvesting (Calogeras et al. 2015). Indigenous-driven planning of traditional use of resources will continue to empower Indigenous people to make more informed decisions about managing impacts and implementing solutions. Continual building of on-ground capacity and local governance will help bridge the gap between common desires for sustainability, and effective monitoring and management of traditional use.

Torres Strait Regional Authority rangers in collaboration with traditional owners play a vital role in monitoring marine turtle populations and associated research that addresses community priorities

Photo by Tristan Simpson

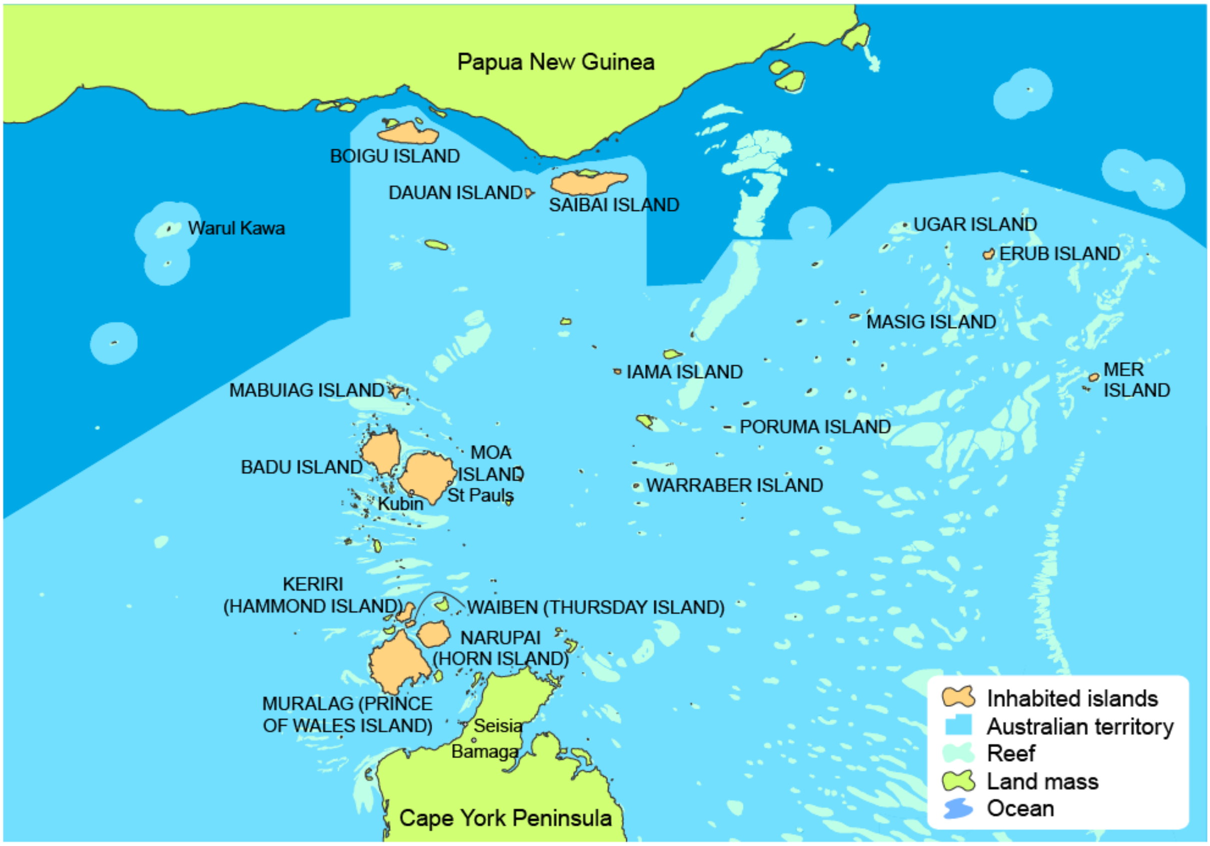
Box MAR9 Supporting the traditional management of dugongs and marine turtles in Torres Strait

The Torres Strait region is renowned for its ecological complexity and biodiversity, providing a multitude of habitats and niches for the highly diverse Indo–Pacific marine flora and fauna, including dugongs and marine turtles. It consists of 247 islands, including 18 Torres Strait Island communities on 17 inhabited islands, and 2 Northern Peninsula Area communities (Figure MAR38). The region is unique in Australia in that it has a diverse marine environment, its population is predominantly Indigenous, and it is the only natural resource management region to have an international border (with Papua New Guinea and Indonesia). Marine and island resources have traditionally been, and continue to be, vital to Torres Strait Islanders from a subsistence and cultural viewpoint. Torres Strait Islanders have a strong and abiding connection with their islands and sea Country, governed by the unique *Ailan Kastom* (Island Custom).

Importance and status of dugong and marine turtles in Torres Strait

Dugong and marine turtles are an integral part of Torres Strait culture, customs and lives, extending beyond traditional harvest for subsistence.

Torres Strait has the largest dugong population in the world, with a legislated dugong sanctuary covering 1.3 million hectares. Six of the 7 marine turtle species occur in Torres Strait, and green, hawksbill and flatback



Source: Torres Strait Regional Authority

Figure MAR38 Torres Strait region, showing inhabited island communities and the Australian territory

Box MAR9 (continued)

turtles nest in the region. It is estimated that there are more than 12,000 dugongs in central and western Torres Strait, and around 600,000 marine turtles in Torres Strait, 95 per cent of which are green turtles. In addition, the northern Great Barrier Reef green turtle population is the largest in the world, and Torres Strait is a significant foraging ground for the species. Torres Strait contains

13,425–17,500 square kilometres of important seagrass habitat for dugong and marine turtles, and has among the largest continuous seagrass meadows globally.

Dugong are protected under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and are listed as vulnerable in Queensland and near threatened in the Northern Territory. Under the EPBC Act and the *Nature Conservation Act 1992* (Qld), loggerhead, leatherback and olive ridley turtles are listed as endangered; and green, hawksbill and flatback turtles are listed as vulnerable. In the Northern Territory, leatherback turtles are listed as critically endangered; loggerhead, hawksbill and olive ridley turtles are listed as vulnerable; and green turtles are listed as near threatened. Scientific research considers dugong and marine turtle populations to be stable and healthy in Torres Strait.

The Torres Strait Regional Authority (TSRA) established a Land and Sea Management Unit in 2006 to champion community-based delivery of natural resource management programs in the Torres Strait region (Table MAR9). Through this program, the capacity of Indigenous rangers in the roles of monitoring, management, and community engagement and awareness has expanded. The unit's dugong and turtle project illustrates how modern management and regulation can support the traditional use of marine resources.

Table MAR9 Torres Strait Regional Authority activities to support the implementation of community-based dugong and turtle management plans in 14 island communities

Scale	Activities
Local	• Facilitation and support of community and shared management area dugong and turtle management meetings • Collaboration with local stakeholders in the dugong and turtle management plan about the delivery of their roles and responsibilities • Monitoring and research in collaboration with traditional owners that address community priorities • Communication of project outcomes to promote informed management decision-making
Regional	• Alignment of various Torres Strait monitoring and research methodologies with those used in adjacent regions, to allow comparison of outcomes and improve management decision-making • Communication and education activities to build awareness and share information at a regional level • Participation in, and provision of feedback to, the Torres Strait Protected Zone Joint Authority
National	• Participation in, and provision of, support and guidance to research institutes in the delivery of relevant projects • Participation in the review of the National Recovery Plan for Marine Turtles • Contribution of monitoring and research outcomes to national databases • Input into policy development based on project outcomes with stakeholder partners
International	• Participation in Papua New Guinea Treaty Awareness Visits, coordinated by the Australian Government Department of Foreign Affairs and Trade • Participation in the Australia – Papua New Guinea bilateral fisheries meeting

Box MAR9 (continued)

Dugong and turtle management plans, developed for each community, integrate a range of cultural hunting protocols and traditional knowledge with contemporary fisheries management arrangements. Management measures within each plan can include seasonal closures, gear restrictions, closed areas, effort reduction, limits on take and compulsory sharing. Where seasonal closures are included in plans, the plan specifies the exact area of the closure and the time of year to which it applies. Collaborative partnerships are helping to deliver environmental services that protect and manage the cultural and environmental values in Torres Strait.

Recent initiatives

Community-based dugong and turtle management plans have been developed and implemented in 14 communities; finalisation of the 15th and final for the Kaiwalagal region is in progress. Marine turtles have been included in the legislated dugong sanctuary as part of collaboration between the TSRA, the Australian Fisheries Management Authority and traditional owners. The TSRA has supported and facilitated shared area management meetings between Torres Strait island communities and Papua New Guinea.

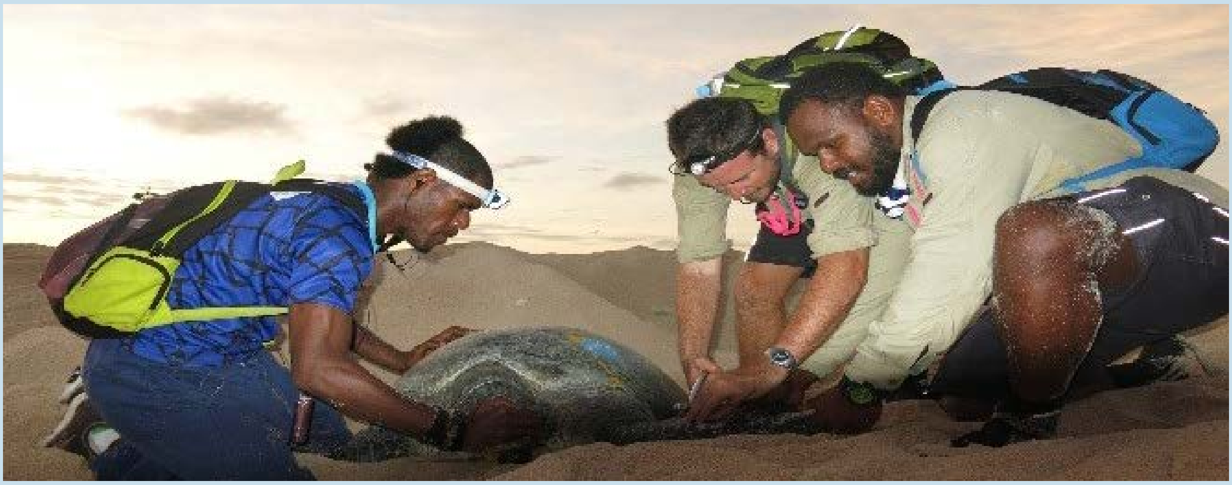
Aerial surveys of dugong and marine turtle populations are continuing, and population estimates for dugong have been available from aerial surveys since 1987. Collaborative efforts between the TSRA and James Cook University aim to improve population estimates of dugong and marine turtles.

Annual nesting and hatchling surveys have been conducted at index rookeries across Torres Strait for nesting species, led by the TSRA Environmental Management Program, which has also collaborated on the Raine Island green turtle recovery project.

Outlook

Primary threats to populations include climate change, potential declining habitat quality and nontraditional take, which may be unsustainable if not managed suitably. Green turtles foraging in Torres Strait and from Raine Island are primarily threatened by the collapse of hatchling success because of multiple causes, the cumulative impacts of which are the focus of targeted research and management programs.

Collaborative work between traditional owners and researchers to refine population models and complete aerial surveys of dugong and marine turtle populations is continuing. More information is needed on flatback and hawksbill turtle populations.



Torres Strait Regional Authority rangers and traditional owners play a vital role in monitoring marine turtle populations, including nesting and hatchling surveys

Photo by Tristan Simpson

Source: TSRA (2016)

Marine oil and gas exploration and production

The 2009 Montara oil spill off the far north-west coast of Western Australia and the resulting commission of inquiry (Borthwick 2010) highlighted critical inadequacies in the management of oil and gas exploration and production activities. It also highlighted industry-wide and government challenges in ensuring that the best technologies, management practices and regulatory processes were in place to prevent an accident of this nature occurring again in Australia.

Regulatory reform resulting from the commission of inquiry led to the implementation of the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA), established in 2012 under the *Offshore Petroleum and Greenhouse Gas Storage Act 2006*. NOPSEMA is responsible for the regulation of safety, well integrity, and environmental management of oil and gas operations in Australian, state and Northern Territory waters, where relevant powers and functions have been conferred (see also Marine oil and gas exploration and production under Pressures affecting the marine environment).

The authority's environmental management authorisation process was endorsed under the EPBC Act in 2014. Subsequently, the Minister for the Environment approved a class of actions that, if undertaken in accordance with NOPSEMA's environmental management authorisation process, no longer required referral, assessment and approval under the EPBC Act. Titleholders seeking to undertake offshore petroleum or greenhouse gas activities in Australian waters in accordance with the EPBC Act must submit an environment plan to NOPSEMA for assessment and can only proceed with the activities once they are accepted by NOPSEMA.

With the implementation of NOPSEMA, there has been an increased level of scrutiny of offshore petroleum environmental management through assessment processes and compliance inspections. Industry environmental reports show that, although a small number of accidental releases of hydrocarbon vapour and liquid petroleum have occurred since 2012, there have been no hydrocarbon releases of a similar magnitude to the Montara oil spill in Australian waters (NOPSEMA 2016). Environmental management investigation and enforcement powers have also been strengthened, which has resulted in better understanding of the impacts of activities, greater focus on industry compliance and increased levels of preparedness for unplanned events.

NOPSEMA is subject to an independent operational review of its regulatory performance and review of the EPBC Act streamlining process every 5 years. The operational review considers NOPSEMA's effectiveness in bringing about improvements in occupational health and safety, environmental management and well integrity, whereas the EPBC Act streamlining review assesses NOPSEMA's compliance with the environmental management authorisation process endorsed under the EPBC Act.

The EPBC Act–endorsed environmental authorisation process carried out by NOPSEMA for petroleum exploration and production activities was independently reviewed 12 months after the Minister for the Environment's endorsement. The review examined NOPSEMA compliance with the environmental management authorisation process endorsed under the EPBC Act, including associated objectives for matters protected under Part 3, and outcomes and commitments (ERM 2015). The review process identified several opportunities for improvement, including:

- greater collaboration between NOPSEMA and the Australian Government Department of the Environment and Energy
- improved provision of information to third-party stakeholders and titleholders, and on the environmental management authorisation process itself
- greater transparency in the authorisation process.

Future reviews of the EPBC Act streamlining process will be incorporated into the independent operational review. Opportunities for improvement identified by the first review have been, or are being, addressed (Christine Lamont, NOPSEMA, pers. comm., 22 February 2016).

Regulatory frameworks in place for oil and gas operations in state and territory waters vary, with some states having undertaken substantial revision of regulations associated with oil and gas activities in the past decade. Activities that may have a significant impact on the environment are referred to state or territory environment agencies under environmental legislation. Many agencies have bilateral agreements, whereby operations that may have an impact on matters of national significance under the EPBC Act are also referred to the relevant state or territory environment agency. Although most state and territory jurisdictions publish information about acreage releases, the accessibility of information on operations, environmental planning and incidents varies. Regulatory streamlining opportunities across Australian Government, and state and territory jurisdictions are currently being investigated, with the aim of reducing regulatory duplication and increasing consistency in industry oversight.

Development of a pragmatic decommissioning policy to address ageing infrastructure in the marine environment off Western Australia is one of the initial science priorities for the implementation strategy for *Blueprint for marine science 2050* (Blueprint for Marine Science 2016). The strategy sets out a marine science collaboration between the scientific community, industry, and regulatory and government sectors in Western Australia, to support sustainable operations in the marine environment.

Marine mining and industry

Because of the low levels of activity in the marine mining and industry sector, and the emerging nature of marine mining and related industries within the Australian marine environment (AIMS 2014), there is currently a low level of understanding of the management strategies that might be required to address environmental pressures. Globally, the marine mining industry is more advanced, and is supported by a growing body of research investigating likely environmental impacts and mitigation strategies.

Legislation exists to regulate the exploration and mining of offshore aggregate resources across Australian Government, state and territory jurisdictions; however, no national or regional assessments exist of mining impacts or potential responses to these impacts. An environmental impact assessment is required under the EPBC Act for all projects that may have a significant impact on the Australian marine environment. A 3-year moratorium on sea-floor mineral exploration was formally implemented in the Northern Territory in 2012 (and extended for 3 more years in 2015), following local objections to potential marine mining around Groote Eylandt. In New South Wales, although not formally enacted, an effective moratorium has prevented exploration for building sands offshore of the Sydney Basin since 2000.

Globally, the International Seabed Authority has enacted a mining code to regulate prospecting, exploration and exploitation of marine minerals in the international seabed area (defined as the seabed and subsoil beyond the limits of national jurisdiction). The principal obligations include applying the precautionary approach, employing best environmental practice and conducting prior environmental impact assessments. The code has been augmented by the International Marine Minerals Society, which has developed a voluntary Code for Environmental Management.

Marine vessel activity

Environmental regulation of commercial vessel activity is regularly reviewed and amended to strengthen environmental protection and reduce the environmental impact of vessel activities globally through the International Maritime Organization (IMO). Recent amendments to international law of significance include:

- amendments to Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL), which tighten the controls on discharge of garbage at sea
- amendments to Annex VI of MARPOL, which introduce technical and operational controls on greenhouse gas emissions from international commercial vessels, especially sulfur oxides and nitrous oxides.

The Australian Maritime Safety Authority is responsible for ensuring that Australia meets its international requirements. This regulatory body is tasked with developing frameworks and standards for protecting the marine environment from environmental damage caused by vessels, including pollution preparedness and response, domestic commercial vessel reform, and navigation safety.

Empirical information that could provide insight into the commercial vessel industry's approach to environmental performance is not available. However, community perceptions, and the commercial relationships between ship owner and ship charterer are among the strongest drivers of environmental performance. Environmental noncompliance can affect a shipping company's bottom line, because charterers contract ships with a good environmental record to minimise risk and exposure. Companies will use their strong environmental record and beyond-compliance approach as a point of differentiation to attract charterers looking for high-quality operators.

The overall rate of vessel detentions (detention being the most severe form of immediate sanction when a deficiency is detected) fell from 9.2 per cent to 6.0 per cent of total inspections from 2011 to 2015 (AMSA 2016). During the same timeframe, inspections increased from 3002 to 4050 per year. The proportion of detainable deficiencies related to pollution increased from 6.5 per cent in 2012 to 11.2 per cent in 2015. Most of the deficiencies related to prevention, as opposed to a sanction, for a pollution offence.

Three significant changes to managing commercial vessel activity in Australian waters have been implemented since 2011 to increase environmental protection:

- designation of the Coral Sea Particularly Sensitive Sea Area
- review of the National Plan for Maritime Environmental Emergencies
- development of the North East Shipping Management Plan.

The National Plan for Maritime Environmental Emergencies (AMSA 2015) details Australia's implementation of provisions set out under international conventions and agreements that Australia is party to, with respect to management of maritime environmental emergencies. In addition, vessel routing measures have been implemented off Ningaloo Reef, the southern Great Barrier Reef and south-western Western Australia, and the Great Barrier Reef and Torres Strait Vessel Traffic Service has been extended.

The International Convention on the Control of Harmful Anti-fouling Systems on Ships, which was adopted in 2001 and entered into force in 2008, prohibits the use of harmful organotin compounds in antifouling paints used on vessels involved in international shipping. It also establishes a mechanism to prevent the potential future use of other harmful substances in antifouling systems. The convention was implemented in Australian domestic legislation by the *Protection of the Sea (Harmful Anti-fouling Systems) Act 2006* in 2008. Under this legislation, a ship complies with the antifouling requirements set out under the Act if it has no harmful antifouling compound applied on any designated external surface, or if the surface on which a harmful

Endangered spotted handfish (*Brachionichthys hirsutus*), found in Tasmania and Bass Strait

Photo by Barry Bruce

antifouling compound has been applied has a coating that forms a barrier to prevent the harmful antifouling compound leaching into the water.

Regulation of recreational vessels (registration, licensing, use of waterways) is the responsibility of state and territory authorities or agencies. Any incidents involving recreational vessels must be reported to these authorities or agencies under the relevant state or territory legislation. Mooring of vessels within state and territory waters is also regulated by these authorities or agencies (see also the *Coasts* report). International conventions relating to pollution are implemented through relevant state or territory legislation.

Currently, there are no management frameworks directly addressing biofouling or disturbance to, or vessel strike of, marine animals (see also Box MAR3). A series of voluntary guidelines for international and domestic vessels, and marine industries have been developed, with the aim of setting out a consensus view of effective biofouling management practices. A national vessel strike strategy is being developed by the Australian Government Department of the Environment and Energy (DoEE 2016). Regulations regarding human activity around whales and dolphins, including small-vessel activity, have been adopted by Australian Government, state and territory jurisdictions (*Australian national guidelines for whale and dolphin watching 2005*). The IMO has adopted measures to minimise vessel strike, including precautionary areas, areas to be avoided, re-routing measures and speed restrictions (Silber et al. 2012). In Australian waters, not enough is known at present about the spatial or temporal distribution of the risk of vessel strike and the scale of the issue to implement targeted management measures.

Introduced species

The problem of introduced species carried by vessels has intensified over the last few decades due to expanded trade and traffic volume and, since the volume of seaborne trade continues to increase, the problem may not yet have reached its peak (see also Introduced species under State and trends of the marine environment).

In response, the IMO, in consultation with member states, has developed 2 sets of international guidelines addressing introduced species:

- *International guidelines for preventing the introduction of unwanted aquatic organisms and pathogens from ships' ballast water and sediment discharges* was adopted by the Marine Environment Protection Committee in 1991.
- *International guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species* was adopted by the committee in 2011.

Although adherence to the guidelines is voluntary, they provide a basis on which to further promote a best-practice approach to ballast water and biofouling management to prevent introduced species incursions.

The *International guidelines for preventing the introduction of unwanted aquatic organisms and pathogens from ships' ballast water and sediment discharges* was further developed into a resolution adopted by the IMO Assembly in 1997, and then the International Convention on the Control and Management of Ships' Ballast Water and Sediments in 2004. Because of a range of concerns about technical feasibility and efficacy of the available technology, the required entry-into-force criteria (ratification by 30 states, representing 35 per cent of the world's merchant shipping tonnage) have only recently been met, and the convention will enter into force in September 2017. Following entry into force, all vessels will need to fit a ballast water management system by their first MARPOL Annex I (International Oil Pollution Prevention) renewal survey. This will have a significant impact on the environmental performance of vessels involved in international shipping with respect to the ongoing translocation of species around the globe and around the Australian coast.

The difficulty and expense of eradicating introduced marine species have focused national management efforts on reducing initial introductions to Australia, detecting introductions early and limiting the spread of species once established. Australia introduced voluntary ballast water management arrangements in 1991 for vessels entering Australian waters, and Victoria introduced comprehensive ballast water arrangements for vessels entering its ports in 1994. It is now compulsory for all international vessels to manage their ballast water according to Australian ballast water management requirements.

The black-striped mussel outbreak in Darwin in 1999 highlighted the need for an integrated approach to managing marine pest incursions in Australia. A national taskforce recommended the establishment of the National System for the Prevention and Management of

Marine Pest Incursions. Established in 2005, the system focuses on the prevention of, emergency preparedness for, response to, and ongoing management and control of, marine pests. Emergency response elements are governed by the National Environmental Biosecurity Response Agreement. Components of the national system—which include guidelines and information on monitoring, biofouling and ballast water—continue to be implemented under the guidance of the Marine Pest Sectoral Committee, a national technical and advisory committee made up of representatives from the Australian, state and Northern Territory governments. The national system applies the biosecurity principles and framework outlined in the Intergovernmental Agreement on Biosecurity to the marine pest sector.

In the event of a marine pest incursion of national significance, the Consultative Committee on Introduced Marine Pest Emergencies would be convened. This national technical forum, comprising members from the Australian, state and Northern Territory governments, would provide advice on the feasibility and coordination of a national response, as per the Emergency Marine Pest Plan.

A recently concluded review of Australian Government policy on introduced species, together with implementation of the new *Biosecurity Act 2015*, should provide an improved and more nationally consistent approach to domestic policy and legislation relating to marine vessels.

Anthropogenic noise

Environmental regulation of noise associated with, for example, oil and gas, military, vessel activity and port-related (e.g. dredging, pile-driving) activities is currently largely addressed at the sector level. However, national, and state and territory environmental regulators are now considering the results of international and national research on marine noise, with a view to applying management strategies to avoid noise sources affecting the marine environment.

Regulation of marine noise from oil and gas activities in Australian Government waters is addressed under the *Offshore Petroleum and Greenhouse Gas Storage Act 2006* and associated environmental regulations. Environmental management authorisation processes under this Act and associated environmental regulations have been administered by NOPSEMA since 2012, and were endorsed by the Minister for the Environment under Part 10 of the EPBC Act in 2014 (see Marine oil and gas exploration and production).

Through environmental impact assessments, military activities are assessed for potential impacts associated with noise. Procedures have been developed to mitigate and manage associated impacts on the environment, and are outlined in the Maritime Activities Environmental Management Plan. Under procedures detailed in this plan, potential areas of higher marine mammal abundances and locations with specific sensitivities (e.g. feeding, resting areas) are avoided for activities generating high noise levels. More generally, cetacean exclusion zones are used around noise sources, and known nesting beaches for marine turtles are avoided (see the specific planning guides set out in the plan). If a marine mammal or other marine fauna is sighted within the exclusion zone, activities are curtailed until the vessel can move. Operations and activities that require regulation under the EPBC Act must be approved by the minister and, depending on the activity, meet environmental guidelines set out under the approval process. Reviews of the Maritime Activities Environmental Management Plan are conducted with the assistance of the Defence Science and Technology Group.

Dredging activities are regulated under the *Environment Protection (Sea Dumping) Act 1981*, which regulates the loading and dumping of waste at sea within Australian waters. The Act also considers the implications of such activities (including noise generated) under the EPBC Act. Few processes are in place for the management of noise generated in other sectors, beyond those that might be defined under EPBC Act approval processes. Through the IMO, nonmandatory guidelines for reducing underwater noise from commercial vessels have been developed: *Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life*. Some initial work has commenced within the Australian Government Department of the Environment and Energy on developing similar guidelines for managing commercial vessels and associated noise at the domestic level.

Environment plans associated with oil and gas activities, and management plans covering activities conducted by the military and involving dredging activities requiring EPBC Act approval must assess all potential risks and impacts arising from activities that generate underwater noise, including cumulative impacts. Although regulation processes for each of these activities vary, in principle, environmental plans must demonstrate that all reasonably practical controls will be implemented to reduce impacts to acceptable levels. Demonstrations of acceptability must be supported by relevant scientific literature, industry standards, government policy documents, species recovery plans and management plans, and must consider stakeholder input. Where scientific evidence to support environmental impact conclusions is lacking, precautionary approaches to management and decision-making are applied. These may result in additional control measures, such as exclusion of sensitive environments from operational areas, as specified by the minister.

Several sanctuaries in Australian and state waters have been implemented with the express purpose of controlling disturbance (e.g. seasonal closure of part of the Great Australian Bight for southern right whales, and the Port Adelaide Dolphin Sanctuary).

The international community is encouraging the establishment of a Global Ocean Acoustical Observing System, building on platforms and capability such as IMOS in Australian waters (Boyd et al. 2011). Such a system would allow the ocean soundscape in Australian waters to be established, consider spatial and temporal variance, and provide direct input into processes to regulate activities generating noise in the marine environment.

Marine debris

The Australian Government has recognised marine debris as a key threatening process under the EPBC Act since 2003. A threat abatement plan was developed in association with the listing (DEWHA 2009a). The plan aims for consistency in evaluating the impacts of marine debris across Australian Government, state and territory jurisdictions, and therefore aims to reduce the impacts of marine debris on marine life.

At the end of the first 5 years of the plan, the achievements against the objectives of the plan, and the effectiveness of the plan in preventing and mitigating the impacts of marine debris on marine vertebrates were reviewed (DoE 2015b). The review found that significant progress on parts of the plan had been made, including:

- amendments to Annex V of the IMO's MARPOL, which provided in-principle support for actions defined by the plan
- research on the scale and distribution of marine debris in the marine environment, including the development of national databases categorising marine debris and its sources
- national education and community action programs
- education and outreach programs involving neighbouring sources of marine debris
- greater engagement with AFMA for removing marine debris from the ocean.

Despite progress in these areas, several identified actions had not been met. Based on measurements against 2 key criteria, it was concluded that the key threatening process being addressed by the plan had not been abated and the objectives of the plan had not been met. It was recommended that the plan be either retained for another 5 years or revised, allowing for actions and objectives to be updated, and emerging issues such as microplastic ingestion to be incorporated. Revisions of the plan are under way, and it is expected that the revised plan will be released in early 2017.

Following the DoE (2015b) review, the Australian Senate in June 2015 referred the threat of marine plastic pollution in Australia and Australian waters for inquiry and reporting by April 2016 (ECRC 2016). The Environment and Communications References Committee conducting the inquiry was tasked with:

- reviewing current research and scientific understanding of marine plastic pollution
- identifying sources of marine plastic pollution
- identifying the impacts of marine plastic pollution on species, ecosystems, fisheries, small business and human health
- identifying measures and resourcing for mitigation.

The inquiry drew on information provided in submissions from researchers, environmental groups, local councils, industry and government departments. Contributions were also made through several public hearings. The inquiry made 23 recommendations in its findings, including:

- supporting research into marine plastic pollution, and its impacts on species, ecosystems and human health to ensure that policies aimed at mitigating threats are based on sound information
- continuing support of the national databases that are in place

- facilitating industry, jurisdictional, regional and community support for research, education and clean-up programs
- establishing a working group for facilitating a comprehensive and coordinated response to threats imposed by marine plastic pollution
- assisting jurisdictions with implementing improved stormwater management and a range of options to reduce the release of plastic pollution into the marine environment.

The report is currently under consideration by the Australian Government.

Dumped wastes

The *Environment Protection (Sea Dumping) Act 1981* regulates the loading and dumping of waste at sea across Australian Government jurisdictions. The Act requires permits for all ocean disposal activities, including dredging operations; creation of artificial reefs; dumping from vessels, platforms or other human-made structures; and burials at sea. The Act fulfils Australia's obligations under the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972, also known as the London Protocol. The areas selected as disposal sites for dredged materials and the nature of disposal of dredged material at sea are highly regulated to minimise the risk of marine organisms being exposed to toxic materials. This regulation also ensures that the sites chosen are the most likely to be minimally affected by the application of additional sediment (Ports Australia 2014).

In 2015, the Australian Government established a new regulation under the Great Barrier Reef Marine Park Regulations 1983, which ends the disposal of dredge material from capital dredging projects (e.g. port developments) in the marine park. Complementary legislation introduced by Queensland in 2015 means that the disposal of dredge material from capital dredging projects no longer occurs throughout the remainder of the Great Barrier Reef World Heritage Area. A dredging science node has been established within the Western Australian Marine Science Institution, which aims to address key areas of uncertainty in the prediction and management of impacts associated with dredging.

Social licence to operate

A social licence to operate (SLO) can be defined as a tacit contract that ensures that the socio-political risk of challenges to a company or agency are reduced if the company or agency behaves in a manner consistent with community values. The stronger the SLO, the greater the community acceptance (Prno & Slocombe 2012). Originating in association with mining, SLO can be applied to any industry and associated governance systems that have potential impacts on the environment. An SLO is quite different from an environmental licence, which is formal permission issued by government in line with legislated requirements. Rather, an SLO must be earned from the community. Local communities are often key contributors to the SLO process by virtue of their proximity to activities and their associated impacts (Prno & Slocombe 2014). SLOs can rarely, if ever, be replicated between activities; acceptance of activities will vary with the community involved and the activity itself (Prno & Slocombe 2014).

Many industries in Australia face issues that may be addressed via SLOs. Even when a company has met all regulatory requirements within the sector, public concern and pressure can result in its operations being restricted or rejected (e.g. large trawling vessels within the Small Pelagic Fishery managed by the Australian Government; Smith et al. 2015).

Noting the need for industry to gain SLOs, there has been a shift towards government regulation of company–community interactions and incorporation of SLOs into environmental licensing systems. The Queensland Government now requires major resource development projects in the state to prepare a social impact management plan, which aims to ensure that stakeholder engagement occurs across the lifetime of the activity. Many fisheries are adopting third-party certification schemes through bodies such as the Marine Stewardship Council (MSC) and the Aquaculture Stewardship Council. Both bodies facilitate independent reviews of fisheries and aquaculture operations for their sustainability and traceability of product, setting standards that operations must meet on both aspects to be certified. Fisheries that have MSC certification include the Exmouth Gulf and Shark Bay prawn fisheries, the Western Australian rock lobster fishery, the Northern Prawn Fishery and the blue grenadier fishery. Many fisheries, including all commercial fisheries in Western

Australia, are currently in the process of gaining certification. In some sectors, biological offsets (see Residual risks to the marine environment) support SLO, whereas, in others, offsets are a means of circumventing environmental responsibilities, thereby reducing SLO (Richert et al. 2015).

Research on measuring and modelling SLO is expanding, with the aims of guiding industry in developing trust-based relationships with community stakeholders and implementing frameworks for operations that uphold that trust (Moffat & Zhang 2013).

Cumulative impacts and management of multiple uses

Ecosystem-based management aims to balance human activities with environmental stewardship to maintain ecosystem properties, functions and services. This requires an appreciation of how human activities interact and affect different ecosystem components (Halpern et al. 2008, Levin et al. 2009, Ban et al. 2010, Curtin & Prellezo 2010). These interactions are known as cumulative impacts, and can result from separate pressures within an activity or interacting pressures from multiple activities (Figure MAR39). Robust assessments of interactions, however, is extremely difficult, as interactions are likely to be nonlinear and may be synergistic (working together) or antagonistic (working against each other). The sectoral approach to marine management in Australia often does not account for the additive or multiplicative effects of activities, which can be a key risk to the environment.

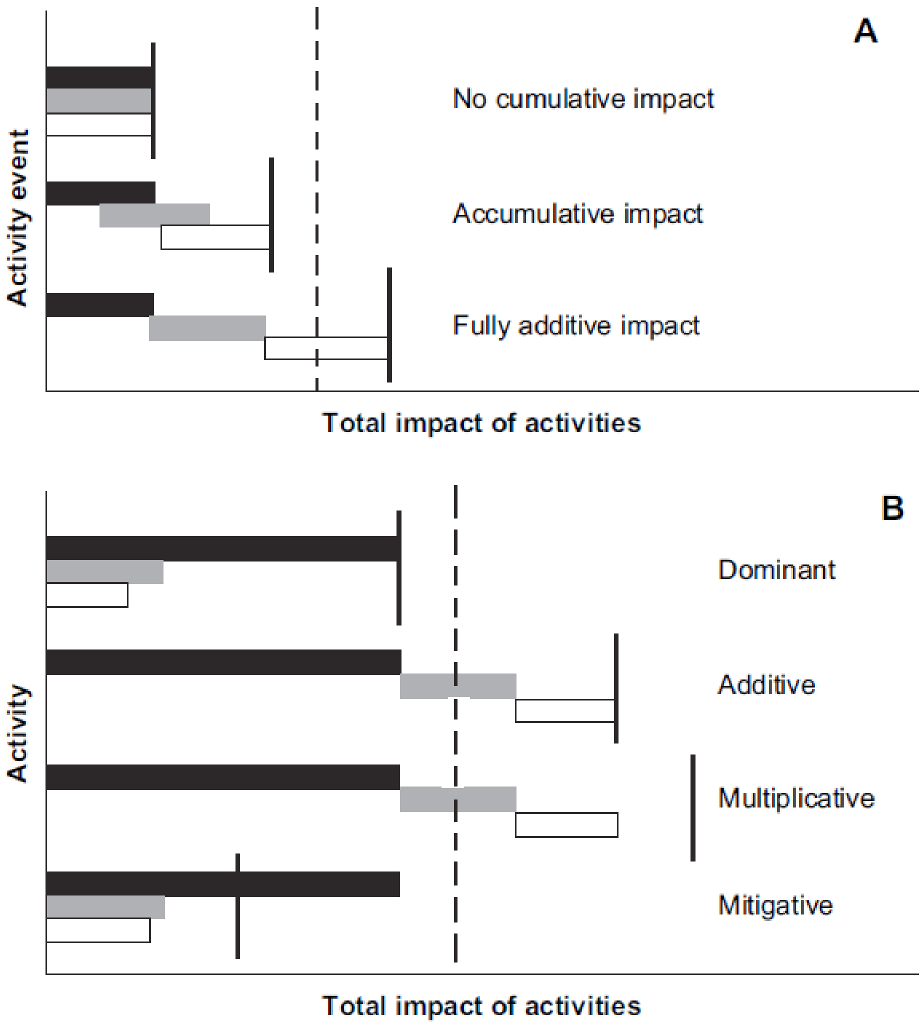
Analysis and mapping of cumulative impacts in the marine environment is an expanding research area (Crain et al. 2008, Halpern et al. 2009, Ban et al. 2010, Halpern & Fujita 2013). It also assists with conservation and marine spatial planning by identifying key areas for planning to focus on (Dunstan et al. 2016). Mapping cumulative impacts, however, requires spatially explicit information on habitats, communities and species groups, human uses, the pressures generated by human uses and any feedbacks within the system—information that is frequently unavailable. In some situations, cumulative impacts can be determined from statistical analysis of existing data (e.g. Foster et al. 2015). In others, many assumptions need to be made about the cumulative nature of impacts themselves and the responses of the marine environment to these impacts (Anthony et al. 2013). Most attempts at estimating cumulative impacts have taken a linear, additive approach (e.g. layering the footprints of various industries within a geographic information system framework), rather than recognising the true combinatory nature of cumulative effects and the varying footprints of different industries.

Within the Australian marine environment, work on developing methods that assess the cumulative nature of multiple impact sources is also expanding. Some sectors have identified the need to incorporate such research into management frameworks for better accounting of cumulative impacts; for example, AFMA and the Commonwealth Fisheries Research Advisory Board have identified developing cumulative risk assessment methods as a priority for research. Work to date includes assessing:

- the impact of multiple environmental pressures (e.g. Butler et al. 2015)
- the temporal additive or multiplicative nature of single-source impacts associated with industry, such as particular types of fishing, on habitats and communities (e.g. Foster et al. 2015, Pitcher et al. 2016a; see Box MAR2)
- multiple-source impacts associated with the environment and industry (e.g. Fulton et al. 2011b, Zhou et al. 2013).

Methods used range from simple effect–response models to complex ecosystem models, with novel combinations of qualitative and probabilistic models providing new options (Anthony et al. 2013).

A review of the management effectiveness of the Great Barrier Reef Marine Park identified that the cumulative and consequential impacts on biodiversity were not well understood. As a result, no explicit strategies or action plans existed for addressing these, particularly in relation to degradation of the southern inshore region of the park (Hockings et al. 2014). In response, the Reef 2050 Long-term Sustainability Plan sets out a series of key actions for managing the cumulative nature of pressures on the Great Barrier Reef (Australian Government & Queensland Government 2015). Approval processes under the EPBC Act have the intent of broad system-level consideration of cumulative effects (see also Managing



Note: Horizontal bars represent the different activities, vertical solid lines indicate the total impact of the activities, and the dashed vertical lines represent a hypothetical threshold of ecosystem functioning. Individual components of a particular activity can interact in a variety of ways to create a cumulative within-activity impact: the impact of one activity is dominant and overrides other activities; the impacts of the individual activities are additive; the impacts of the individual activities are multiplicative, resulting in an impact that is larger than the sum of the individual parts; 1 activity mitigates the impact of the other activities.
Source: Halpern et al. (2008), used under CC BY NC ND

Figure MAR39 Schematic of different types of cumulative impacts

for resilience). However, little practical guidance is provided on how the cumulative nature of impacts, even if identified, can be assessed.

Integrated management

Truly integrated management of the marine environment should bring the principles of ecosystem-based management, sea-use management and marine spatial planning into 1 framework. This framework should allow for the multiple uses of the marine environment, while ensuring that ecosystem structure, functioning and services are maintained, and that safeguards are in place to protect components of marine ecosystems (Ehler & Douvere 2007). The reality is that ecosystem-based and integrated management mean different things to different people and different sectors.

Uptake of integrated approaches to the management of natural resources has been slow, and, although such an approach may have been adopted at a policy level, practical implementation is limited (Garcia et al. 2003, Smith et al. 2007). For example, although Australian Government, and state and territory fisheries management agencies have adopted ecosystem-based fisheries management as the approach to future management, in principle (Smith et al. 2007), most management frameworks concentrate on individual fish populations strictly in demographic terms. That is, they account for the input of individuals as population growth or immigration, and the output in terms of natural and fishing mortality. Few fishery management frameworks explicitly account for variability in external factors, such as predator and prey abundances, and variability in the biophysical environment, and the impacts of changes in the abundance of populations on the surrounding ecosystems. Although the science may be available to support comparisons of alternative management options at the general strategic level (Fulton et al. 2011a, 2014), quantitative assessment and evaluation require simpler models that can be fitted to data (Plagányi et al. 2014). New approaches, however, are starting to become available and to be tested (e.g. Dichmont et al. 2016). Tight resource constraints have a major impact on the capacity of jurisdictions to implement what has been identified as best practice and aspirational. This will be a constraining factor into the foreseeable future for ecosystem-based fisheries management and the management of other marine activities.

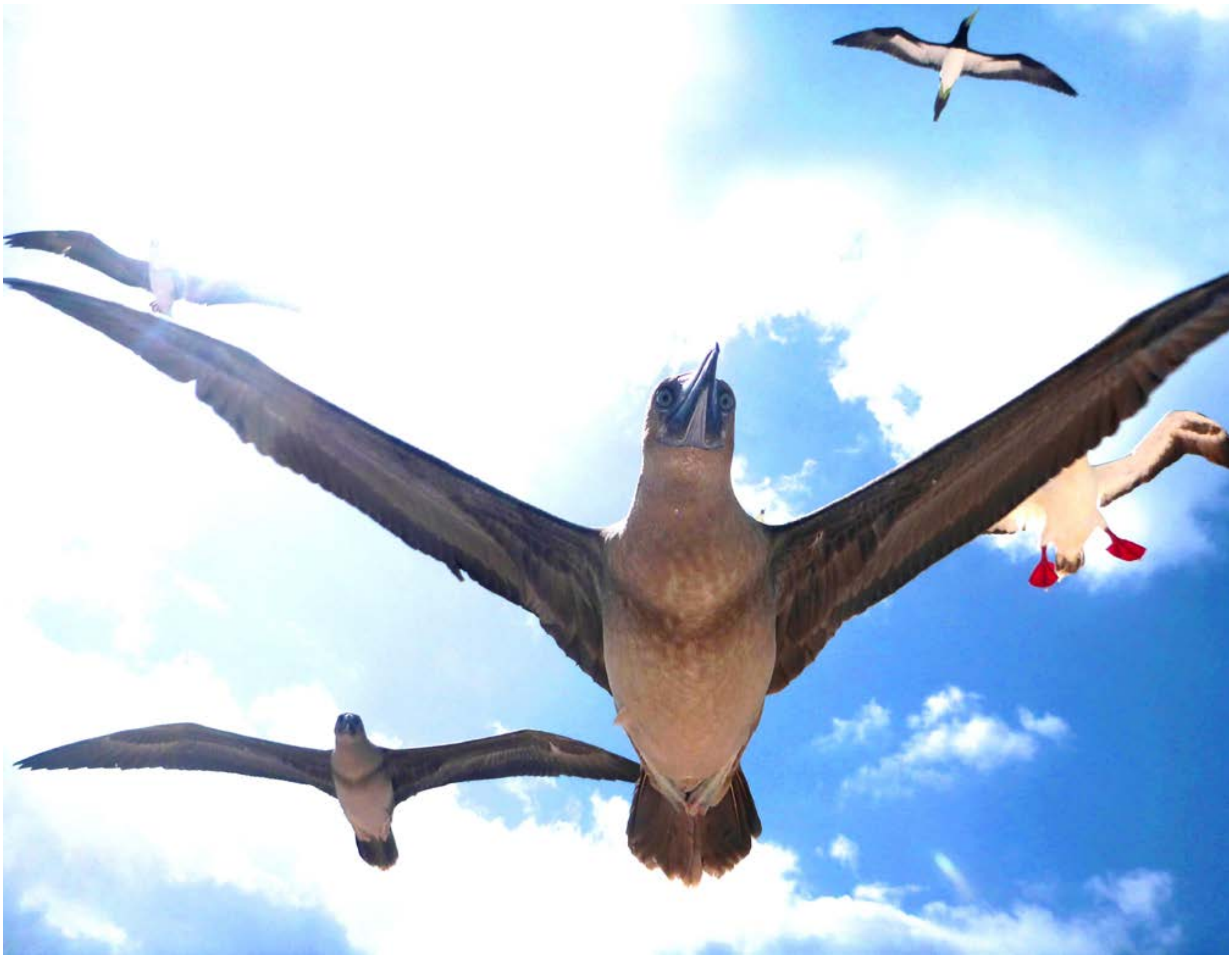
Although monitoring programs are in place for the Great Barrier Reef Marine Park, allowing the identification and evaluation of cumulative impacts, management has largely focused on individual elements or activities within the park, and spatial planning only manages some activities (Hockings et al. 2009). In particular, differences in legislation, policy, planning, and actions addressing pressures and impacts across jurisdictions have been identified as inhibiting effective management of the region (Hockings et al. 2009). The Reef 2050 Long-term Sustainability Plan (Australian Government & Queensland Government 2015) aims to include all levels of government, the community, traditional owners, industry and the scientific community in the management of external pressures affecting the reef (e.g. water quality and dredge disposal). A Reef-wide integrated monitoring and reporting program is currently being developed to measure the success of the plan and support adaptive management of the World Heritage Area (Hedge et al. 2013).

Triage responses to changes resulting from pressures

Research and management initiatives ultimately require prioritisation, because investment is finite for both funds and available effort. Evaluation of prioritisation and planning processes is limited. Similarly, the benefits and costs of investing in planning exercises have had limited evaluation (Bottrill & Pressey 2012, Jarić et al. 2014). Assessments of planning exercises tend to focus on quantifiable outputs (e.g. number of hectares reserved), rather than indicators that directly demonstrate changes in ecological systems or the achievement of conservation goals because of planning (Bottrill et al. 2009). Where resources are especially limited, programs can focus on monitoring without a clear understanding of whether any results would inform management, or indeed whether any management actions would be acceptable (McDonald-Madden et al. 2010). Linking objectives, planning, management actions and monitoring is part of the well-accepted adaptive management cycle that is rarely completed in practice, reducing the value of already limited resources, and failing to inform and improve subsequent decisions (Ban et al. 2012).

At the same time, the practicalities of carrying out conservation research and management in an increasingly open and informed community tend to introduce biases in planning processes. Rather than focusing on species that are in high need of information for conservation planning, species that are wide ranging, highly abundant (and therefore more easily accessed) and charismatic tend to be the most studied (Clark & May 2002, Jarić et al. 2014). The reality is that conservation managers and funding agencies allocate funds knowing that some habitats and species might degrade anyway (Bottrill et al. 2009).

Some support exists for wise allocation of funds assisted by approaches such as triage and cost-efficient optimisation (Bottrill et al. 2009). Although examples of this approach are limited in the Australian context, the Department of Conservation in New Zealand has developed a cost-efficiency framework for threatened species conservation based on triage principles (Joseph et al. 2009), with the objective that recovery of more species could be funded at a level of higher success (i.e. more 'bang for the buck'). It should be noted that such decision-making should not be interpreted as 'sanctioning degradation or extinction in the name of efficiency' (Bottrill & Pressey 2012). Rather, it is about being clear about strategic planning in the expenditure of limited funds and being clear about what conservation funding can achieve.



Brown boobies (*Sula leucogaster*) in flight over North-east Cay, Coral Sea Commonwealth Marine Reserve
Photo by Andy Warnbrunn

Assessment summary 5
Effectiveness of marine management

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Climate and system variability				
Understanding: Understanding of climate variability and its management is reasonably high and improving				X
Planning: Planning for icons such as the Great Barrier Reef is continuing, and commercial fisheries are aware of the need to plan around climate variability. Elsewhere, efforts are patchy				X
Inputs: Support for research required operates on timescales that are ineffective for meeting long-term goals and sustainability, thereby undermining effective management				X
Processes: Management tools and approaches exist, and in some cases are applied. Strong management frameworks are required for long-term environmental health				X
Outputs: Regulatory frameworks are underdeveloped, and are not adaptive to interactions between economic development and sustainable ecosystems, resulting in gradual long-term environmental declines				X
Outcomes: Further policy and management controls are required to address declining environmental health, and interactions between climate variability and climate change				X

Assessment summary 5 (continued)

Summary	Assessment grade: Ineffective / Partially effective / Effective / Very effective	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Climate change				
Understanding: Strong institutional partnerships and high-quality research are progressing understanding				
Planning: Recognition of the impacts of climate change is becoming widespread; however, it is only beginning to be incorporated into the planning of effective management and mitigation initiatives				
Inputs: Although resources exist for planning, support for policy and resourcing for action is limited				
Processes: Transitioning from planning to action is slow. Widespread acceptance of the need for active and effective management is required				
Outputs: Lack of action, combined with the accelerating rate of climate change, is delivering a progressive deterioration in the marine environment				
Outcomes: Continuing failure to recognise and manage the effects of climate change runs the risk of irreversible damage to the marine environment				

Assessment summary 5 (continued)

Summary	Assessment grade				Confidence		Comparability
	Ineffective	Partially effective	Effective	Very effective	In grade	In trend	To 2011 assessment
Commercial fishing (Note: In 2011, this was combined in 'Fishing')							
Understanding: Understanding of fisheries and effective management frameworks is reasonably high and improving			↗		◕	◕	◇
Planning: Improved planning processes directed towards research and risk-based assessment processes are resulting in more robust outcomes			↗		◕	◕	◇
Inputs: Greater use of technology for data collection informs management decisions and measures the trajectory of trends over time			↗		◕	◕	◇
Processes: Improved processes have been developed to expand the range of fishery assessment tools, with an increased use of risk-based approaches			—		◕	◕	◇
Outputs: Assessment output is provided by annual *Fishery status reports* and biennial *Status of key Australian fish stocks* reports for national commercial fisheries; state/territory fisheries agency reports provide assessment outputs for state/territory jurisdictions			—		◕	◕	◇
Outcomes: Improvements in data gathering and reporting direct resources towards commercial fishing operations that pose the highest risk to the marine environment			—		◕	◕	◇

Assessment summary 5 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence (In grade / In trend)	Comparability (To 2011 assessment)
Recreational fishing (Note: In 2011, this was combined in 'Fishing')			
Understanding: National and state/territory surveys have been conducted, although overall impacts on stock status are not always known. In some jurisdictions, ecosystem-based approaches include understanding of risks to species, habitats and ecosystem structure			
Planning: Most jurisdictions have formal recreational fisheries management capacity, and most incorporate an ecosystem-based approach to assessing risk, with an increasing focus on habitat and fishery improvement			
Inputs: Survey data include catch and effort data, and some social/behavioural and economic information. Information gathered varies across jurisdictions, limiting the ability to aggregate the information; efforts to develop methods for national surveys are in progress			
Processes: All jurisdictions rely on surveys for collecting catch and effort information. In some jurisdictions, these data are incorporated into assessments and management frameworks, allowing updating of management frameworks			
Outputs: National and jurisdictional survey data and reports can be used to provide information across species and stock ranges, and help inform the development or updating of control limits. However, there has been little, if any, coordination of surveys between jurisdictions			
Outcomes: In some jurisdictions, some previously overfished species are recovering. In others, catches continue to be larger than commercial catches, and stock assessments do not include recreational catches			

Assessment summary 5 (continued)

Summary	Assessment grade: Ineffective	Partially effective	Effective	Very effective	Confidence: In grade	In trend	Comparability: To 2011 assessment
Traditional use of resources							
Understanding: There has been a gradual shift from the well-recognised need to understand sustainable traditional harvest levels towards building on-ground capacity and solutions for quantification		↗			◒	◒	X
Planning: Indigenous-driven planning is growing, but it is not consistently linked to a framework that assesses the performance of stated objectives		↗			◒	◒	X
Inputs: Further progress on consistent recording and storing of data on traditional harvesting is needed before the data can inform management frameworks relating to the impact of this use		↗			◒	◒	X
Processes: An extensive range of Indigenous-based initiatives are advancing to support the management of marine resources; assessing their performance is the next increment for effective management		↗			◒	◒	X
Outputs: Improved community involvement in developing protocols for cultural resource management is empowering Indigenous people to make more informed decisions about regulatory solutions		↗			◒	◒	X
Outcomes: Indigenous-driven planning and management achieve higher environmental outcomes and greater effectiveness with rolling forward programs to meet future priorities and challenges		↗			◒	◒	X

Assessment summary 5 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Marine oil and gas exploration and production				
Understanding: Understanding of the impacts of exploration, production and decommissioning activities of the oil and gas industry has increased during the past decade				
Planning: A single national regulator is in place for oil and gas operations in Australian waters where most activity is currently occurring. Individual states and the Northern Territory regulate across coastal waters				
Inputs: Data on operations in Australian waters are collected by the national regulator, analysed for trends across industry, and used to inform future environmental management improvements and regulatory activity. Inputs at the state/territory level are less clear				
Processes: The national regulatory framework for Australian waters is subject to an independent operational review of its performance. Processes at the state/territory level are less clear				
Outputs: Assessment and inspection of oil and gas activities in Australian waters by the national regulator are used to inform required areas of industry improvement. Outputs at the state/territory level are less clear				
Outcomes: An increased level of regulatory oversight for operations in Australian waters, covering the majority of activity, is supporting effective management of offshore oil and gas activities				

Assessment summary 5 (continued)

Summary	Assessment grade				Confidence		Comparability
	Ineffective	Partially effective	Effective	Very effective	In grade	In trend	To 2011 assessment
Marine mining and industry							
Understanding: The likely environmental impacts, while expected to be local in nature, remain unclear, with only ad hoc baseline information available							
Planning: Resource assessment and planning are ad hoc and conducted on local scales, driven by commercial constraints and community pressures							
Inputs: Limited data are available. International studies and established marine mining codes of conduct can inform understanding and planning							
Processes: Australian Government and state/territory regulatory frameworks are largely untested, except where marine mining is established. State/territory-level decisions are limited to temporary moratoriums							
Outputs: Established operations have management programs; proposed operations have only desktop analysis. Limited research outputs exist (e.g. bathymetric mapping, benthic surveys)							
Outcomes: Established operations mitigate local impacts, but not cumulative impacts							

Assessment summary 5 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Marine vessel activity				
Understanding: There is currently reasonably good understanding of impacts associated with groundings, pollution and introduction of marine species, and less understanding of impacts associated with ongoing low-level noise and vessel strike				
Planning: There is a good level of national and international coordination to manage the direct impacts of pollution and grounding of commercial vessels. Management systems for mitigating impacts of introduced species are improving, and some planning associated with the impacts of vessel strike is being conducted				
Inputs: Monitoring and reporting systems for maritime safety, pollution and grounding of vessels are well developed				
Processes: Commercial vessel management systems, and implementation of national and international provisions continue to provide effective protection in most areas. There is little direct management of vessel strike and general vessel noise, largely because of a lack of information quantifying impacts that management frameworks could be informed by				
Outputs: Management frameworks ensure that environmental noncompliance in association with safety, pollution and grounding is addressed; however, empirical information that could provide insight into the commercial shipping industry's approach to environmental performance is not available				
Outcomes: Management frameworks currently largely address impacts associated with groundings, pollution and introduction of marine species. Management of impacts associated with ongoing low-level noise and vessel strike is impeded by a lack of data				

Assessment summary 5 (continued)

Summary	Assessment grade (Ineffective, Partially effective, Effective, Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Anthropogenic noise				
Understanding: Sources of underwater noise across sectors are well known; however, impacts require a greater level of understanding				X
Planning: Acute impacts across sectors are largely managed through EPBC Act approval processes, regulatory frameworks and internal environmental planning, reducing risks. Planning associated with chronic impacts is less established				X
Inputs: Substantial information is available to inform management, with varying degrees of uptake across sectors				X
Processes: Environmental authorisation processes associated with the EPBC Act are in place across sectors for acute impacts; there is little management of chronic impacts				X
Outputs: Assessment and inspection of noise-producing activities associated with the oil and gas industry, and environmental assessments and collaborative research programs conducted by the Navy are used to inform required areas of improvement in these sectors. Outputs and improvement processes across other sectors are less clear				X
Outcomes: An increased level of regulatory oversight for oil and gas activities, and ongoing research and inputs into environmental plans for the Navy aim to ensure effective management of underwater noise in these sectors. Management outcomes for other sectors are less clear				X

Assessment summary 5 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Marine debris				
Understanding: Local sources of marine debris are well known, with increasing understanding of sources from neighbouring areas. Knowledge of impacts is increasing but requires a greater level of understanding	Partially effective, Improving	Adequate	Adequate	Somewhat comparable
Planning: International conventions addressing the release of marine debris are in place, and there are some efforts to improve waste reception facilities at both Australian and regional international ports; however, there are few practical arrangements in place for comprehensive and coordinated mitigation	Ineffective, Deteriorating	Adequate	Adequate	Somewhat comparable
Inputs: Waste management programs have been developed but are yet to be implemented into fishery management arrangements. Identification of port waste reception facilities is currently voluntary	Ineffective, Deteriorating	Adequate	Adequate	Somewhat comparable
Processes: Management frameworks for land-based sources operate across multiple jurisdictions; these are not coordinated, and there is currently no clear management framework at the Australian Government level	Ineffective, Deteriorating	Adequate	Adequate	Somewhat comparable
Outputs: Measures made against the objectives of the threat abatement plan have been identified as being ineffective at addressing threats associated with marine debris	Ineffective, Deteriorating	Adequate	Adequate	Somewhat comparable
Outcomes: Marine debris continues to impact species and ecosystems, with no decline in pressures on the marine environment	Ineffective, Deteriorating	Adequate	Adequate	Somewhat comparable

Recent trends

- Improving
- Deteriorating
- Stable
- Unclear

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

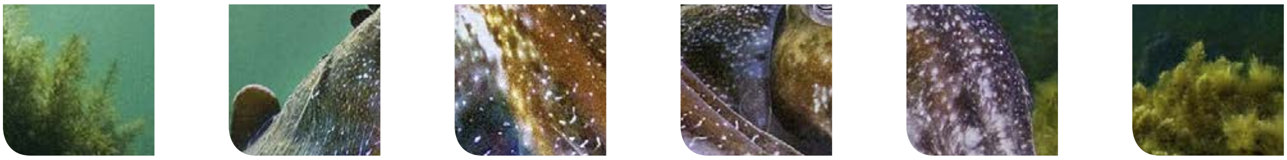
- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

Assessment summary 5 (continued)

Management context (understanding of environmental issues; adequacy of regulatory control mechanisms and policy coverage)	
Elements of management effectiveness and assessment criteria	**Grades**
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
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
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

Assessment summary 5 (continued)

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 marine environment

At a glance

Resilience can be considered to be the capacity of a system to keep functioning even when disturbed. Current understanding of the resilience of Australia's marine environment is limited because of the vast spatial extent of Australia's marine ecosystems, their complexity, the many and varied sources of pressures exerted on them, and the limited capacity to monitor them across relevant timescales. Recent research has shown that reduction of pressures in marine reserves can increase the resilience of reserve species to remaining pressures, such as freshwater incursions associated with flooding or establishment of range-shifting species. The contribution of individual reserves or reserve networks to the resilience of the larger marine ecosystem, however, remains to be determined.

Two useful tools for building resilience in socio-ecological systems are structured scenarios and active adaptive management. In marine ecosystems, structured scenario frameworks are being used to investigate the impacts of commercial industries and climate change, and to test management strategies that might be implemented in response. Adaptive management frameworks, which monitor and assess biological and economic conditions, and adjust management strategies as required, are being implemented for commercial fisheries across Australian Government, and state and territory jurisdictions. Australia now provides regional and international leadership on adaptive fisheries management frameworks.

For most sectors, however, existing management plans for the marine environment are reactive rather than proactive, and are not coordinated across sectors. As a result, many plans fail to address the cumulative nature of multiple impacts and do not support the development of resilience within marine ecosystems. Adaptive governance and adaptive management may be needed to address the cross-sectoral and cross-jurisdictional contributions to cumulative impacts. The expanding National Representative System of Marine Protected Areas provides an opportunity to determine how removal of local pressures contributes to long-term resilience within, and external to, the protected area or network. This will require sustained ecological monitoring for at least the next decade.

Resilience of marine systems

The concept of resilience is not straightforward, with definitions varying across social and scientific disciplines. Complexities in the level of detail also vary, depending on the system of focus. Definitions of resilience can contain any combination of 3 major principles (Folke et al. 2002, Bernhardt & Leslie 2013):

- the magnitude of shock or pressure that a system can absorb while remaining within a given state
- the degree to which the system is capable of self-organisation in light of the shock or pressure
- the degree to which the system can build capacity for learning and adaptation.

Depending on the interpretation, self-organisation and adaptation can be associated with the absorption of shocks without a fundamental change (e.g. returning to an original ideal state). Self-organisation and adaptation can also include readjustment to a new state (e.g. adaptation without sacrificing the provision of ecosystem services; Folke et al. 2004). Ultimately, at the core of any definition of resilience is the capacity of a system to keep functioning even when disturbed (Levin & Lubchenco 2008). Protection of the ecosystem services provided by the marine environment requires that the resilience of marine ecosystems is maintained.

Organisms have developed mechanisms for coping with both short-term variability (e.g. waves, tides) and longer-term variability (e.g. seasonal changes in temperatures, occasional extreme events). Natural selection across long timescales has operated to ensure resilience to variability within historical environmental conditions. However, there is no reason to expect that this same resilience will be maintained as conditions change on shorter timescales, such as those associated with anthropogenic pressures (Hughes et al. 2005, Levin & Lubchenco 2008). The maintenance of resilience is therefore driven by 2 essential components: the adaptive capacity of individual organisms and the timescale at which changes in their environments are occurring.

Similarly, the resilience of ecosystems to disturbance depends on the spatial scale at which both disturbance and resilience operate (Hughes et al. 2005). Improving resilience at small scales might, ultimately, be little defence against pressures that operate at larger scales. For example, climate change is a global pressure with the potential to overcome resilience built at the local scale. The high connectivity of the marine environment means that additional remote pressures, including invasive species, marine debris and coastal run-off, also have the potential to threaten local resilience.

Recent research indicates that local management, including the establishment of marine reserves (see Managing for resilience), can build resilience to external pressures, perhaps buying some time for more effective regional or global management measures to be put in place (Abelson et al. 2016). Understanding and managing the coupled socio-ecological system may increase resilience to changes that the ecological system itself cannot resist. This will require a clear understanding of the properties and value of future environmental conditions, so that managers can help direct the trajectory of change.

Current understanding of the resilience of Australia's marine environment is sparse. This is because it is difficult to monitor the environment across the timescales relevant for assessing resilience, as a result of the vast spatial extent of Australia's marine ecosystems, their complexity, and the many and varied sources of pressures exerted on them. It is accepted that even well-managed systems such as the Great Barrier Reef are unlikely to resist anthropogenic pressures originating outside the management area, making their future prognosis poor (GBRMPA 2014a, Hughes et al. 2015).

Ecosystems that have relatively high diversity tend to be more resilient to external pressures, largely because of high variability in population densities and their ability to maintain aggregate properties, such as nutrient cycling or trophic functioning (Levin & Lubchenco 2008, Hughes et al. 2010). Studies of shallow-water marine reserves around Australia have shown an increased stability in fish populations compared with waters outside the reserve (Babcock et al. 2010). High abundance of larger predators in marine reserves in Tasmania has been shown to reduce the numbers of range-extending *Centrostephanus rodgersii* by 2–10 times (Ling & Johnson 2012), and increased herbivore abundance and coral recruitment have increased the resilience of habitats within marine reserves to coastal run-off associated with flood events in eastern Australia (Olds et al. 2014). However, determining direct effects on populations takes at least 5 years, and more than 10 years before cascading indirect effects on other species are identified (Babcock et al. 2010).

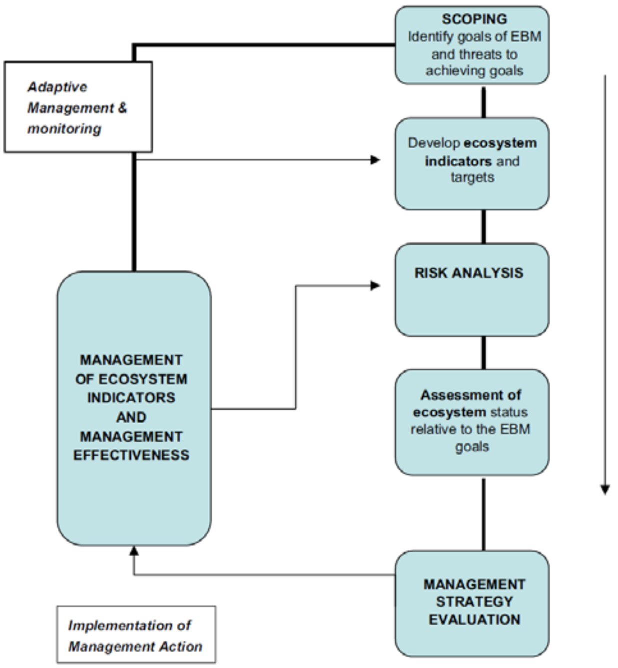
Understanding the resilience of the Australian marine environment currently provides indications of how local resilience can be built successfully, but not whether this will be enough to support resilience in the longer term or at the broader scale. Further, there are substantial gaps in the understanding of the thresholds beyond which ecosystem functioning cannot be maintained, particularly where the responses to pressures are highly uncertain (e.g. those associated with climate change).

Managing for resilience

Most management systems aimed at maintaining or enhancing resilience in components of the marine environment focus on reducing the cumulative nature of multiple impacts and avoiding dramatic shifts in species composition, also known as regime shifts. This is because such shifts are often long-lasting and difficult to reverse (Hughes et al. 2005). However, there are few practical tools available to managers for anticipating and responding to such shifts across the broader environment (Levin & Möllman 2015).

Two useful tools for building resilience in larger socio-ecological systems are structured scenarios and active adaptive management (Folke et al. 2002). Socio-ecological systems are constantly changing, often unpredictably. A way of assessing potential impacts and the management systems that might be required to address these impacts is to investigate a range of scenarios producing projections or if–then case studies (e.g. if we follow a certain scenario, then this is the expected outcome for the future; Evans et al. 2015). Prominent examples of such scenario investigations are those for climate change conducted by the Intergovernmental Panel on Climate Change (IPCC), where a range of scenarios of greenhouse gas emissions, and the associated impacts on atmospheric, terrestrial and marine systems are examined (IPCC 2014). By envisaging multiple alternative futures and actions that might attain or avoid particular outcomes (i.e. mitigative measures), resilience-building management policies can be identified that slow, or even reverse, undesired change (Folke et al. 2002).

Management that builds resilience can sustain socio-ecological systems in the face of surprise, unpredictability and complexity. Because of the unpredictability of change often occurring within these systems, any management frameworks aimed at building or maintaining resilience need to be flexible and open to learning through evaluation. They also need to have the capacity to innovate to ensure that any changes are responded to on relevant temporal and spatial scales (Folke et al. 2002). Governance may also need to be adaptive, crossing jurisdictional and sectoral boundaries as new information, such as that on cumulative impacts, becomes available (Schultz et al. 2015). Management frameworks require clearly articulated and defined management objectives, including desired future ecosystem states (Figure MAR40)—for example, a healthy, functioning reef. Key indicators that can be used to monitor the trajectory of the ecosystem against these objectives need to be identified (Hedge et al. 2013; see also Box MAR11) and, in association, reference points or thresholds that the system is to be maintained above. Assessments of the risk that these reference points or thresholds might be exceeded should be carried out (e.g. Hobday et al. 2011). Finally, modelling approaches for evaluating the consequences of differing management strategies in responding to changes to the system should be incorporated into the framework.



EBM = ecosystem-based management
Source: Curtin & Prellezo (2010), used under CC BY NC ND

Figure MAR40 Integrated ecosystem assessment steps that can be applied for adaptive management of the marine environment

Within Australian marine ecosystems, ecosystem modelling approaches are being used to build structured scenarios that can investigate anthropogenic impacts on ecosystems—including increased nutrient input, climate change and fishing—and test management strategies that might be implemented in response (e.g. Fulton et al. 2005, 2011b). Ecosystem models are now at the development point where model comparisons (similar to those of the IPCC's Climate Model Intercomparison Project) are being carried out by the Intergovernmental Platform on Biodiversity and Ecosystem Services. These efforts aim to provide projections of the impacts of different levels of global emissions scenarios on marine ecosystems.

Evaluation frameworks are also being developed to assess management approaches to sectors within the marine environment. Management strategy evaluation models have been used to:

- assist in the restructuring of frameworks for fisheries managed by the Australian Government in the South-east Marine Region (Fulton et al. 2011b, 2014)
- evaluate biosecurity measures to reduce the risk of the northern Pacific seastar spreading further (Dunstan & Bax 2009)
- evaluate multiple-use management strategies in the Pilbara and the Gascoyne regions of the North-west Marine Region (Gray et al. 2006, Fulton et al. 2009)
- evaluate management options for prawn trawl fishing and differing levels of spatial zoning in the Great Barrier Reef Marine Park (Gribble 2007, 2009) and the North Marine Region (Dichmont et al. 2013).

Management frameworks that include adaptive capabilities have been, or are being, implemented for commercial fisheries across Australian Government, and state and territory jurisdictions (e.g. Kolody et al. 2010, Hillary et al. 2016). The Harvest Strategy Policy includes management actions to monitor and assess the biological and economic conditions of individual fisheries, with the aim of achieving defined biological and economic objectives, set out in the form of quantifiable reference points (see also Box MAR8). The harvest strategies are formally tested using management strategy evaluation methods and amended when necessary (e.g. when understanding of the status of a fishery changes or when improved estimates of reference points become available; e.g. Smith et al. 2014). In association, ecological risk assessments are carried out, and appropriate risk management responses are developed (DAFF 2007). Australia provides leadership on fisheries management strategy evaluation frameworks, both regionally and internationally.

For most sectors, however, existing management plans for the marine environment are reactive rather than proactive (see also Effectiveness of marine management) and are not coordinated across sectors. As a result, management plans fail to address the cumulative nature of multiple impacts and do not currently support improved understanding of how to build resilience within coupled socio-ecological marine ecosystems.

The National Representative System of Marine Protected Areas (NRSMPA), which aims to be representative, comprehensive and adequate, is one exception to this reactive approach. It provides an experimental framework that could improve our knowledge of resilience in the Australian marine environment. The review process incorporated into the NRSMPA also provides for adaptive management of the marine environment. Sustained ecological monitoring for at least the next decade will be required to understand the role that marine protected areas have in building long-term resilience at local and broader scales.

Residual risks
to the marine environment

At a glance

Avoidance and mitigation measures, which are the primary strategies for managing impacts of activities on the marine environment, may not address all impacts associated with the activities. Management may be absent or only partially effective, there may be some impacts that are difficult to avoid or mitigate, and the severity of some impacts may be unknown. These impacts are regarded as residual risks.

Assessment of the residual risks associated with pressures on the marine environment identified that those associated with climate change and marine debris were the most extensive because effective management is lacking. Management frameworks currently in place for most other pressures reduce either the likelihood of residual risks (e.g. commercial fishing impacts on habitats) or the impact of residual risks (e.g. planned oil and gas exploration and production activities).

Ecological risk assessments provide a quantitative and often hierarchical framework for identifying risks associated with activities and their probability. Their use would improve the identification of residual risks in the future, and increase opportunities for the more effective use of avoidance and mitigation options. Application of formal ecological risk assessment frameworks within the Australian marine environment has, to date, been limited.

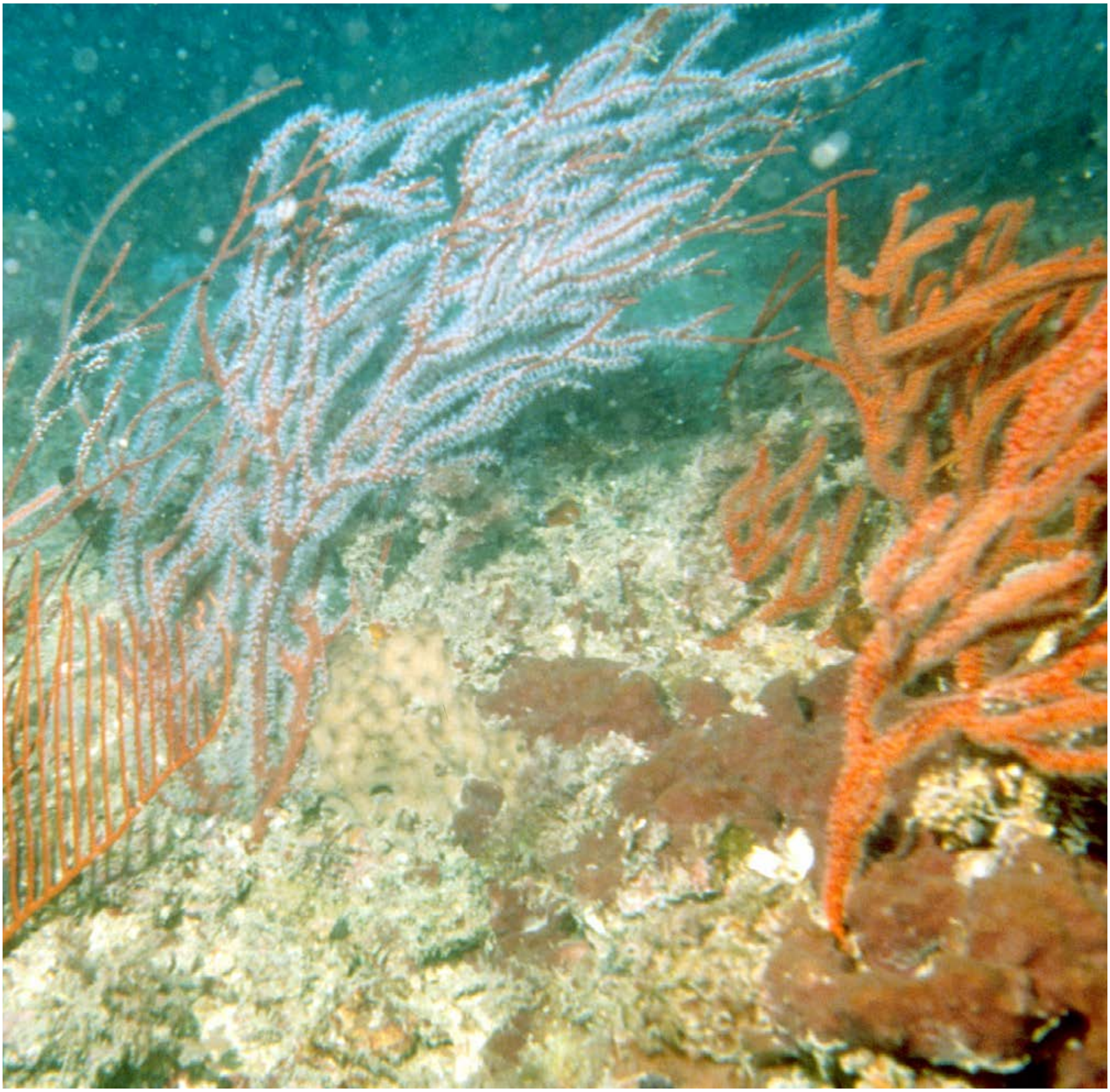
Environmental offsets, as set out in the Australian Government's EPBC Act Environmental Offsets Policy 2012, are designed to ensure no net environmental loss as a result of residual risks. The suitability of any proposed offsets is considered as part of the assessment of actions under the *Environment Protection and Biodiversity Conservation Act 1999* and is not justification for a proposal to go ahead without adequate avoidance or mitigation, if at all. Similar policies have been set out for various sectors by some state governments and some industry sectors. However, evaluation of the success of offsets in achieving environmentally sustainable outcomes is often not integrated into approval processes. The recently released *Policy statement: advanced environmental offsets under the EPBC Act* may improve environmental outcomes through implementation of offsets before any impact occurs, and a more strategic approach to the application of offsets.

Avoidance and mitigation measures are the primary strategies for managing potential significant impacts of activities on the marine environment, and form the basis of management frameworks regulating activities in the marine environment. These strategies, however, may not address all impacts associated with the activities. There may also be some impacts on the marine environment (e.g. severe storm events) that are unable to be predicted, and cannot be avoided or mitigated. These impacts are regarded as residual risks.

The assessment summary identifies residual risks for the marine environment using a classification system outlined in the SoE *Approach* report (Jackson et al. 2016). The method for applying the classifications does not follow a formal risk assessment framework, but instead uses best judgement based on available information. Because of the subjective nature of the assessment, the authors recommend that the assessment summary be used as a guide only, as it may not necessarily reflect the output of a robust, quantitative approach to risk assessment.

Residual risks have been divided into 2 groups: those associated with pressures that are currently managed; and those associated with pressures that are currently not managed, or whose impacts are unable to be predicted, and cannot be avoided or mitigated. The identified risks associated with pressures that are currently managed are based on a 'business as usual' situation, where current management processes and frameworks continue as they are. Risks are classified according to their likely impacts on populations at a national scale, not on an individual or a local scale.

Each classification includes a pressure (e.g. commercial fishing) and the component of the environment affected by that pressure (e.g. bycatch species). Where a component being affected is not identified, the impact relates to the whole marine environment. The residual risks are discussed below.



Gorgonian corals 50 kilometres offshore, far northern Queensland
Photo by CSIRO Marine Research

Assessment summary 6

Residual risks

Managed pressures

	Catastrophic	Major	Moderate	Minor	Insignificant	Unknown
Almost certain		Marine debris	Fishing (commercial, bycatch species) Fishing (recreational) Fishing (traditional use of resources)	Fishing (commercial, target species) Oil and gas (planned activities)		Anthropogenic noise
Likely				Marine vessel activities (operational) Marine vessel activities (ship strike) Marine mining and industries		
Possible		Fishing (commercial, habitats) Marine vessel activities				
Unlikely		Oil and gas (unplanned activities, accidents)				

Assessment summary 6 (continued)

Unmanaged pressures or impacts that are unable to be predicted

	Catastrophic	Major	Moderate	Minor	Insignificant	Unknown
Almost certain	Climate change (ocean temperature: sessile biota)	Climate change (ocean temperature: mobile biota	Climate change (ocean currents)			Climate change (ocean acidification)
Likely			Extreme or severe event			Cumulative impacts
Possible						Climate change (nutrient supply)
Unlikely		Climate change (dissolved oxygen)	Disease outbreaks			

Our understanding of the likelihood of occurrence and the associated impacts of residual risks varies, depending on our understanding of impacts and the management frameworks in place to mitigate these impacts.

Residual risks associated with ongoing pressures—climate change, fishing (commercial, recreational and traditional use), oil and gas extraction and production, marine debris, and anthropogenic noise—are identified as 'almost certain' in their occurrence. Impacts range from catastrophic to unknown. In these cases, pressures will continue to affect the marine environment; however, the impact of these pressures varies, depending on the management frameworks currently in place.

Residual risks associated with climate change are currently the most extensive and are likely to have the largest impacts. Those associated with marine debris are also considered extensive and likely to have major impacts on the marine environment. These residual risks are classified in such a manner because jurisdictions currently do not have management frameworks in place that can mitigate or reduce impacts. As a result, risks are widespread rather than being truly residual in nature. Management frameworks currently in place for residual risks associated with most other pressures result in reductions in either likelihood (e.g. commercial fishing impacts on habitats) or impact (e.g. planned oil and gas exploration and production activities).

The classification of residual risks identifies some areas where current management frameworks may be less effective and require improvement. For example, although management of the impacts of commercial fishing is considered effective, and therefore residual risk to target species is considered to be minor, there is less information on bycatch species, thus increasing the potential impact on these species to moderate. The impacts of recreational fishing and traditional use of resources are also considered moderate, because less information is available and their management is only partially effective.

Several residual risks have unknown impacts, yet are considered to be almost certain (anthropogenic noise, ocean acidification) or likely (cumulative impacts), indicating a need for further information in these areas. Identification of unknown impacts highlights key challenges in developing strategies for managing impacts—that, is the paucity of data and understanding about the broader ecological impacts of industries on the marine environment, the effectiveness of current management, and likely future trends.

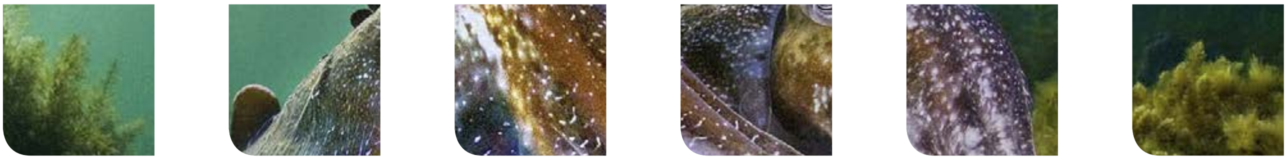
Ecological risk assessment methods are available to identify known residual risks in a quantitative and often hierarchical framework (Hobday et al. 2011). These risk assessments can play a central role in an adaptive management process, integrating stakeholder values and identifying how to improve future management effectiveness (Van den Brink et al. 2016). Such frameworks should not be confused with ecological impact assessments, which frequently fail to explicitly identify risks, potential impacts and likelihoods (Gibbs & Browman 2015). Ecological risk assessment frameworks have been developed in Australia to identify risks associated with fishing (e.g. Smith et al. 2007, Hobday et al. 2011, Fletcher 2015) and introduced species (e.g. Hayes 2003, Hayes & Sliwa 2003). Application of quantitative frameworks to other pressures is lacking, identification of residual risks associated with these pressures is less clear, and opportunities for earlier and more effective avoidance and mitigation may be missed.

Biodiversity loss because of development or use once avoidance and mitigation options have been fully exercised can, in some cases, be compensated for through environmental offsets. Such approaches have been implemented as part of the approval process of the EPBC Act and as part of approval processes operating in a number of states. According to an Australian Government policy released in 2012 under the EPBC Act, companies have to compensate for their residual adverse impacts on national environmental assets by implementing biodiversity offsets, with the aim of ensuring no net environmental loss (DSEWPaC 2012f). The suitability of any offsets proposed is considered as part of the decision-making process associated with the assessment of actions under the EPBC Act. Offsets must meet 10 requirements associated with the delivery of conservation outcomes, proportional to impacts on the environment; monitoring, auditing and enforcing of offsets once in place; and management of risks associated with the offsets failing to meet their targets (DSEWPaC 2012f). Similar policies have been set out for various sectors by some state governments (e.g. the marine fish offset policy developed by the Queensland Department of Agriculture, Fisheries and Forestry). Examples of marine offsets implemented under Australian Government legislation include support for sea ranger programs, conservation programs for particular species, and education and management programs (Richert et al. 2015).

Community responses to the implementation of offsets vary, depending on how closely related the offset activity is to the residual risk, the location of the offset, and social acceptance of governance systems in place at the time (Rogers 2013). Offsets that may be construed as providing future predicted benefits to counter current real loss are especially contentious (e.g. Pascoe et al. 2011).

Evaluation of the success of offsets in achieving environmentally sustainable outcomes is often not integrated into approval processes (Maron et al. 2012). A review of offsets proposed for the Great Barrier Reef under the EPBC Act found that offset strategies were often vague, were submitted before residual impacts were properly described and quantified, and were often finalised after the development was approved—thereby increasing the risk that developments with inadequate offsets and unmeasurable benefits were approved. Offsets often comprised indirect rather than direct offsets, thereby failing to meet the target of 90 per cent direct offsets set out in the policy. Additionally, sites where offsets were implemented were not coordinated with regional planning and zoning, and were limited only to the period of the development, increasing the risk of degradation over time and future development impacts. Budgets set out for offsets were found to be arbitrary, and lacking in transparency and justification, and frameworks for monitoring offsets were lacking. It was concluded that many of the offsets approved did not provide protection for matters of national environmental significance under the EPBC Act (Bos et al. 2014).

Frameworks to assess offset management strategies are now becoming available. They allow testing of strategies under alternative scenarios relating to both ecological and societal responses to development or use, and the implementation of associated offsets (e.g. Thébaud et al. 2015). The recently released *Policy statement: advanced environmental offsets under the* Environment Protection and Biodiversity Conservation Act (DoE 2016) may also provide improved environmental outcomes through implementation of offsets before any impact occurs, a more strategic delivery of offsets, and a streamlined environmental assessment process.



Outlook

for the marine environment

At a glance

The contribution of the marine environment to the economy is projected to continue to grow 3 times faster than Australia's gross domestic product in the next decade. It is in Australia's interest that our ocean ecosystems continue to bring economic, cultural and social benefits that can be sustained into the future.

The outlook for the marine environment is mixed. The trends of many marine environmental resources and, in particular, many listed species, are unclear. Although overall status for habitats, communities or species groups may be good, habitats or communities in specific locations or individual species (e.g. some reef fish species, Australian sea lions) remain in poor condition, and the prospects for improvement are unclear.

Management of some sectors (e.g. commercial fishing) has clearly improved during the past decade, resulting in better oversight of sustainable practices and, in some cases, the recovery of species and habitats. Although specific pressures on habitats, communities or species groups may have been reduced (e.g. commercial fishing on seamounts), the future outlook for many remains unclear as a result of the unpredictable nature, or lack of management, of remaining pressures (e.g. climate change). Without improved management of external pressures that are not currently directly managed, or are not managed effectively (e.g. marine debris), ongoing gradual deterioration of the marine environment is expected to occur. Some sectors (e.g. marine mining, recreational fishing) lack nationally coordinated management, which reduces Australia's capacity to respond to external pressures and cumulative impacts that are already evident in some areas and seem certain to increase in coming decades. Seabed environments, and associated demersal and benthopelagic species groups across shelf and slope regions are expected to continue to recover in response to reduced fishing pressures. Habitats that are expected to continue to deteriorate in the future include coral reefs, fringing reefs and algal beds, largely in association with increasing pressure associated with climate change. Without coordinated effective management of pressures affecting species groups that demonstrate connectivity with regions external to the Australian exclusive economic zone, ongoing gradual deterioration of these species groups is expected.

Given continuous and ongoing change in the marine environment, and a lack of information on what historical states might have looked like, our ability to compare the current state of ecosystems with some historical ideal becomes ambiguous and somewhat arbitrary, and may not be appropriate. This is particularly true if the historical ideal is inaccurate. The concept of preserving components of marine ecosystems in a condition that was (hopefully) measured at an arbitrary point in time loses meaning, especially when reduction or removal of a single sector's pressure may be insufficient to return a species or habitat to its prior condition in a reasonable timeframe. Ecosystem restoration and artificial habitats are likely to become increasingly important. However, many restoration efforts will focus on maintaining particular species, or restoring them to particular locations or to an agreed 'threshold' level rather than to earlier (unknown) states. Recovery targets for species listed under the *Environment Protection and Biodiversity Conservation Act 1999* are less clear; although removal from the list would be a clear indication of species recovery, this has yet to happen for any marine species.

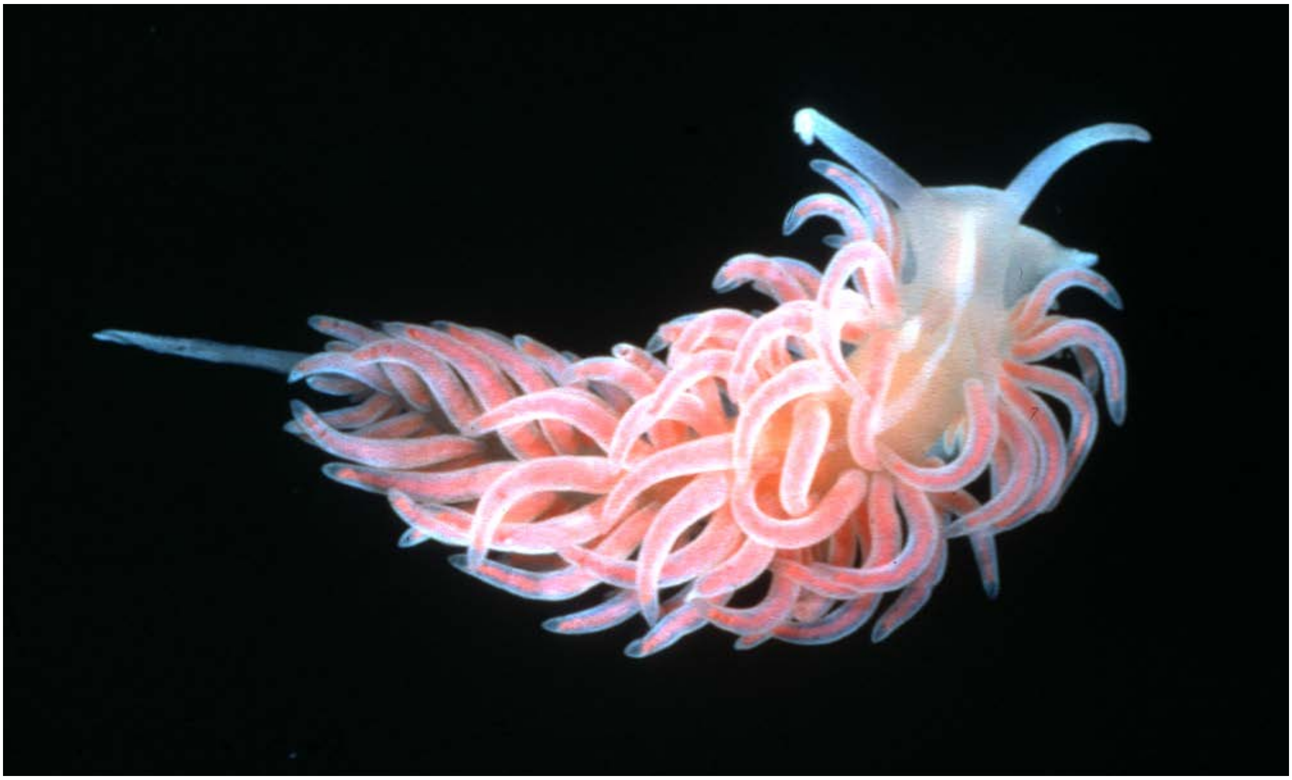
The increasing complexity and mixture of local and remote pressures will require increasingly sophisticated information for managers to choose the most cost-effective and enduring interventions that satisfy individual sectors while ameliorating cumulative impacts. Improved, sustained monitoring can provide the indicators against which resources can be managed and management effectiveness can be reviewed. Addressing challenges for the marine environment as we look to the future will require a coordinated, collaborative and dedicated effort involving researchers, government, industry and the Australian community.

At a glance (continued)

Current key gaps that limit our capacity to undertake national assessments of the marine environment include a lack of ongoing consistent monitoring, identification of standardised indicators for monitoring the marine environment, integrated approaches to understanding cumulative impacts and robust risk assessment frameworks for the environment. If addressed, these will substantially improve future state of the environment reporting.

Australia's marine environment is globally, regionally and nationally important, providing ecosystem services such as nutrient cycling and climate regulation, and economic wealth through industries such as fisheries, aquaculture, and oil and gas exploration and production. The value of the economy sourced from the marine environment is projected to continue to grow 3 times faster than Australia's gross domestic product in the next decade (NMSC 2015). It is therefore important that our ocean ecosystems are managed in such a way that they continue to bring economic, cultural and social benefits that can be sustained into the future.

The outlook for the marine environment, based on the assessments presented here, is mixed. Although many of the physical, biogeochemical, biological and ecological characteristics that are monitored appear stable, others—especially those closer to shore (e.g. coral reefs, fringing reefs, algal beds)—are deteriorating in response to changing and more variable human uses and climate. The trend of many marine environmental resources and many listed species is unclear, largely because most are not monitored in a standardised or ongoing manner. Although the overall status of many habitats, communities and species groups may be good, habitats or communities in specific locations, or individual species remain in poor condition, with prospects for improvement unclear. Improved understanding that leads to the identification of effective management options and adaptation strategies is needed to minimise risks to our existing assets and uses. The potential



Nudibranch (*Phyllodesmium serrata*), found in rocky reefs

Photo by Graham Blight

also exists to maximise new opportunities, especially across climate-sensitive industries such as fisheries and energy, and this will be a key requirement for future sustainability.

Management of many marine sectors, including commercial fishing, oil and gas, and marine vessel activity, is reported as effective. Improvements in the past 5–10 years have resulted in sustainable practices and, in some cases, the recovery of species and habitats. However, others, including recreational fishing and marine mining, lack nationally coordinated management. What management is in place may become less effective as pressures increase. At the same time, external pressures that are not directly managed lack clear governance frameworks across jurisdictions, or are the result of many interacting human uses; these pressures include climate change, marine debris and the chronic impacts of noise. The lack of coordinated governance and management across sectors reduces Australia's capacity to respond to these external pressures and cumulative impacts that seem certain to increase in coming decades.

The EPBC Act remains an effective legislative instrument under which the environmental impacts of existing and emerging activities fall. This includes the Commonwealth marine reserves of the NRSMPA that were proclaimed in 2012. The Australian Government focus on outcome-based management, and the reduction of duplication by devolving management responsibility for environmental issues to individual sectors or jurisdictions provide the opportunity to focus on overall management performance and ecosystem condition at the national (or bioregional) level. The recent strategic assessment of the Great Barrier Reef World Heritage Area, which followed the decision by the World Heritage Committee to consider listing this heritage area as 'in danger' and resulted in the production of the Reef 2050 Long-term Sustainability Plan (Australian Government & Queensland Government 2015), is one example of how to promote coordinated management and science.

To identify ongoing changes in the marine environment, and facilitate provision of information to inform management and policy, there is an equivalent need for academic and consultant scientists (and the growing community-monitoring or citizen-science sector) to coordinate their activities. This would ensure that their data are collected, managed and reported in a way that enables use and re-use of the data (see Box MAR10).

The Australian marine science and management community has identified key challenges for the marine environment as we look to the future, and the science needed to address these challenges (see Box MAR11). Addressing these challenges will require a coordinated, collaborative and dedicated effort involving researchers, government, industry and the Australian community. Self-organising initiatives such as the Research Providers Network, the National Marine Science Committee and the Australian Fisheries Management Forum are helping to provide national coordination of research and development opportunities.

Box MAR10 Monitoring and reporting on biodiversity in Australia's oceans: towards a blueprint

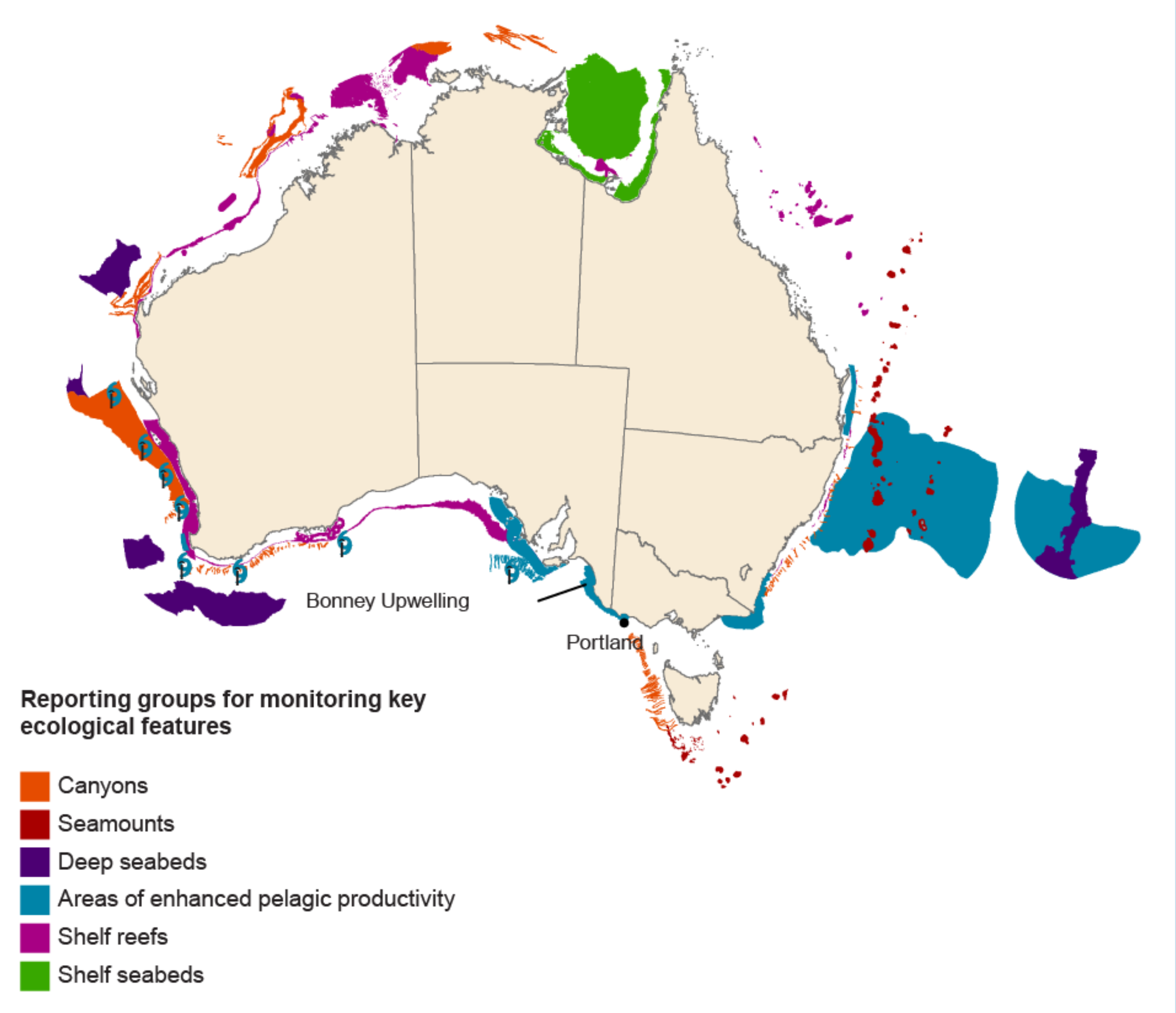
Monitoring Australia's marine regions is fundamental to understanding and reporting on how the ocean is changing in response to human pressures. The National Environmental Science Programme Marine Biodiversity Hub, in collaboration with the Australian Government Department of the Environment and Energy, has developed an outline for the monitoring of marine biodiversity (*Towards a blueprint for monitoring key ecological features in the Commonwealth marine area*; Hayes et al. 2015), based on identifying the informative links between the key ecological features (KEFs) in our marine regions and pressures on these features.

The KEFs are parts of the ocean identified in the Australian Government's marine bioregional plans as highly valued for their importance to biodiversity or ecological function and integrity. Marine bioregional planning processes identified 54 KEFs in Australian waters, with 50 mapped in detail to date (Figure MAR41). The KEFs can be grouped for reporting purposes into areas of enhanced pelagic productivity, canyons, deep seabeds, seamounts, shelf reefs and shelf seabeds. Identification of these features provides an important focal point for developing monitoring programs that can provide indicators of change in the marine environment.

Box MAR10 (continued)

Although the oceanography of most KEF groups has been studied, the degree of biological understanding of each varies. Areas of enhanced pelagic productivity are the best understood, and shelf seabeds and deep seabeds the least. Thirty-three KEFs are sufficiently well understood to include in modelling efforts aimed at better understanding of the impacts on each and their responses to a range of anthropogenic pressures.

Towards a Blueprint details how Australia can expand its institutional capacity to meet the reporting needs of the department. It identifies existing data for areas where monitoring can begin, and assesses Australia's capability to collect new monitoring data as a basis for decision-making.



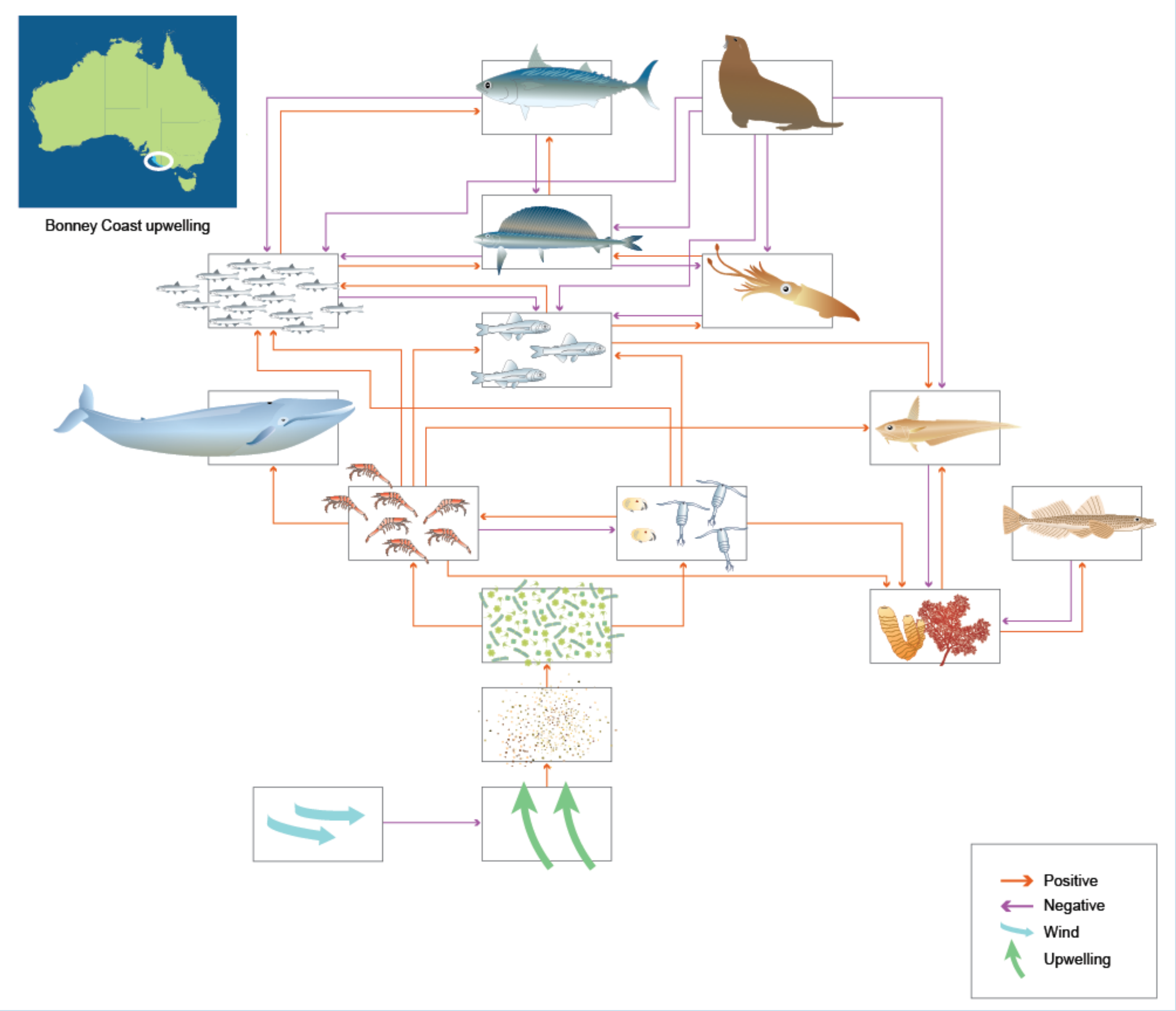
Note: Not all key ecological features are shown here because some have yet to be mapped in detail.
Source: National Environmental Science Programme Marine Biodiversity Hub

Figure MAR41 Key ecological features identified by the Australian Government in marine bioregional plans

Box MAR10 (continued)

Example of focused biodiversity monitoring: the Bonney Upwelling

The Bonney Upwelling is one of 9 enhanced pelagic productivity KEFs identified in Australian waters and provides a good example of how KEFs can serve to focus biodiversity monitoring. From November to May, the surface waters of the Bonney Coast are blown offshore by south-easterly winds and replaced by cold, nutrient-rich water that rises from deeper depths (upwelling) to replace the surface water. The sunlit nutrients fuel an explosion of phytoplankton that sustains a seasonal abundance of marine life, from zooplankton species such as krill to large marine animals such as pygmy blue whales (Figure MAR42). Understanding long-term changes to this biophysical system and identifying what is most likely to have caused change or may cause change in the future is the focus of monitoring.



Source: National Environmental Science Programme Marine Biodiversity Hub

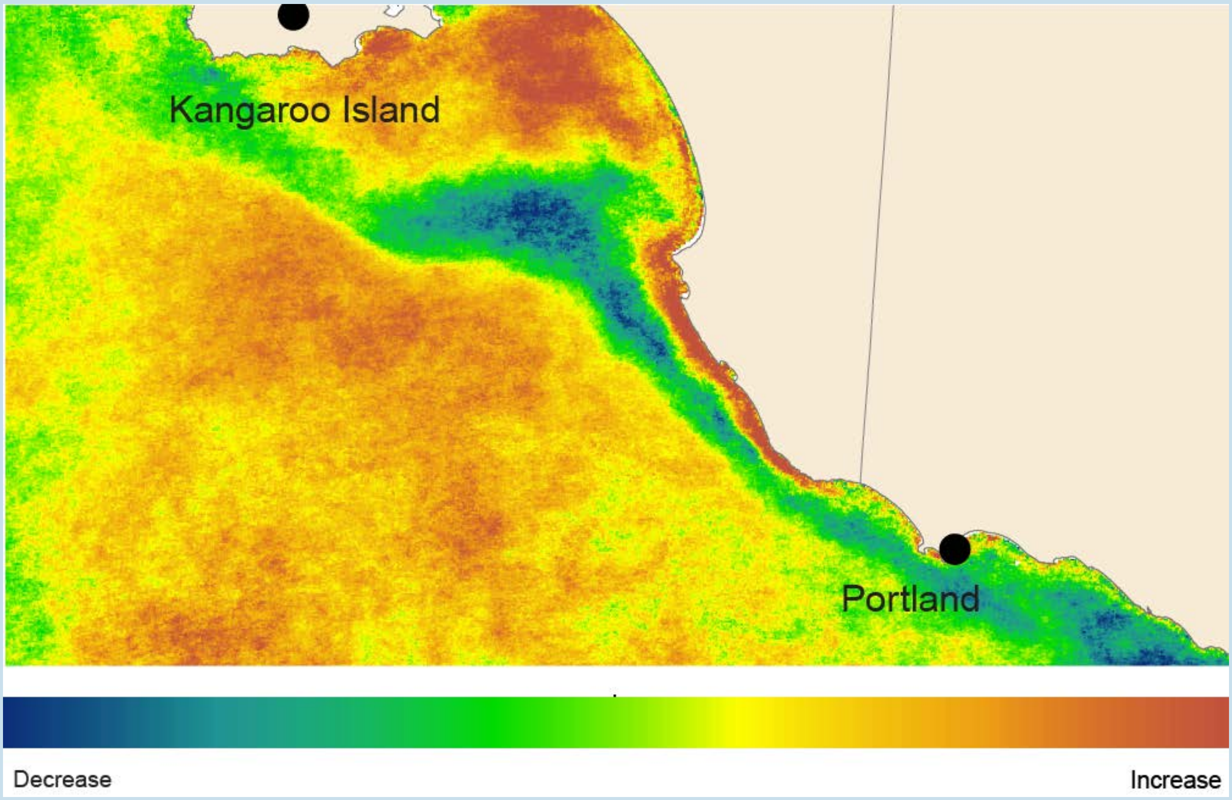
Figure MAR42 Schematic of the Bonney Upwelling ecosystem

Box MAR10 (continued)

Qualitative modelling (Hosack & Dambacher 2012), informed by existing data and expert advice, was used to identify the main pressures affecting marine life in the Bonney Upwelling. The primary pressures on the system identified were climate change, which can affect the base of the system and its productivity, and an increase in fur seal species, which can affect the overall level of predation in the system and trophic processes.

Statistical analysis (methods described in Foster et al. 2014) of satellite-derived concentrations of surface chlorophyll (an indicator of surface productivity) suggests that a slight, long-term trend of decreasing chlorophyll concentrations in the Bonney Upwelling occurred from 2000 to 2015 (Figure MAR43).

A reduction in upwelling processes and associated productivity through the region that may occur with climate change is likely to affect marine life that uses this seasonal food source. Continued monitoring of upwelling processes, productivity and dependent marine life is needed to better understand the drivers of any changes to the system, and the impacts this might have on the marine environment. Ongoing monitoring of biophysical indicators will also provide a better understanding of the contributions of multiple pressures (e.g. climate change, increased predation) to any changes observed in the region and help inform management measures that might be implemented to address these pressures.

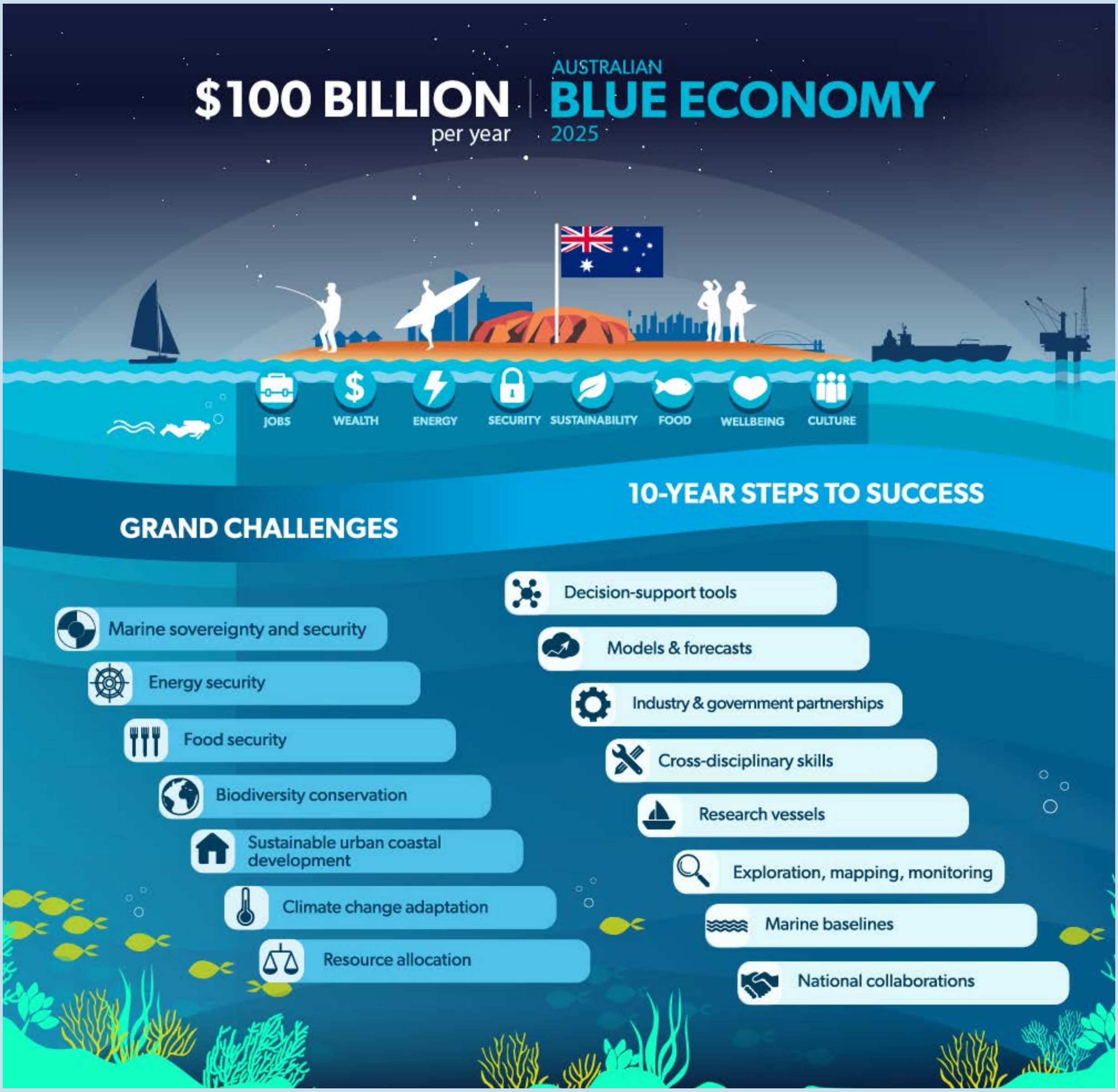


Source: National Environmental Science Programme Marine Biodiversity Hub, based on data from the Australian Ocean Data Network

Figure MAR43 Trend in satellite-derived surface chlorophyll concentrations along the Bonney coastline, 2000–15

Box MAR11 National Marine Science Plan

The National Marine Science Plan is a decadal plan that is designed to focus investment on the biggest development and sustainability challenges facing Australia's marine estate, and the highest priority science needed to tackle these challenges to fulfil the potential of the marine blue economy. Challenges to Australia's marine environment identified under the plan (Figure MAR44) are highly relevant to its state.



Source: NMSC (2015)

Figure MAR44 The grand challenges to be addressed in driving development of Australia's blue economy and the 10-year steps to success

Box MAR11 (continued)

The plan was developed under the auspices of the National Marine Science Committee (NMSC), in which senior representatives of 23 research institutions, universities and government departments worked together to plan, coordinate and communicate marine science and its application to national priorities. The NMSC (formally the Oceans Policy Science Advisory Group) is an advisory body promoting coordination and information sharing between Australian Government marine science agencies and the broader Australian marine science community.

More than 500 marine scientists and stakeholders took part in the development of the plan, beginning with the development of 8 community white papers. The white paper process involved stakeholders from the different marine science sectors working to identify the science required to address current challenges. The white papers were presented and discussed at a National Marine Science Symposium in November 2014, followed by 2 further rounds of consultation. The finalised plan brings together the highest priority science and science capabilities (skills, infrastructure and relationships) to meet the identified challenges to Australia's marine environment in an integrated and strategic manner.

Recommendations

To focus coordination efforts and investments, the plan sets out 8 high-level recommendations:

- create an explicit focus on the blue economy throughout the marine science system
- establish and support a national marine baseline and long-term monitoring program to develop a comprehensive assessment of our estate, and to help manage Commonwealth and state/territory marine reserve networks
- facilitate coordinated national studies on marine ecosystem processes and resilience to enable understanding of the impacts of development (urban, industrial and agricultural) and climate change on our marine estate
- create a national oceanographic modelling system to supply defence, industry and government with accurate, detailed knowledge and predictions of ocean state to support decision-making by policy-makers and the marine industry
- develop a dedicated and coordinated science program to support decision-making by policy-makers and the marine industry
- sustain and expand the Integrated Marine Observing System to support critical climate change and coastal systems research, including coverage of key estuarine systems
- develop marine science research training that is more quantitative, cross-disciplinary and congruent with industry and government needs
- fund national research vessels for full use.

These recommendations will improve the national capacity to provide evidence-based assessments on the state of Australia's vast and valuable marine environment. Ten-year steps to success underpin these recommendations (Figure MAR44).

Outlook

Since 2011, the NMSC has contributed to Australia's having a better coordinated, more management-relevant marine science community. It has established and sustained national collaborations such as successive Marine Biodiversity Research Hubs and the Integrated Marine Observing System. This approach has helped the 2016 state of the environment report use indicators that are more clearly defined and measurable, and make use of available synoptic data. This positive trend will accelerate through implementation of the National Marine Science Plan.

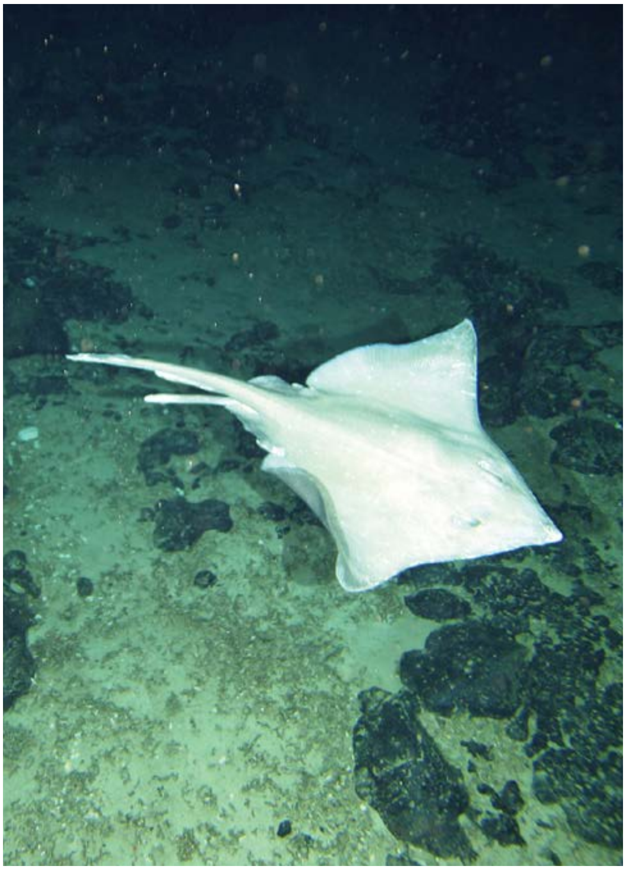
Ecosystem restoration

Marine ecosystems and their attributes, including species composition, ecosystem functions and resilience, are constantly changing. These changes can be biotic (e.g. species invasion) or abiotic (e.g. climate change), and can occur across evolutionary timescales or much shorter timescales of months to years. Given this continuous and ongoing change, definitions of the terms 'natural', 'historical' and 'altered' become blurred, and our ability to compare the current state of ecosystems with some potentially unknown historical ideal becomes ambiguous and somewhat arbitrary (Hobbs et al. 2009). Additionally, the concept of preserving components of marine ecosystems in a condition that was (hopefully) measured at an arbitrary point in time loses meaning. The reduction or removal of a single sector's pressure may be insufficient to return a species or habitat to its prior condition across reasonable timescales (e.g. Williams et al. 2010b). This complicates the identification and selection of management goals and objectives (and how to measure these), because reference to condition at an arbitrary point becomes less important than reference to the potential environmental conditions that could be maintained, restored or even created in the changed social and physical environment we find ourselves in. It is therefore important to monitor changes in the environment, understand the drivers of change, identify thresholds below which the environment becomes compromised and identify measures required for continuing ecosystem functioning.

In the case of ecosystems that have undergone substantial change, ecosystem restoration may be required to ensure that ecosystem functioning and provision of ecosystem services are maintained. Ecosystem restoration can involve 4 key components:

- natural recovery of an ecosystem from a natural or anthropogenically induced change (e.g. recovery from a cyclone or the grounding of a vessel)
- anthropogenic interventions in response to a degraded or anthropogenically stressed environment (e.g. removal of crown-of-thorns starfish)
- anthropogenic responses to a single pressure (e.g. closure of an overfished area to fisheries)
- habitat enhancement or creation (e.g. re-establishment of lost shellfish reefs or development of an artificial reef; Elliott et al. 2007, Creighton et al. 2015).

Many restoration efforts focus on maintaining or restoring particular species to particular locations to an agreed 'threshold' level. For example, recovery of fisheries species from past overexploitation focuses predominantly on rebuilding the species to an agreed level at which the species can be considered as not overfished (e.g. CCSBT 2014, Upston et al. 2014). Recovery targets for species listed under the EPBC Act are less clear, and, although removal from the list would be a clear indication of species recovery, this has yet to happen for any marine species. There has been steady progress in recovery of populations depleted by past exploitation in Australia, although some have been slow



First live sighting of *Bathyraja richardsoni* skate off southern Tasmania from CSIRO's Wealth from Oceans Flagship Commonwealth marine network monitoring project

Photo by CSIRO

to recover (e.g. the eastern population of southern right whales), show no signs of recovery (e.g. eastern gemfish) or, at least in some locations, appear to be declining (e.g. Australian sea lions), despite protection and implementation of management actions.

Restoration of habitats or communities is typically more complicated than restoration of single species because it can be a challenge to identify, characterise and monitor marine communities that are not easy to access from the shore. Efforts where ecosystem restoration is focused consequently tend to be areas close to shore and subject to intensive change, large historical loss and obvious poor ecosystem health (e.g. shellfish reefs; Gillies et al. 2015; see also Box COA13 in the *Coasts* report).

One of the management approaches used to restore identified habitats or communities situated in marine areas that are out of easy access is to reduce or stop the major pressures affecting those habitats or communities. This can take the form of marine protected areas, which aim to limit a range of pressures within a region (e.g. Abelson et al. 2016), or closure of certain areas to a specific industry or a component of that industry. Examples include:

- protection of the South Tasman seamounts, initiated in 1995 by industry, codified under Australian Government legislation in 1997 and included in the South-east Commonwealth Marine Reserves Network in 2007 (Williams et al. 2010b)
- closure of all waters deeper than 700 metres to bottom trawling by AFMA in 2007, to aid the recovery of orange roughy and reduce impacts on slow-growing and unassessed deepwater sharks (some areas have since been reopened following some recovery and specific risk assessments).

Artificial habitats, such as artificial reefs, are starting to be introduced at specific locations, to enhance growth of encrusting and attached habitats, and support particular invertebrate and vertebrate species (e.g. rock lobster off Tasmania; S Frusher, Institute for Marine and Antarctic Studies, University of Tasmania, pers. comm., 9 April 2016). A purpose-built offshore artificial reef to improve recreational fishing was introduced off the New South Wales coast in 2011 (NSW DPI 2015b). It was rapidly colonised, with 49 fish species present after 2 years, and, in response, recreational fishing effort increased across the site. The number of artificial reefs has expanded since this deployment, with the building of a fifth offshore artificial reef off New South Wales announced in June 2015. The reefs are designed to be nonpolluting and have a maximum life of about 30 years. Other examples include scuttling of old ships to provide new dive sites that will also aggregate marine life, and potentially deploying used oil rigs as artificial reefs in Bass Strait, where oil and gas infrastructure is already used by Australian fur seals (Arnould et al. 2015).

Sustained ocean monitoring

Responding to a changing and increasingly modified environment, especially one where directing or modifying the trajectory of change is planned, requires sufficient monitoring on relevant temporal and spatial scales, and an adaptive approach to management. Without ongoing measurements of specific components of the marine environment, no indicators are available against which resources can be managed or management effectiveness can be reviewed. Monitoring of the marine environment relies on 3 key infrastructure components (NMSC 2015):

- vessels that can conduct targeted monitoring of particular areas
- observing systems—including in situ, robotic and satellite systems—that can monitor at a diversity of spatial and temporal scales
- experimental facilities that can calibrate, analyse and interpret data; and can manage, archive and interpret data streams, and make them available.

Within the Australian marine environment, research institutions contribute to long-term monitoring datasets through a number of initiatives, the largest being the Integrated Marine Observing System (IMOS). IMOS was established in 2007 as a partnership between Australia's major marine research institutes (Lynch et al. 2014).

Central to IMOS's collection of long timeseries data from locations dispersed throughout Australia's marine estate are the network of National Reference Stations and associated regional moored sensor arrays. These measure Australia's coastal and continental-shelf oceanography, biogeochemistry and marine soundscapes (Lynch et al. 2014, Erbe et al. 2015, Richardson et al. 2015). Along with the other IMOS facilities, such as Argo floats, ocean gliders, the continuous plankton recorder, automatic underwater vessels and ships of opportunity, IMOS provides ongoing monitoring of our marine environment. Data collected via IMOS are managed and made publicly available through the Australian Ocean Data Network.

Australian scientists are key contributors to global marine data collection, verification and analysis. This provides Australia with access to global infrastructure, data streams and expertise that would otherwise be unavailable or prohibitively expensive to access.

Some datasets contribute to global repositories such as the Global Temperature and Salinity Profile Programme and the World Ocean Database. Many have contributed to this SoE report. IMOS is a partner in the Global Ocean Observing System (GOOS), a permanent global system for observing, modelling and analysing marine and ocean variables to support operational ocean services (IOC 1996a,b). Within GOOS, the Ocean Observations Panel for Climate, the Global Ocean Biogeochemistry Panel, and the Biology and Ecosystems Panel provide direction on essential ocean variables of marine environments where effort should be placed towards monitoring over sustained timeframes. The Global Ocean Acidification Observing Network is also developing complementary frameworks for identifying variables for monitoring and how they should be monitored, with the objectives of supporting assessments of the marine environment and informing management of its use (Newton et al. 2015).

Other highly important sustained monitoring programs for the marine environment include the Australian Institute of Marine Science Long-term Monitoring Program. This program includes the only long-term, comprehensive dataset covering the health of the Great Barrier Reef, spanning 3 decades. The program is now being paired with the Long-term Temperate Marine Protected Areas monitoring program, and the more recent and globally extensive citizen-science Reef Life Survey (see Box MAR5). Combining dedicated science facilities with citizen scientists and traditional owners, empowered through recent technological advances, provides one of the more promising options to increase marine monitoring in Australia, at least in coastal waters.

Further, several initiatives are providing data products such as spatial maps that are publicly available for use, such as eAtlas, the Atlas of Living Australia and the National Environmental Science Programme (NESP) Marine Biodiversity Hub.

The number of components or processes that can be monitored in the marine environment is endless, especially among its biological components. Prioritising what, when and how components of the marine ecosystem are monitored is essential if scientific data are to support marine managers in the changing and increasingly complicated environment they find themselves in (see also State and trends of indicators of marine ecosystem health).

The prioritisation of monitoring of a physical marine environment component (e.g. ocean temperature) can be directed by the component's contribution to system models that are already being used in environmental decision-making (e.g. those used as part of the IPCC reporting process). Similarly, agreed system models do not exist for the biological components of the marine environment. The NESP Marine Biodiversity Hub (formerly the National Environmental Research Program), with the Australian Government Department of the Environment and Energy, has developed an outline for the monitoring of marine biodiversity based on identifying the informative links between values and pressures (Hayes et al. 2015; see Box MAR10). The outlined process could support bioregional planning, and the reporting and evaluation of the marine environment necessary to inform ongoing assessment of the marine environment at the national level, including its response to the cumulative impact of all industry sectors. The outline details current capacity and the most appropriate methods available for monitoring of the key ecological features identified for each of the marine bioregional planning areas (Hayes et al. 2015). Similarly, *Science strategy and information needs 2014–2019* for the Great Barrier Reef Marine Park outlines priority information needs to ensure that monitoring activities are relevant and targeted to address management issues, and that the outcomes for the Great Barrier Reef Marine Park are easily identifiable and accessible (GBRMPA 2014b).

Careful consideration of strategies for meeting the needs for monitoring, assessing and responding to changes in the marine environment is, and will continue to be, a priority if we want to continue to access the socio-economic, cultural and aesthetic values of our marine environment in the future.

Key gaps in evaluating the marine environment

This report has highlighted a number of key gaps in our current ability to assess the state of the Australian marine environment. In this section, we summarise these key gaps and identify potential avenues by which they might be addressed. Progress in these areas would help to improve the assessments undertaken as part of the SoE process, and ensure that future SoE reports can provide a clearer indication of trends in the state of the marine environment and provide increased reliability of information to inform management.

Data provision and long-term, national-scale datasets

A recurrent theme throughout this report has been the difficulty in determining state and trend with high certainty because of an overall lack of consistent ongoing monitoring of the marine environment at a national scale. There are exceptions to this, including components of the physical environment (e.g. temperature), some pressures (e.g. commercial vessels), some commercially fished stocks and a few timeseries for biodiversity, such as shallow reefs. This lack of ongoing consistent monitoring is a significant issue that contributes to many of the policy and management challenges highlighted in this report. The National Marine Science Plan recommends establishing and supporting a National Marine Baselines and Long-term Monitoring Program, to develop a comprehensive assessment of our estate, and to help manage Commonwealth and state marine reserves.

The lack of data stems from 2 sources: data and information that have not been collected (usually because of a lack of resources and capacity), and data and information that are not available (i.e. data streams collected but not currently made publicly available). Systems are now available to provide for public access to data—for example, the Australian Ocean Data Network (AODN) (for metadata and actual data) and the various 'atlases', such as eAtlas and the Atlas of Living Australia (for spatial maps and derived data products). Unfortunately, many research agencies are not providing their data and associated products in a format that supports direct access. This reduces our capacity to analyse and compare data, and identify trends.

Several recommendations made in the reviews of the Commonwealth marine reserves (Beeton et al. 2015, Buxton & Cochrane 2015) and the draft report of the Productivity Commission inquiry into the regulation of fisheries (PC 2016) highlight areas in which data provision could be improved. These have relevance to the SoE reporting framework and should also be highlighted here. They include:

- improved reporting of interactions with protected species that is publicly accessible (online)
- regular surveys of recreational fishing either nationally or on a coordinated basis across states and territories, to better understand the impacts of recreational fishing and inform management
- maintenance of existing marine research and monitoring data in the long term
- making marine research and monitoring data readily accessible to the scientific community, reserve managers and other relevant users for input into management. This should include ensuring that approvals and funding for research and monitoring activities require that the raw data and metadata be made publicly accessible through the AODN
- continued support of IMOS and the AODN.

Research providers should be encouraged to ensure that their data and associated products are made available online (without compromising proprietary or commercial-in-confidence information) through infrastructure such as the AODN, eAtlas and the Atlas of Living Australia, including historical data wherever possible. Data holders across the research and industry communities should also be encouraged to make their datasets and derived products publicly available in a timely way. Expansion of IMOS by establishing sustained funding for other existing long-term or comprehensive biological monitoring programs, including the Reef Life Survey, and additional nationally agreed priorities would further build up datasets on the marine environment at the national scale. Regular reporting of progress in archiving data could be facilitated through quarterly reporting undertaken by the National Marine Science Committee.

Making relevant data and derived products available in a timely fashion would support more efficient and effective approvals and licensing; allow monitoring of the footprint of industries over time and better understanding of pressures on the marine environment; and support regional assessments of the state of the environment. Provision of such data in standard format could be facilitated by making it a requirement of public funding and environmental approval processes.

Standardised indicators for monitoring the marine environment

Current monitoring of many indicators is often not spatially and temporally comprehensive enough, nor sustained for long enough, to capture dynamics in a robust manner. As a result, determining the trends of these indicators is difficult, if not impossible. Methods used for identifying, measuring and monitoring indicators can vary between systems and researchers, resulting in data that may not be meaningful for identifying state or trends at national scales. Although there is sometimes justification for local variation in monitoring approaches to meet local needs and development, there is typically always some level at which monitoring can be designed to contribute to regional and national comparisons. Therefore, there is a need to identify a standard set of biological and physical indicators. There is also the need to provide standard operational approaches to collecting information on these indicators that will adequately and robustly measure resource status and system health, and allow meaningful comparisons between regions, nationally and across SoE reporting periods.

SoE reporting on the marine environment provides a context for determining indicators that are common across marine ecosystems and can be monitored in a consistent manner, along with related initiatives such as the Reef 2050 Integrated Monitoring and Reporting Program Strategy. The GOOS provides international standards and measurement standards for a set of agreed essential ocean variables, which can be used to inform decision-making.

Integrated approaches to understanding cumulative impacts

The sectoral approach to marine management in Australia will often not account for the additive or multiplicative effects of the activities of different sectors on the environment, nor the potential conflict between different sectors. The lack of an agreed and integrated approach to managing multiple uses in the marine environment contributes to a continuing lack of capacity to identify and measure multiple impacts, and reduces the potential for coordinated approaches to their management. This could result in gradual declines in the state of the marine environment, despite appropriate management of individual pressures, sectors or jurisdictions. Many management plans do not currently build the resilience of marine ecosystems, and environmental approval processes currently lack means by which proposals can be assessed in terms of addressing multiple stressors.

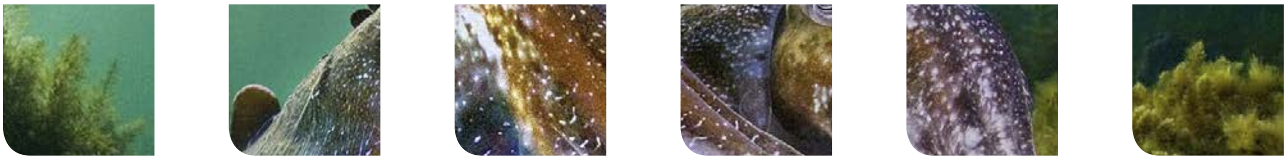
A real need exists to define and map cumulative impacts of activities across sectors and jurisdictions, supported by spatially explicit information on habitats, communities and species groups, human uses, pressures generated by human uses, and any feedbacks within the system. Providing this integrated scientific knowledge would support complementary management, where each sector has the information to develop more robust assessments of options for addressing triple-bottom-line outcomes, and clearer guidance on appropriate monitoring of performance against the agreed outcomes. This enables each sector to understand the additional impact of their own activities now and in the future, and to identify where cross-sectoral cooperation is required to produce an improved outcome for multiple sectors. The National Marine Science Plan recommends developing a dedicated and coordinated science program to support decision-making by policy-makers and the marine industry.

Robust risk assessment frameworks

Risk assessments currently incorporated into SoE reports are largely based on best judgement using available information. If the SoE report is to meet its aims in identifying areas of concern, thereby providing useful information for managing the marine environment, it would benefit from the incorporation of robust risk assessment frameworks. Ecological risk assessment methods are available to identify known residual risks in a quantitative and often hierarchical framework, and can play a central role in an adaptive management process. Classification of residual risks using such frameworks would build confidence in assessments of residual risk and in identification of areas for improved future management effectiveness.

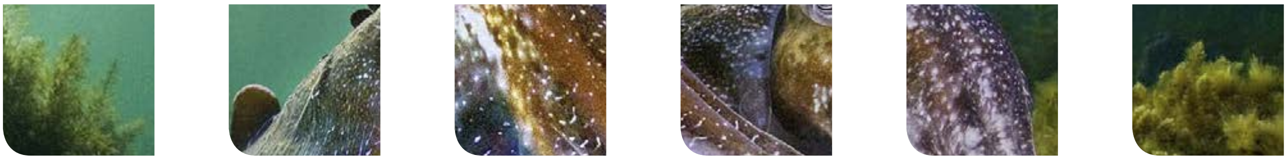
Pair of ornate ghost pipefish (*Solenostomus paradoxup*), Cape Byron Marine Park, New South Wales

Photo by David Harasti



Acronyms and abbreviations

Acronym or abbreviation	Definition
AFMA	Australian Fisheries Management Authority
CMR	Commonwealth marine reserve
CO_2	carbon dioxide
EAC	East Australian Current
EEZ	exclusive economic zone
ENSO	El Niño–Southern Oscillation
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
GOOS	Global Ocean Observing System
IMCRA 4.0	Integrated Marine and Coastal Regionalisation of Australia
IMO	International Maritime Organization
IMOS	Integrated Marine Observing System
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
MARPOL	International Convention for the Prevention of Pollution from Ships
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
NRSMPA	National Representative System of Marine Protected Areas
SAM	Southern Annular Mode
SLO	social licence to operate
SoE	state of the environment



Glossary

Term	Definition
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.
benthic	Associated with the sea floor.
Commonwealth marine area	Also known as 'Commonwealth waters'; refers to any part of the sea—including the waters, seabed and airspace—within Australia's exclusive economic zone and/or over the continental shelf of Australia, excluding state and Northern Territory coastal waters. Generally, the Commonwealth marine area stretches from 3 nautical miles from the territorial sea baseline to the outer limit of the exclusive economic zone, 200 nautical miles from the baseline. The territorial sea baseline is normally the low water mark along the coast.
Commonwealth marine reserve	A reserve established and managed under Division 4 of part 15 of the *Environment Protection and Biodiversity Conservation Act 1999*, which must be assigned an International Union for Conservation of Nature (IUCN) category; it may be subdivided into a number of different zones with different management objectives and IUCN categories.
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.
continental shelf	The legal continental shelf is defined under article 76 of the United Nations Convention on the Law of the Sea: 'where not limited by delimitation with another state (country), it will extend beyond the territorial sea to a minimum of 200 nautical miles from the territorial sea baseline. In some places where certain physical characteristics of the seabed are met it can extend further'. This differs from the geoscientific definition of a continental shelf: the seabed adjacent to a continent (or around an island) extending from the low water line to a depth at which there is usually a marked increase of slope towards oceanic depths. This increase of slope usually occurs at water depths of 200 metres around the Australian continent.
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 if the thermal stress extends for long enough.
demersal	Associated with the region just above the sea floor.
endemic	Unique to a spatially defined area; in this report, used mainly to refer to large bioregions of the continent and marine environment.

Term	Definition
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.
exclusive economic zone	The marine seabed, subsoil and waters between the 3 nautical mile boundary and the 200 nautical mile boundary off the coast of Australia.
extended continental shelf	An area of continental shelf that extends beyond the Australian exclusive economic zone, proclaimed by Australia following recommendations of the United Nations Commission on the Limits of the Continental Shelf, the seabed of which forms part of Australia's marine jurisdiction.
high seas	All parts of the sea that are not included in the exclusive economic zone, territorial sea or the internal waters of a state.
nutricline	A zone of rapid nutrient change with depth in the water column.
nutrification	The process by which water bodies such as estuaries or embayments receive excess nutrients from a variety of sources (primarily agriculture, aquaculture and sewage), setting off a cascade of environmental changes.
pelagic	Associated with the open ocean or upper waters of the ocean.
pH	A measure of acidity or alkalinity on a log scale from 0 (extremely acidic) through 7 (neutral) to 14 (extremely alkaline, or basic).
primary production	The production of organic compounds from atmospheric or aquatic carbon dioxide, principally through photosynthesis.
resilience	Capacity of a system to experience shocks while retaining essentially the same function, structure and feedbacks, and therefore identity.
seamount	Submerged pinnacle, hill or mountain with a peak below the surface of the sea, which supports habitats that difer from that of the surrounding sea floor.
triple bottom line	A framework that addresses social, environmental and financial factors.
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).
upwelling	A process by which deep, cold (and usuallly nutrient-rich) water rises to the ocean surface driven by wind and/or topographical features.

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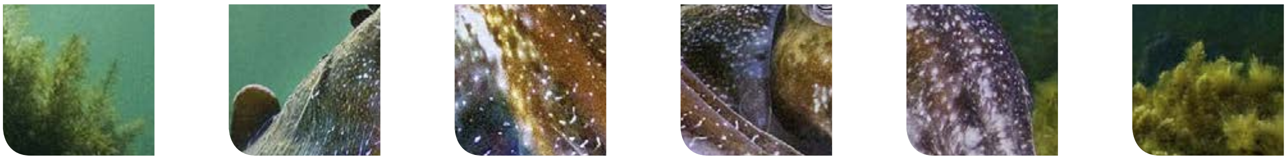

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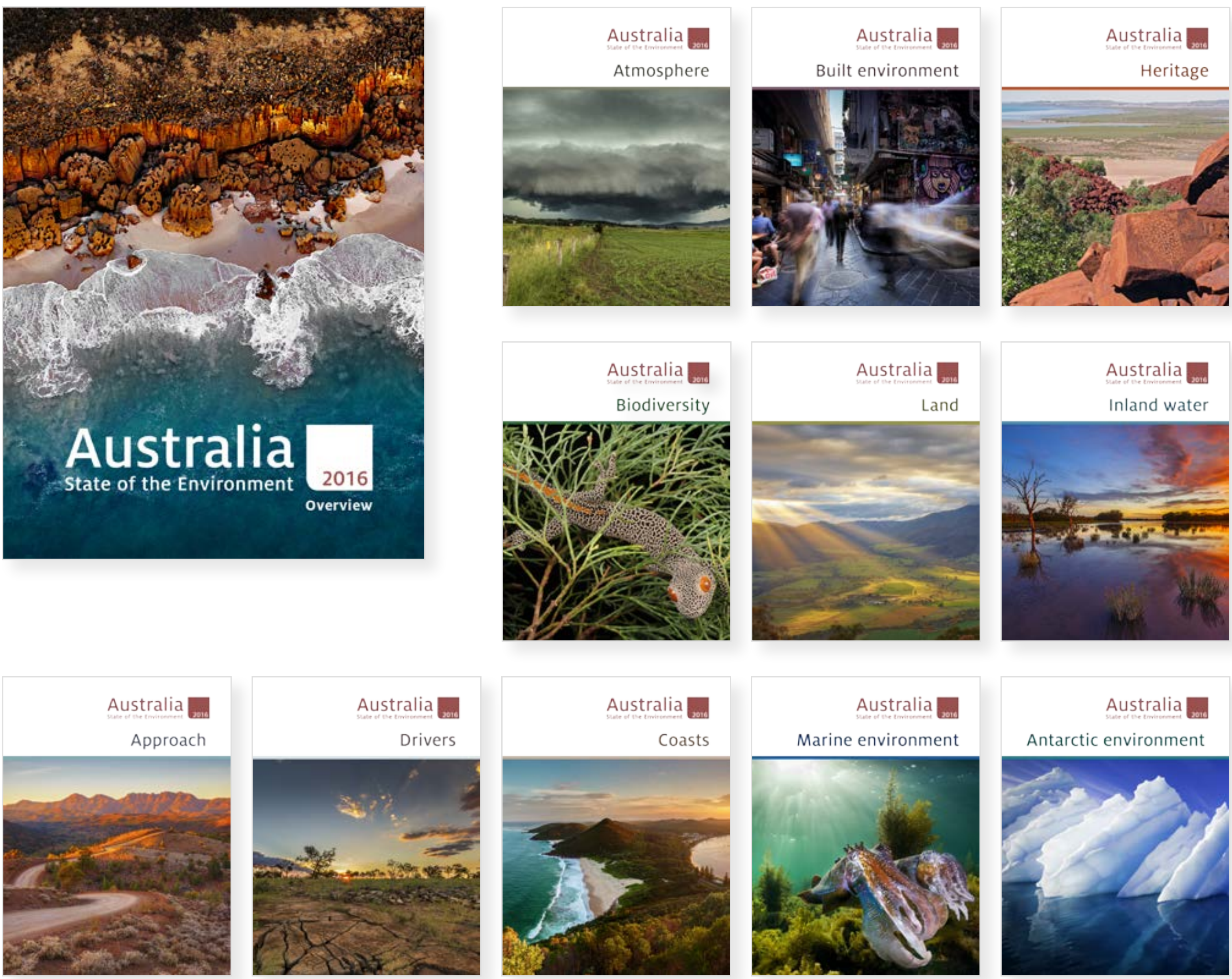

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