CHAPTER 2

BIODIVERSITY

« *A horned seastar nestled in the seagrass at Green Island.* © Dieter Tracey 2014

BIODIVERSITY

(an element of natural heritage)

'an assessment of the current biodiversity …' within the Great Barrier Reef Region, s 54(3)(b) of the *Great Barrier Reef Marine Park Act 1975*

2.1 Background

Biodiversity is the variety of all living things, including plants, animals and microbes (and their genetic information). Biodiversity forms an important component of natural heritage and is integral to ecosystem resilience (Chapter 8). Species diversity, or the number of species in a given area, is often used as a measure of biodiversity. In order to understand ecosystem health, an understanding of species diversity, species abundance and ecosystem processes are required, rather than biodiversity alone. The Reef remains one of the world's most diverse and remarkable ecosystems and is the largest coral reef system in the world. Biodiversity is critical to the Traditional Owners of the Reef and the outstanding universal value of the world heritage property. Interactions between species and communities, and the processes that underpin and support biodiversity, are addressed in Chapter 3.

The assessment in this chapter focuses on the broad habitats that make up the Region's ecosystem (Figure 2.1), and the species and groups of species supported by these habitats. It includes an assessment of beaches, coastlines and island habitats, some of which fall outside the jurisdiction of the Region, but are connected to and critical to the health of the Region. Condition and trend assessments for coastal ecosystems that support the Reef (for example, woodlands, Figure 2.1) are assessed in Chapter 3. The species and habitats assessed are consistent with those in the 2009 and 2014 Outlook Reports, with the exception of macroalgae and benthic microalgae; these have been combined into a single component called benthic algae (Appendix 2).

Islands support a variety of plants and animals. © GBRMPA

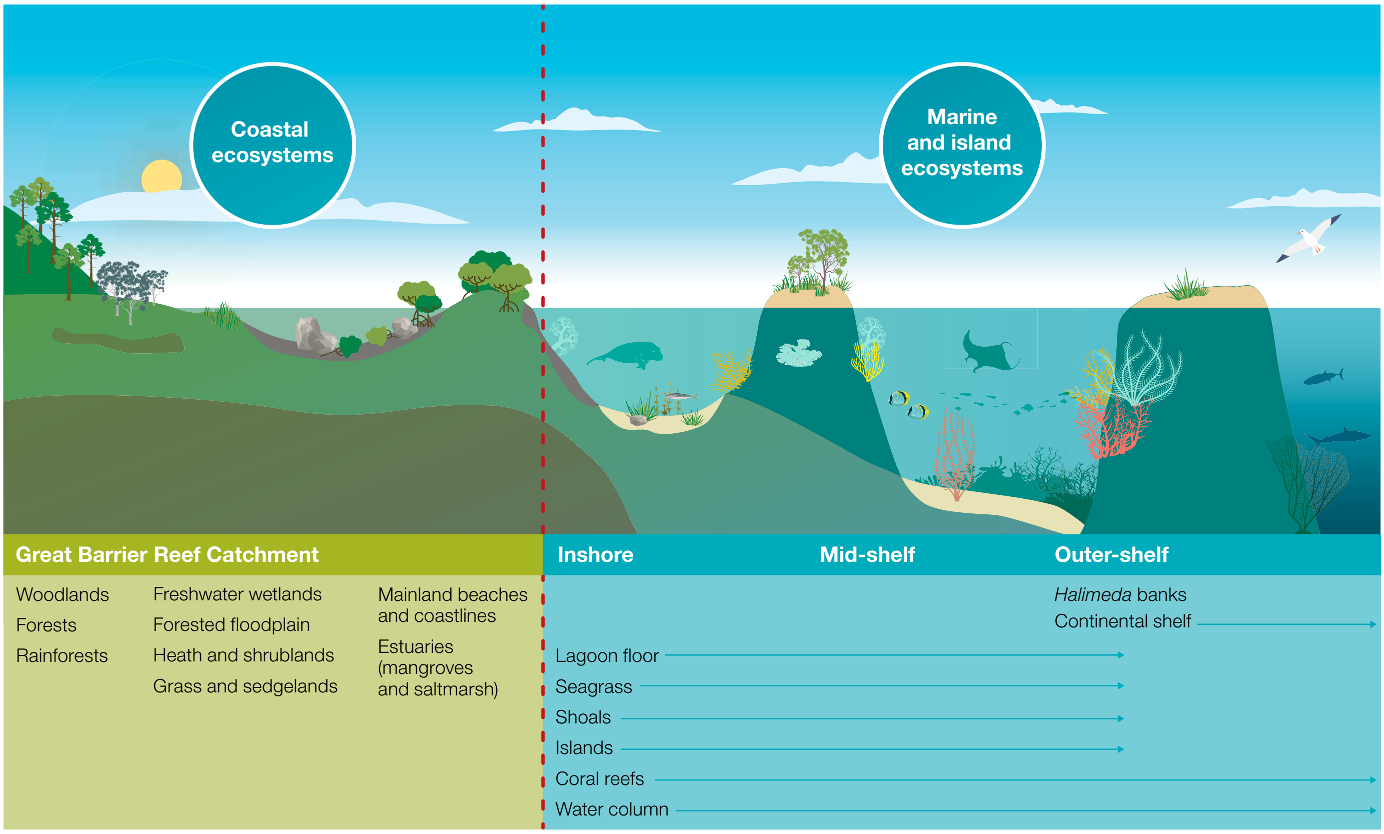


Figure 2.1 Major habitats that comprise the overarching ecosystems of the Reef and Catchment
A wide variety of habitats make up the Reef's coastal and marine ecosystem. The most pronounced variation is across the continental shelf from the inshore coastal habitats, such as mangroves and beaches, eastwards to the continental slope and deep ocean.

2.2 Legacies and shifted baselines

2.2.1 Legacy impacts

Legacy human use impacts encompass activities, such as historical land clearing and overfishing, that caused significant environmental change in the past and continue to have major effects today.[11] Some species and habitats that were commercially exploited in the past are showing signs of recovery (for example, humpback whales Sections 2.4.14 and 8.3.7), while others are not (for example, some marine turtle stocks).

It may take decades or longer for populations and habitats to fully recover to their pre-disturbance state. Species and habitats that are still recovering include dugongs, turtles and some islands that were cleared and mined for guano (Sections 2.3.1, 2.4.10, 2.4.16 and 8.3.6). For example, after 100 years of European settlement, many Reef islands still require active pest management programs to treat the legacy of pests introduced over a century ago (Sections 3.6.1).

Introduced goats on High Peak Island remove native vegetation and cause erosion. © Queensland Parks and Wildlife Service, photographer: Ben Geddes

2.2.2 Shifting baselines

Human activity has caused significant environmental change for centuries. Identifying the pristine state, or natural baseline, from which to measure environmental change can be problematic. This is due to shifting baseline syndrome, whereby the natural baseline gradually shifts over human generations as accepted norms for the condition of the natural environment change due to a lack of experience, memory and knowledge of its past condition.[12] A shifted baseline can result in increased tolerance for progressive environmental degradation.[13] In this way, progressive

Trevor Fuller holding two 33 kilogram Spanish mackerel caught at the Palm islands, Townsville, ca. 1988. © Trevor Fuller

degradation, such as large declines in species over long periods of time[12] or the current pace of global warming[14], may not be clearly recognised. Therefore, it is important to acknowledge the risk of using a shifted baseline to underpin a current assessment.

Within the Region, long-term scientific data and multi-generational knowledge enable a relatively accurate assessment of the condition and trend of Reef values over time. However, early accounts of the Reef may consist of first-hand observations or unwritten records, which some may consider to be anecdotes. The use of such information can provide important knowledge about the past, complement scientific records and help avoid a shifting baseline syndrome. The concept of a shifting baseline is described below using two examples within the Region.

Spanish mackerel fishery: Spanish mackerel (*Scomberomorous commerson*) is among the top three fish prized by recreational fishers and is one of Queensland's most valuable commercial fish species (Section 5.4). Today's recreational fishers are limited to three fish per person per day, and commercial catch rates are approximately 11 fish per vessel per trip.[15] Young fishers just beginning their careers might perceive this as a good day's catch, accepting the current catch rate as normal and the baseline from which they will evaluate future change. However, the previous generation of fishers may recall that only 15 years ago (2004) the recreational catch limit was 10 fish per person, and 80 years ago (1940s) commercial catch rates averaged 120 fish per vessel per trip.[15] Compared to their baseline, older generations of fishers will perceive drastic changes in the fishery that modern fishers might not recognise. Recent research has reconstructed catch rates and exploitation trends of this fishery by collecting information from newspaper archives, fisher knowledge, and contemporary fishery logbooks.[15,16] The findings have validated older generations' perceptions of drastic change, indicating that over-exploitation of vulnerable spawning aggregations led to a 90 per cent decline in catch rates from 1934 to 2011.[15,16] Incorporating historical information can provide a more accurate baseline from which to assess the sustainability of a fishery, determine current management actions, and potentially help overcome shifting baseline syndrome.

Coral composition (Section 2.3.5): An individual's perception of a baseline will be influenced by their recollection of what the coral reef looked like from a previous visit. The actual natural baseline may be very different and may have changed several times over thousands of years. A change in the types of coral present is a critical factor in determining a shifted baseline. While historical photographs may not provide definitive quantitative proof of change, they can provide a useful qualitative benchmark to identify a potential shifted baseline.[17] It is also possible to identify changes to the Reef from a past baseline through coral coring and reef sediment coring techniques that infer historical coral reef condition. Quantitative data, ongoing long-term monitoring programs of reef condition and oral histories can help identify changes to the Reef. When combined with geological dating and monitoring, time-series photographs that are taken with precision can provide a valuable reference point.[17]

To demonstrate this concept, historical inshore reef flat photos were compared with recent images from four locations between Cairns and Townsville, following previous methodology (Figure 2.2).[18] Changes in coral cover varied over time and across locations. The greatest visual changes in coral cover were evident at Dickson Inlet (near Cairns, top series) and Geoffrey Bay (Magnetic Island, third series). At these sites, previously diverse reef flats characterised by high coral cover are now predominantly dominated by algae and sediment, interspersed with only small amounts of live coral. Coral cover and assemblages on a Fitzroy Island reef flat (second series) and Middle Reef (on Magnetic Island, bottom series) have also changed over time but not to the same extent.

The visible changes in reef structure on the photographed inshore reefs may reflect higher exposure to land-based run-off and they align with results from more rigorous quantitative studies on inshore reefs.[19] Some of the photographs and coring research[20,21] also highlight that, despite being exposed to more land-based influences now than in the past, certain inshore corals can grow and persist in marginal conditions.[22,23]

Reef users understand the condition of the Reef has deteriorated in their lifetime. This deterioration was accelerated by unprecedented back-to-back mass bleaching events in 2016 and 2017. Since then, research and development funding to explore reef restoration and intervention techniques has increased.[24] Permit applications to undertake small-scale restoration research projects have also increased. From a shifting baseline perspective, performance indicators that do not recognise historical baselines[25] may be working towards a desired state set on the basis of recent social perception rather than the historical ecological baseline.[26]

Figure 2.2 Potential shifting baselines — inshore coral reefs over time
First row: Dickson Inlet (Cairns) 1950 (© Lee Middleton) *and 2018* (© Qld Government – Graham Barnes)
Second row: Fitzroy Island (Cairns) 1900s (© James Cook University), *1995* (© GBRMPA), *and 2018* (© Qld Government – Tayce Cook)
Third row: Geoffrey Bay (Magnetic Island) 1995 (© Stuart McAulay) *and 2018 (*© Qld Government – Patrick Centurio)
Fourth row: Middle Reef (Magnetic Island) 1996 (© GBRMPA) *and 2018* (© Qld Government – Sarah Ballard)

2.3 Current condition and trends of habitats to support species

Ten habitats are assessed; a large amount of variability in condition occurs across the Region. *Halimeda* banks continue to be considered in very good condition (although data are limited) and the continental slope has been upgraded to very good. Islands, mainland beaches and coastlines, mangrove forests, lagoon floor, shoals, and the water column remain in good condition (although data are limited and water column condition is considered borderline with poor). However, seagrass meadows continue to be assessed as poor, and coral reefs have deteriorated to a very poor condition (based on adequate data).

↓

Full assessment summary: see Section 2.5.1

The Region comprises a range of habitats (Figure 2.3). The entire Region (habitats, species and processes) is under increasing threat from the broad-scale impacts of climate change. Also, human activities in the Region and Catchment continue to affect biodiversity values, with areas of the Region adjacent to large human populations and significant agricultural use generally under higher pressure.

Climate change and climate extremes have been the primary causes of habitat deterioration since 2014, adding to legacy and current impacts, such as pollutants in land-based run-off and an ongoing crown-of-thorns starfish outbreak. Unprecedented ocean warming causing mass coral bleaching in 2016 and 2017 has significantly affected large areas of the Region. Large-scale loss of coral habitat has resulted, and flow-on effects for species and ecosystem processes are still unfolding.

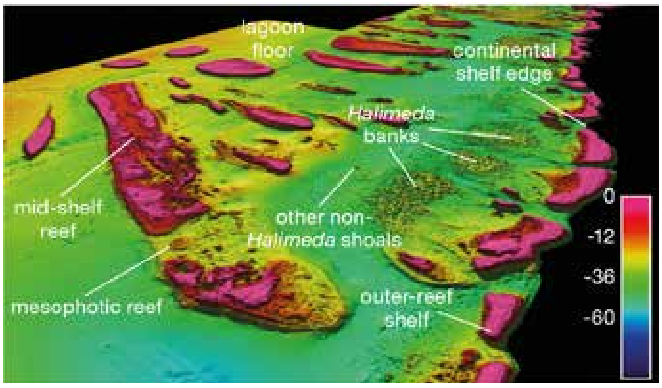


Figure 2.3 Reef geomorphological features
A 3D image of the Ribbon reefs in the northern Great Barrier Reef identifying different habitat types. © Dr Robin Beaman, James Cook University

Habitats can be highly variable across space and time, creating challenges for monitoring and evaluation of their condition at a Region-wide scale. Where good quality information is available, assessments are given a higher confidence rating compared to where data are more limited or lacking (Section 2.5.1 assessment summary table).

2.3.1 Islands

The Reef ecosystem includes approximately 1050 islands, comprising coral cays, continental islands and mangrove islands. The islands within the Region include 70 under Commonwealth jurisdiction, with the remainder under Queensland Government jurisdiction or privately owned. This assessment includes all islands because of their connection to, and influence on, the values of the Region. Islands support unique assemblages of flora and fauna and are critical to the life cycles of many species.[27] The diversity of islands and the habitats they provide are attributes that contribute to the Reef's outstanding universal value.[28]

Some islands are showing signs of recovery from past impacts

Continental islands, cays and mangrove islands support over 200 bird species and provide important nesting sites for marine turtles. Islands are important refugia for animals and plants, such as *Pisonia* forests which, in Australia, are largely restricted to coral cays within the Region.[27] Islands also provide a number of ecosystem services, such as buffering the coast from storms, supporting nutrient cycling to adjacent marine ecosystems, and contributing to soil and sand formation.[27,29]

While long-term standardised data on the condition of most islands and species that depend on them are lacking, considerable efforts and monitoring programs are currently directed towards improving this.[30] Since 2015, 118 islands have been assessed, resulting in several detections of invasive species and rapid management responses. While the data-set remains limited to short-term assessments of approximately 10 per cent of the Region's islands, it remains difficult to assess the overall state of the Region's islands. Where data are available on the condition and trend of islands, generally their condition remains good.

In locations where islands have suffered recent disturbances (for example, Whitsunday Island), recovery is being observed. Intervention actions over many years have aimed to remove or mitigate threats, enable recovery and build resilience to future threats. These actions include habitat restoration through replanting, re-profiling beaches, installing fencing (for example, Raine Island) and fire management.

Islands around the world, particularly low-lying islands, are already threatened by sea-level rise and coastal erosion. Evidence suggests that these stressors are already affecting the Region's islands. Coral reef islands, such as Raine Island, are one of the most vulnerable habitats to climate change because they are low-lying and growth and maintenance depend on sediment accumulation. These sediments are derived from reef organisms, such as benthic foraminifera, and are particularly susceptible to ocean acidification.[31,32] Since 2014, some Reef islands, such as Whitsunday and Curtis islands, have been affected by severe cyclones, wildfires, and changes driven by coastal development and industrial and residential infrastructure. Marine debris and invasive plant and animal pests also remain a significant threat to island values (Section 3.6.3).[33,34,35,36,37] Although localised damage has occurred on some islands, the overall condition remains stable across the Region.

2.3.2 Mainland beaches and coastlines

The mainland beaches and coastlines of the Reef stretch for approximately 2300 kilometres. Beaches and coastlines provide important habitats for a range of species, such as marine turtles[38], shorebirds[39], crustaceans, worms and molluscs. Intertidal and shallow coastlines provide suitable hard surfaces for attachment of corals, algae and invertebrates, while soft sediments support seagrass meadows and burrowing invertebrates. Beaches and coastlines provide significant natural resources and valuable ecosystem services, including recreation, spiritual values and coastal protection against cyclones and waves.[40]

Coastlines are constantly changing as a result of natural processes.[41] The coastal zone north of Port Douglas is relatively unaltered due to intact vegetation and limited coastal development. Nonetheless, this remote area can be affected by cyclones and marine debris transported by currents.[42,43] Climate change impacts, including extreme weather events, increased erosion and changes in sea level, are affecting beaches and coastlines.[41] Whitehaven Beach was one of the sites most affected by cyclone Debbie in 2017.[35] Fallen trees and debris were removed by machinery, and 10,000 cubic metres of sand was shifted to reinstate the beach profile.[35] There are knowledge gaps in relation to the current condition and trend of mainland beaches and coastlines due to limited monitoring across the Region. However, these habitats are generally considered stable across the Region.

Beaches and coastlines provide significant natural resources and valuable ecosystem services

2.3.3 Mangrove forests

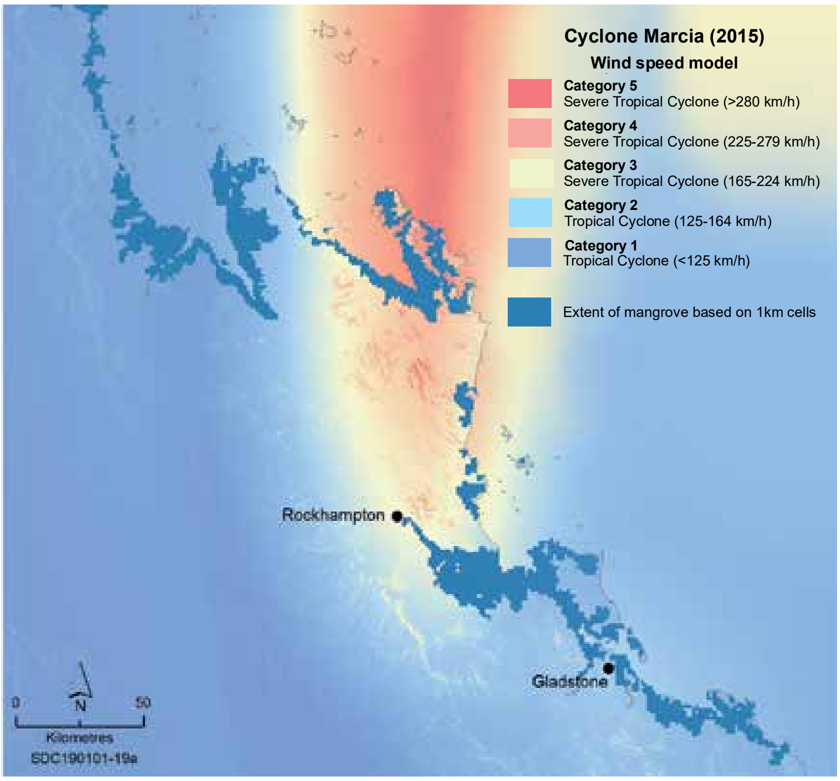
Mangrove forests are tidal habitats defined by the trees, shrubs and palms adapted to grow in the salty, oxygen-limited soils of the upper intertidal zone. These habitats cover an estimated 2710 square kilometres in, and adjacent to, the Region.[44] They occur in estuaries, rivers and bays and around islands, often where sediments accumulate and seawater regularly inundates the habitat during the tidal cycle.[45] Mangrove forests are a critically important habitat providing nursery and breeding areas for many commercial and non-commercial species, such as mangrove jack and prawns.[46,47,48] They also provide important ecosystem services, including coastal protection, pollution absorption, nutrient cycling, primary production and carbon storage.[47,49,50,51]

Several cyclones have resulted in localised mangrove forest dieback in some locations, including Starcke River, Cape York (cyclone Ita, 2014 and cyclone Nathan, 2015), Hinchinbrook Island (cyclone Yasi, 2011) and the Whitsundays (cyclone Debbie, 2017).[52] Before cyclone Marcia crossed the coast in 2015, mangrove extent in the Fitzroy region was relatively stable. After exposure to wind speeds at or above Category 4, the Fitzroy region experienced a decline in canopy cover, from 30 square kilometres to one.[53] After three years, the canopy cover is showing signs of recovery with increases in both open and closed forest (Figure 2.4).[53]

Globally, most mangrove loss is caused by coastal development, although weather-related events can also cause significant impact, particularly cyclones, extreme sea-level variation and heatwaves.[54] Clearing of mangroves occurred widely as a result of coastal development and legacy issues still exist. However, clearing is now strictly regulated. Therefore, the main driver of change in mangrove condition within the Region is currently cyclones, which are projected to increase in intensity.[52,55,56] Localised mangrove forest damage from cyclones is expected to have long-term effects on Reef habitats and species[52,57] due to reduced filtration of land-based run-off. Evidence to date indicates the reduction in localised canopy cover from cyclones is likely to recover in less than a decade[57], in the absence of other pressures (sea level rise and extreme temperature). However these pressures are expected to increase under climate change projections.

Severe tropical cyclones have reduced mangrove canopy cover in some local areas

Some mangrove forests will be negatively affected by the continuing intensification of El Niño with climate change and associated sea-level fluctuations and temperature increases.[49] Shoreline retreat and erosion are occurring along the Queensland coast, with sea-levels rising faster in the north than in the south.[52] Although localised loss of mangrove forests has occurred, recovery has been observed and overall they remain in a stable condition.



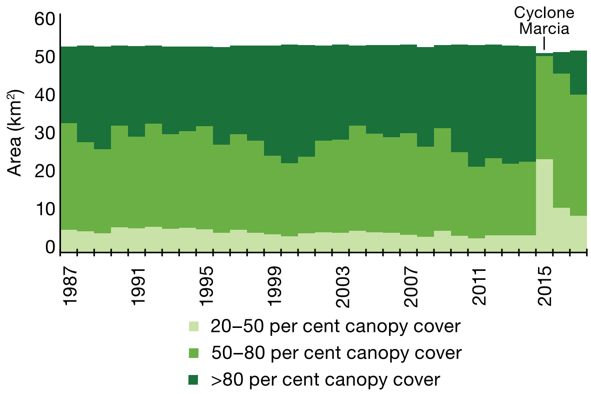


Figure 2.4 Exposure of mangrove forests to cyclone Marcia (2015) and impact on canopy cover
The map shows exposure of mangrove forests near Rockhampton to Category 1, 2, 3, 4 and 5 wind speeds from cyclone Marcia (2015) and the graph shows the impact of the cyclone on mangrove canopy cover. Source: Lymburner *et al.* in press[53]

2.3.4 Seagrass meadows

Seagrass meadows are one of the most important habitats in the Region. They stabilise the seafloor, protecting it from erosion and cyclones, and play an important role in nutrient cycling and carbon sequestration.[58,59,60,61] Seagrass meadows form highly productive habitats for fish, invertebrates and algae[59] and are the primary food source for dugongs and green turtles.[62,63,64] In turn, dugongs and green turtles assist in connecting seagrass meadows by potentially distributing viable seagrass seeds through faecal matter.[65] Inshore seagrass habitats provide important connectivity pathways for many reef fish, such as emperor and tuskfish.[59,66,67,68] Deep-water seagrasses have been found down to 61 metres. Though generally sparse compared to shallower inshore meadows, they can be denser in some locations, such as around Green and Lizard islands.[69,70,71,72]

Recovery of inshore seagrass meadows stalled in 2016–17 as a result of marine heatwaves and cyclone Debbie

Inshore seagrass abundance and condition varies across the Region. Inshore seagrass abundance increased at most locations from 2011 to 2016, following multiple years of above average rainfall and climate-related impacts (Figure 2.5).[64,73] However, recovery slowed or stalled across most of the Region in 2016–17.[74] The disruption to recovery was due to a number of factors, including marine heatwaves that affected all inshore seagrass meadows in the northern and central sectors in 2016 and 2017, increased nutrients and sediments from land-based run-off, increased turbidity from Cyclone Debbie in 2017 (the Whitsundays), and above-average winds which, may have contributed increased inshore turbidity in the far northern and central regions.[74,75] Assessment of the overall seagrass condition also considered reproductive effort (a measure of seeds and fruits). Reproductive effort within inshore seagrass meadows remains low in the Region.[74] The absence of seed banks and low reproductive effort has resulted in many seagrass meadows being vulnerable to future disturbances.[74]

Reduced resilience following multiple stressors means that seagrass meadows may take longer than five years to recover.[76,77,78,79] Recovery will depend on available seed resources[59], connectivity[80] (Section 3.4.10), good water quality and adequate recovery windows. Climate change impacts (such as heavier rainfall events and marine heatwaves) have already caused seagrass diebacks in Australia (Section 6.3.2). The loss of seagrass meadows causes the releases of stored carbon, further contributing to global warming.[51,61] Overall, seagrass abundance has been positive, albeit with some variability across the Region. Seagrass meadows, however, remain vulnerable to ecosystem disturbances and inadequate recovery windows.

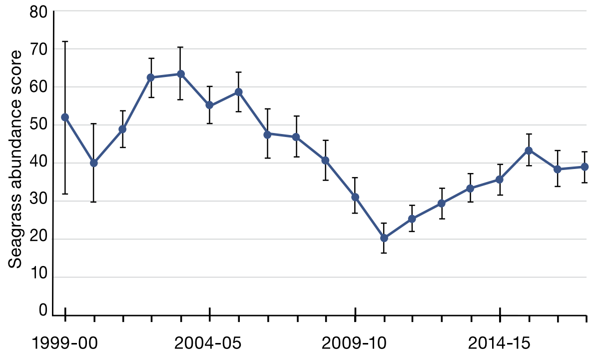


Figure 2.5 Seagrass abundance score for inshore meadows, 1999–2018
Abundance scores (with standard errors) for inshore seagrass meadows from Cape York to Burnett–Mary region. Note: more sites, including intertidal and subtidal, were added since Outlook Report 2014, which may have affected the scores. Source: McKenzie *et al.* 2019.[74]

2.3.5 Coral reefs

Of all the habitats within the Reef ecosystem, coral reefs are the most iconic and support the greatest known diversity of plant and animal species.[81,82,83] The Reef is the world's largest coral reef ecosystem, stretching 2300 kilometres and comprising almost 3000 individual reefs.[84] The Region's reefs occur in various depths, from very shallow estuarine areas to deeper oceanic waters off the continental shelf.[85] Coral reefs provide the Region's communities with substantial benefits, such as tourism, productive fisheries[86] and coastal protection against natural hazards, such as damaging waves.[87] The Region's coral reefs are key contributors to its outstanding universal value as a World Heritage Area.[28]

The Region was affected by consecutive mass bleaching events in the summers of 2016 and 2017. In 2016, intense heat exposure caused severe bleaching in the northern third of the Reef, while in 2017 severe bleaching mainly affected the central region.[88] Aerial surveys conducted in both years along the entire length of the Reef measured the spatial extent and scored the severity of coral bleaching.[89] The combined footprint of severe bleaching extended along the northern two thirds of the Region, while most of the southern third escaped impact (Figure 2.6).

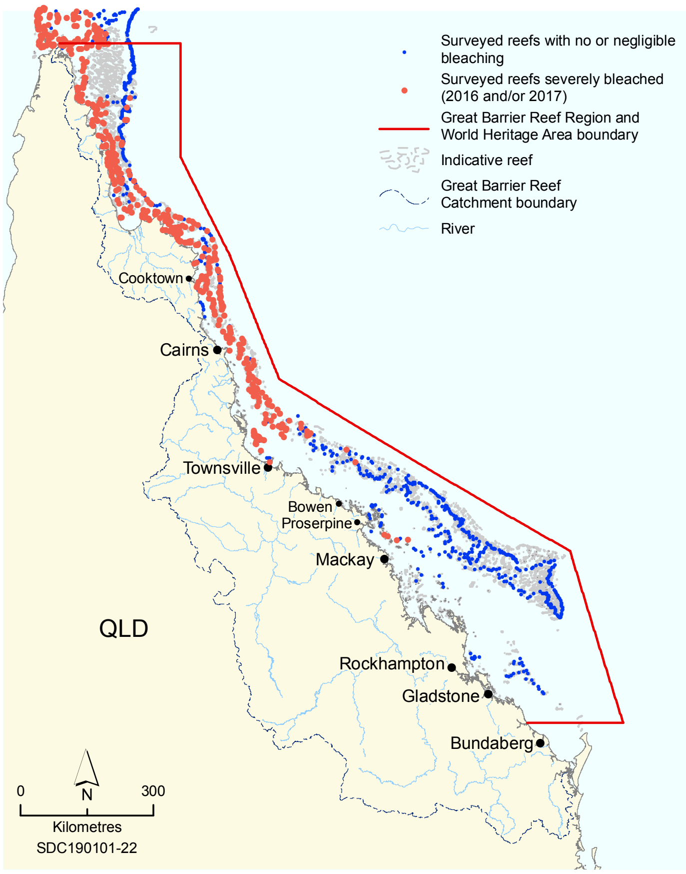


Figure 2.6 Cumulative footprint of coral bleaching in the Great Barrier Reef during the summers of 2016 and 2017
Dots indicate: (red) surveyed reefs where >60 per cent of corals were bleached; and (blue) reefs that were surveyed but had no or negligible bleaching. Source: ARC Centre of Excellence for Coral Reef Studies[94]

Severe disturbances since 2014 have resulted in the greatest loss of coral habitat ever recorded on the Reef

In late 2016, underwater surveys were conducted at depths between two and 10 metres, to ground-truth aerial surveys and record the level of post-bleaching coral mortality on over 100 reefs.[89,90] An estimated 30 per cent of shallow-water coral cover was lost.[90,91] Severe bleaching and some mortality of corals were also observed on northern mesophotic (deep) reefs at 40 metres depth along the outer shelf.[92] However, coral bleaching and mortality generally declined with increasing depth.[93] In 2017, the spatial extent of severe bleaching was estimated by aerial surveys only (Figure 2.6)[88], therefore coral mortality was not quantified. However, given the severity of bleaching observed, it is certain that the 2017 bleaching event caused a further decline in coral cover across the northern two thirds of the Marine Park.[90,91]

In addition, five severe cyclones (Section 3.2.2) have affected various parts of the Region since 2014. Cyclone Debbie crossed over the Whitsundays area in late March 2017 as a slow-moving Category 4 cyclone. Damaging waves cause up to 97 per cent loss of coral cover on some shallow reefs in that area (Figure 2.7).[95] A recent increase in crown-of-thorns starfish outbreaks has reduced mean coral cover on the Swain Reefs in the southern Region since 2017.[95] As at mid–2018, trends in mean hard coral cover on shallow-water reefs in all three regions (northern, central and southern) show steep declines; such widespread decline following these events has not been observed in the historical record of coral reef monitoring.[95] The substantial loss of adult corals caused a subsequent 89 per cent decline in coral recruitment across the Region in 2018[96] and evidence is emerging of flow-on effects to fish populations (Section 2.4.7). Not all reefs in the Region have been affected; reefs that escaped impacts of bleaching, cyclones and crown-of-thorns remain in good condition.

Coral recovery requires adequate periods of time without further disturbance, favourable environmental conditions, inter-reef connectivity, an adequate supply of coral larvae, and successful coral recruitment. Survey data from 2019 found widespread, low-level coral bleaching and recent storm damage on some outer-shelf reefs in the northern Region, probably due to cyclone Penny in January 2019.[97,98] Coral juveniles were observed in densities likely to support future reef recovery.[97] The back-to-back bleaching events in 2016 and 2017 are indicative of the global trend toward more frequent extreme temperatures resulting from global warming. They also illustrate the reduced opportunity for recovery of corals between recurrent bleaching events.[99] The cumulative effects of prolonged thermal stress and unprecedented peaks in summer temperatures in 2016 and 2017, crown-of-thorns starfish predation, and regional cyclone damage have caused widespread loss of corals and significant deterioration in the condition of coral reef habitats since 2014.

Figure 2.7 Changes to coral communities from disturbances since 2014
Time series photographs depicting changes to coral reef habitats due to mass coral bleaching and cyclone Debbie.
First row: Opal Reef in the northern Great Barrier Reef before, during and after the 2016 mass bleaching event.
(left to right: September 2015, April 2016, November 2016). High mortality of all coral types was observed, with turf algae growing over dead coral skeletons. © Taylor Simpkins
Second row: Double Cone Island in the Whitsundays area of the Great Barrier Reef in 2014, post-cyclone Debbie in 2017 and mid-2018 (left to right). This inshore reef monitoring site exhibited a 97 per cent reduction in coral cover and removal of coral structure by destructive waves. © Australian Institute of Marine Science 2019

2.3.6 Lagoon floor

The lagoon floor is a diverse and important habitat within the broader coral reef ecosystem, accounting for approximately 61 per cent of the Region and supporting over 5000 species.[100,101] It includes the non-reefal seafloor inside the outer barrier reefs, typically at depths of between 20 and 40 metres.[102]

The lagoon floor consists of variable surfaces, including structurally simple muddy and sandy sediments, and more complex structures formed by algae, sponges, corals, ascidians, gorgonians and other sessile organisms. Economically, these inter-reefal habitats are vital to the prawn, scallop and sea cucumber fisheries.[103] Ecologically, lagoon floors are important in primary production, nutrient cycling, carbon sequestration and sediment trapping.[102]

Thousands of species of echinoderms, molluscs, crustaceans and worms inhabit the sediment and are vital in supporting the food web.[104] Large organisms, such as sharks, turtles and fish, rely on the surface and structures found on the lagoon floor for food, shelter and breeding.[104,105] Smaller organisms, such as deposit-feeding sea cucumbers, burrow in the sediments and influence sediment community structure and function.[106] Culturally, the lagoon floor is also a place of underwater sacred sites and sites of particular significance for Traditional Owner groups.[107]

Nutrients, pollutants and heavy metals in the water column (Section 2.3.10) can settle onto and penetrate the lagoon floor, contaminating the associated fauna.[108] Climate change, bottom trawling and dredging pose the greatest current threats to this habitat.[109,110,111] The current and projected effects of climate change (Section 6.2), such as gradually rising temperatures, extreme heatwaves and an increase in storm severity, directly threaten a broad suite of lagoonal species, particularly those with limited mobility, such as sponges and molluscs.[109] Bottom trawling (Section 5.4) can remove key habitat-forming species (such as corals, algae and sponges) and damage the seafloor. However, trawl paths often overlap, reducing the potential impact footprint.[110] Trawl bycatch of non-target species is also a concern.[112,113] Reduced trawling effort and better management since 1999 have reduced the area of lagoon floor affected by trawling by approximately 40 per cent.[110,114] Impacts of dredging include burying or smothering lagoon floor plants and animals (Section 5.7.3).[115] Additional impacts to the lagoon floor originate from land-based run-off, anchoring and strong storm activity.

Knowledge of the condition and trend of the Region's lagoon floor is limited. Since 2014, portions of the lagoon floor habitat have been exposed to prolonged thermal stress and damaging waves from severe tropical cyclones (Section 8.3.1). It is probable these impacts have caused some habitat loss, degradation or alteration in some areas.

2.3.7 Shoals

Shoals are submerged features, ridges or banks on the seafloor separated from the surrounding lagoon floor and emergent coral reefs.[116] These habitats vary in shape and size, and are found anywhere from 10 metres depth to the shelf break at 130 metres depth, covering an estimated area of 25,600 square kilometres.[117,118] Shoals generally comprise hard and soft corals, gorgonians, sponges, algae and seagrasses.[119,120,121] Because shoals can harbour high densities of fish, they are valued by fishers. Shoals are also important culturally, containing underwater sacred sites and sites of particular significance for Traditional Owner groups.

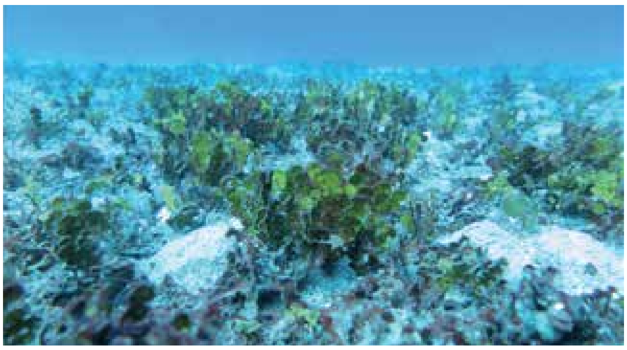
Shoals dominated by coral are often referred to as 'submerged reefs' due to their potential to grow into larger emergent reefs over time[122] and because they support an abundance of coral.[85,123,124] However, a significant proportion of shoals, particularly in the northern Reef, were built and are maintained by calcareous algae and are referred to as *Halimeda* banks (Section 2.3.8). Non-*Halimeda* shoals comprise approximately 14,000 square kilometres of coral reef habitat within the Region.[118] These shoals are numerous on the outer shelf in approximately 15 metres depth.[85,120]

Over 1580 shoals have been mapped in the Region.[117,125] While the location and shape of these shoals is known, knowledge of their condition and how they have changed over time is lacking. Although their deeper location may buffer shoals from some disturbances, such as cyclonic waves and extreme sea surface temperatures, cyclone impacts have been recorded down to 65 metres in the central section of the Reef.[126] The five severe cyclones that crossed the Reef since 2014 have potentially exposed over 160 shoals (10–11 per cent of the total) to damaging waves (Section 3.2.2). Increased sea temperatures responsible for mass coral bleaching in 2016 were recorded down to 40 metres[92] and probably affected many coral-dominated shoals in the northern region.

Since 2014, it is highly likely that the overall condition of shoals across the entire Region has deteriorated due to exposure of shallow shoals to thermal stress in 2016 and 2017, and damaging waves from severe cyclones (Section 8.3.1).

2.3.8 *Halimeda* banks

Halimeda banks are composed of large expanses of accumulated skeletons of calcareous green macroalgae (genus *Halimeda*).[85] The surface layer of these banks consists of meadows of live *Halimeda* algae.[127] The geological accumulation process contributes to the Reef's outstanding universal value. *Halimeda* banks form in deeper waters (greater than 20 metres) adjacent to the inside of outer barrier reefs where clean, cold, nutrient-rich water upwells and is forced across inter-reefal areas by tidal jets pushing through openings between the reefs.[128]



Halimeda bank in the northern Great Barrier Reef.
© McNeil and Kennedy 2018[129]

The undulating banks of *Halimeda* can be up to 20 metres thick, with structurally complex topography. The banks provide a unique and ecologically important inter-reef habitat for fish and invertebrates.[130,131] Significant areas of inter-reefal habitat support *Halimeda* banks in the northern Reef (Figure 2.8), and small areas also exist in the Swain Reefs.

Since 2014, improved mapping technology has increased understanding of the distribution of *Halimeda* banks. A large area (1740 square kilometres) of *Halimeda* banks has been re-mapped to the north of Raine Island (Figure 2.8). These banks have a diverse shape and morphology, with some forming large craters approximately 250 metres across and 20–40 metres deep.[132]

Climate change, ocean warming, acidification[133] and changes to water circulation patterns remain the main pressures affecting the future condition of *Halimeda* banks and the species that rely on them.

Although understanding of the extent of *Halimeda* banks has improved since the 2014 Outlook Report, information on the condition and trend of this habitat and its ecological role is limited. Exposure to potentially damaging cyclonic waves and thermal stress has occurred since 2014 (Section 8.3.1), but this has not affected all *Halimeda* banks, resulting in no consistent trend in their condition.

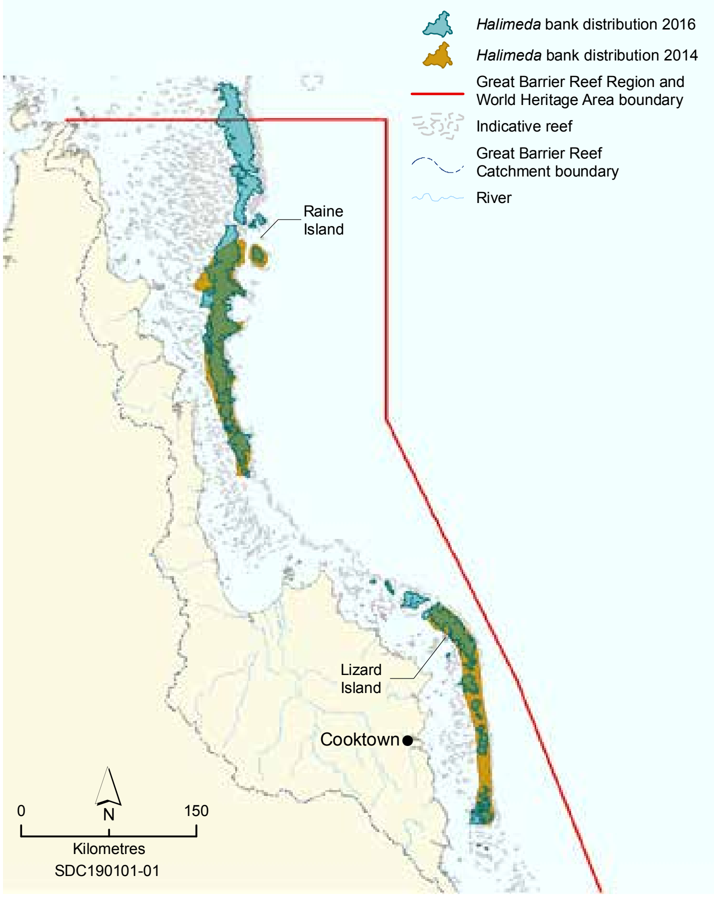


Figure 2.8 *Halimeda* bank extent in the Ribbon Reefs, 2014 and 2016
Areas in the northern section of the Region containing known Halimeda banks from new lidar LADS data (blue sections) compared to earlier mapping (2014). Source: Adapted from McNeil *et al.* 2016[132]

2.3.9 Continental slope

At the edge of Australia's continental shelf is the continental slope — a transition from the shallow shelf to the adjacent deep ocean basins, extending down to more than 1000 metres and characterised by vast submarine canyons and numerous undersea landslides (Figure 2.9).[134,135] On the Reef, the shelf edge is generally around 100 metres deep and the continental slope is defined as the deepening sea floor out from the shelf edge to the upper limit of the continental rise, or the point where there is a general decrease in steepness. The slope comprises approximately 15 per cent of the Region (about 51,900 square kilometres).[1]

The continental slope's submarine canyons are potential hotspots for benthic production and habitat for diverse marine life.[136,137,138] Bathymetry data have revealed over 100 canyons stretching from the central Reef to the far northern Reef and Torres Strait (for example, Figure 2.9). High-resolution mapping of these canyons has also revealed a complex and active system of channels along the canyon axis, internal sand waves, and localised submarine landslides.[139]

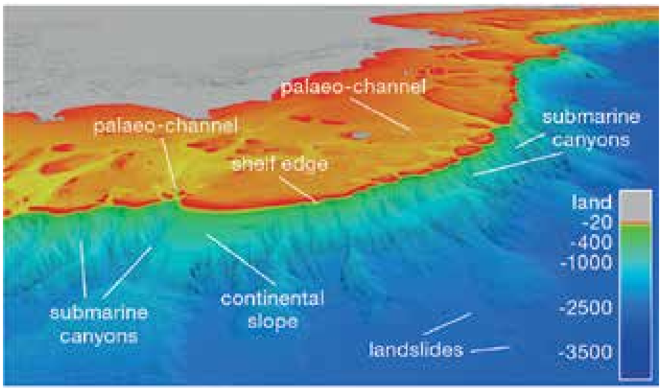


Figure 2.9 Continental slope features
The morphology of the continental margin of north-eastern Australia, indicating the continental shelf edge, slope depth, submarine canyons and underwater landslides. © Dr. Robin Beaman, James Cook University

Upwelling also occurs along the continental slope, delivering both nutrients and cooler water up from deeper water mass layers within the Coral Sea onto the Reef shelf through inter-reef passages.[92,140] This upwelling supports phytoplankton blooms and increased biological productivity. Upwelling can also reduce thermal stress on offshore reefs during bleaching events, producing a gradient towards less severe bleaching from inshore to offshore.[88,141]

While the Ribbon Reef canyons[142] are relatively well-mapped, the current condition and trend of the continental slope is largely unknown. Deeper sections of the continental slope may be buffered from storm-driven wave activity[143] and thermal stress.[144] However, the depth of the thermocline can vary substantially, depending on factors, such as the El Niño–Southern Oscillation.[145,146] The upper continental slope (to about 300 metres) around the Swain Reefs in the southern Reef is exposed to high levels of trawl effort from the deepwater eastern king prawn fishery (part of the East Coast Otter Trawler Fishery, Section 5.4).[110] Damage to seabed communities and bycatch of vulnerable and protected species is a concern for this area, and more ecological and biological information is required to more confidently assess the risks posed by this fishery.[110,147]

Based on expert opinion, the extent of the continental slope has been determined to be slightly deeper than was assessed in the 2014 Outlook Report. Mesophotic coral reefs had been included as part of the continental slope assessment, but as they form part of the shelf edge rather than the slope, they are now assessed in coral reef habitats (Section 2.3.5). This change led to the continental slope being considered in better condition in 2019 than in 2014, but the change reflects the adjustment to spatial boundaries rather than any improvement in the habitat's actual condition.

2.3.10 Water column

For the purposes of this section, the water column (previously referred to as 'open waters') comprises the pelagic (open ocean) zone between the coast and the continental shelf. It connects all habitat types. The Region has a total water volume of around 7200 cubic kilometres.[148] The water column serves as the main habitat for many species of fish, cetaceans, dugong, turtles, invertebrates and microbes and provides critical links between benthic and pelagic communities. The water column is the primary medium through which energy and nutrients cycle[149] and larvae are dispersed. It also supports plankton communities that form the basis of marine food webs.[150]

Water movement and flow are generated by ocean currents, wind, tides and upwelling across the Region. This movement transports organic matter, nutrients, larvae and plankton communities. Run-off, upwelling, tides, rain, winds and cyclones also affect nutrient concentrations and, in turn, primary productivity in this habitat.[85,151,152]

The water column links all habitats within the Region

The condition of the water column habitat can be inferred by measuring parameters such as nutrient and sediment concentrations, pollution, temperature and pH. The decline of inshore water quality associated with land-based run-off (Section 6.5) from the adjacent Catchment is a major cause of the current poor state of the inshore water column along the coast.[43,153,154,155] Mid-shelf and offshore waters are typically less influenced by land-based run-off, and water quality in those areas is considered to be in better condition.[43,156,157] However, sediment run-off and resuspension can also affect mid-shelf and offshore areas, and may take up to six months to dissipate.[158] Marine debris is also a growing threat to species throughout the water column (Section 6.5.2).[159,160,161]

Inshore reefs (those within 10 kilometers of the coast) are more vulnerable to ocean acidification than offshore reefs.[162,163,164] The reason is unclear but may be linked to changes in temperature and biological processes in the water column.[162] Water temperatures are warmer now than ever before[165] and are probably affecting the suitability of this habitat for sensitive species.

Water residence times within the Region show flushing time of a few weeks for most of the lagoon.[166] This indicates that the water column habitat may recover relatively quickly after a disturbance, such as a heat wave. Conversely, fine sediments, nitrogen, phosphorus, pesticides and trace metals in the water column may be present for years to decades.[167] Important gaps remain in knowledge of the water column, such as how temperature increases affect plankton and pelagic species. The suitability of the water column as a habitat has continued to deteriorate since 2014, because a number of processes (including temperature and land-based run-off) that significantly affect this habitat have also declined.

2.4 Current condition and trends of populations of species and groups of species

Sixteen species groups are assessed; a large amount of variability in condition occurs across the Region. Mangroves continue to be graded in very good condition. Benthic algae, bony fishes, estuarine crocodiles, whales and dolphins remain in good condition. Several components have deteriorated (plankton and microbes are graded good, other invertebrates are poor and corals are very poor). Condition of seagrasses, sharks and rays, sea snakes, marine turtles, seabirds, shorebirds and dugongs remains poor.

↓

Full assessment summary: see Section 2.5.2

The Region is home to thousands of species (Table 2.1), with new species still being identified.[168,169,170,171] It provides particularly important habitat for species of conservation concern, such as dugongs, whales, dolphins, seabirds, marine turtles, sharks and rays. Given the changing thermal regime, the previous ranges of some species are changing[172], resulting in new records in some areas.[173] The Great Barrier Reef's inscription on the World Heritage List recognises the global significance of its species diversity.[28]

2.4.1 Mangroves

The Region's mangroves are highly diverse, encompassing at least 41 mangrove species and hybrids recorded from 20 plant families; the highest diversity occurs north of Port Douglas.[169,170,177,178] In total, this diversity represents 50 per cent of mangrove species worldwide.[46]

Since 2016, three new species of mangrove been recorded in the Region, through either new species identification or range extension. *Bruguiera hainesii*, never before recorded in Australia, was found in Trinity Inlet (Cairns) by a citizen scientist.[170] This species is listed as critically endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth). This discovery is considered to be the largest population of this rare species in the world. Another species, *Bruguiera cylindrical*, previously thought to occur between Cooktown and Cape York, was discovered in the Cairns region in 2016, extending our knowledge of its southern range by approximately 150 kilometres.[52] A recently described hybrid species, *Bruguiera x dungarra*, was discovered from the Cape York to Fitzroy regions.[169] The identification of new species of a mature size in close proximity to the urban coast highlights the lack of comprehensive data on mangrove diversity and extent along the Catchment.

Mangrove species are exposed to a range of impacts (Section 2.3.3). Although new species have been found in some locations, the overall condition of mangrove species remains stable across the Region.

Table 2.1 Species diversity of plants and animals in the Region
For some, the number of species recorded is provided; for others the most up-to-date estimate is given.[174,175,176,266] The table includes the number of listed migratory species (M) and listed threatened species (T) under the Environment Protection and Biodiversity Conservation Act 1999 (Cth).

Plants and animals of the Great Barrier Reef	Number of species recorded
Mangroves	41 (T:1)
Seagrass	15
Benthic algae	880
Sponges	at least 2500
Soft corals and sea pens	at least 1000
Hard corals	450
Echinoderms	630
Crustaceans	at least 1300
Molluscs	at least 6000
Worms	at least 1000
Bryozoans	332 species
Jellyfish	at least 100 species
Anemones	at least 150 species
Tunicates	at least 300 species
Bony fishes	1625
Sharks and rays	136 (M:5, T:7)
Sea snakes	14 breeding species
Marine turtles	6 (M:6, T:6)
Crocodiles	1 (M:1, T:1)
Seabirds	20 nesting species (M:23, T:6)
Shorebirds	41 (M:30)
Whales and dolphins	more than 30 (M:10, T:4)
Dugongs	1 (M:1)

2.4.2 Seagrasses

Species composition of disturbed inshore seagrass meadows is maturing, a sign of recovery

The Region contains some of the greatest species diversity of seagrasses in the world.[64,179] Fifteen seagrass species occur within the Region, with one deep-water species, *Halophila tricostata*, being endemic to the area.[64] Most seagrass species in the Region are found in water shallower than 10 metres. *Halophila* is the only genus in the Region found in deep-water meadows (occurring in water greater than 15 metres).[64,71,180] Species composition within seagrass meadows changes as it recovers from disturbance. Seagrass species are typically either colonising (fast growing), opportunistic (mixture of fast and slow growing) or persistent (slow growing).[181] Generally, the Region is dominated by disturbance-tolerant species, such as *Halophila, Halodule* and *Zostera*.[59] These colonising species generally have low abundance and high turnover rates.[182,183] The composition of inshore seagrass meadows in the Region matured from 2011 to 2018, switching to more opportunistic (*Zostera*) and persistent (*Thalassia* and *Enhalus*) species, replacing colonising species (*Halophila*) that establish post disturbance.[74] This indicates a transitioning system, which is becoming more tolerant of disturbances.[181,184]

Seawater temperatures measured within inshore seagrass meadows in 2016–17 and 2017–18 were warmer than the long-term (11-year) average, a trend observed for the past five years.[74] The current trend of higher sea temperatures is likely to have chronic impacts on some species of seagrass, particularly heat-sensitive species, such as *Zostera muelleri* or species sensitive to light reductions (as high temperatures increase seagrasses' light requirements).[184,185]

Seagrass species are exposed to a range of impacts (Section 2.3.4). Although still in poor condition, seagrass species composition is recovering at many inshore sites following extensive losses in previous years.

2.4.3 Benthic algae

Following disturbances, corals may be replaced by benthic algae

Benthic algae includes three main growth forms: large fleshy macroalgae, crustose coralline algae (which form a photosynthesising 'cement' layer over some parts of the seafloor), and short turf algae (Figure 2.10). Turfing algae are one of the most abundant benthic habitats in the Region and an important source of primary productivity on coral reefs for crustaceans and microbes.[186,187] More than 880 species of benthic algae exist in the Region.[127,188] The three different growth forms provide a variety of ecosystem services, food for many organisms, primary production (Section 3.4.3), reef building (Section 3.4.8), stabilisation of the seafloor, and settlement habitat for juvenile fish and invertebrates. On inshore reef flats, macroalgal stands can provide important nursery habitats for herbivorous fish (for example, rabbitfish and parrotfish).[189]

The total number of species of large, fleshy macroalgae on the Reef is unquantified. These algae are generally more common on inshore reefs where nutrient levels are higher, and their cover decreases with distance from the coast.[188,190,191] Fleshy macroalgae can be highly seasonal, the largest species (for example, *Sargassum* species, which grow up to three metres high) can dominate shallow inshore habitats in summer before partially detaching in winter[192]; the habitat then transitions to compact winter species. However, this seasonality may be changing with some of the summer-blooming species persisting longer through winter.[193] Following disturbances, algae may inhibit coral recruitment and replace coral as the dominant benthic cover.[194,195]

How benthic algal abundance has changed over time and across the Region is not well understood, with quantitative data only available in limited areas. The trend in abundance of inshore macroalgae has been variable since 2014 (Figure 2.11).

Figure 2.10 Benthic algae growth forms
Left: Fleshy macroalgae growing in and around coral on an inshore reef. © GBRMPA
Middle: Pink coloured crustose coralline algae. © Andrew Hoey
Right: Turf algae. © Andrew Hoey

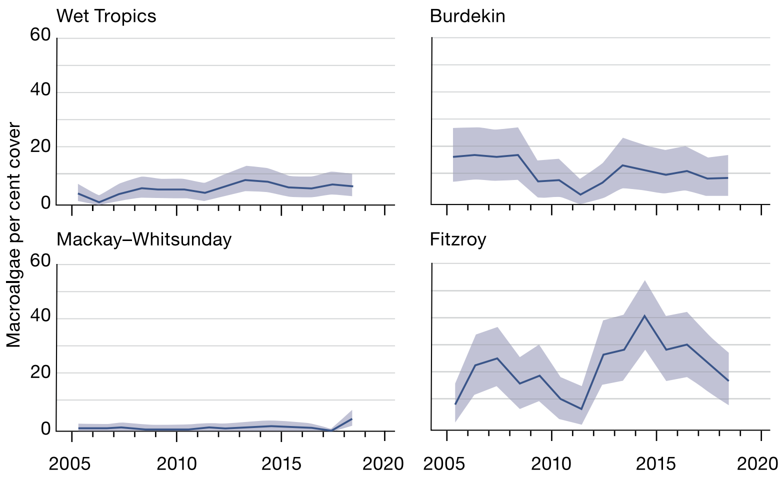


Figure 2.11 Macroalgae abundance, 2005–2017
Mean abundance of macroalgae from inshore reefs in four natural resource management regions: Wet Tropics (n=19), Burdekin (n=10), Mackay–Whitsunday (n=10) and Fitzroy (n=6). Totals calculated for a financial year.
Source: Thompson *et al.* 2018[193]

Of the inshore reefs monitored, large fleshy macroalgae appear to have slightly increased in the Wet Tropics and Mackay–Whitsunday areas, probably in response to reduced coral cover following bleaching, crown-of-thorns starfish predation and cyclone damage (particularly around the Whitsundays). Conversely, macroalgal cover peaked in 2014 then declined in the Fitzroy region and has gradually decreased in the Burdekin region.[193] These declines may be attributed to a number of factors: reduced recruitment of macroalgae, herbivory, or coral returning as these sites recover from disturbance.

Crustose coralline algae plays an important stabilising role, creating a cement-like mat over the seafloor and dead and broken coral, strengthening the reef structure. These benthic algae, being a more encrusting form, reinforce a coral-dominated state by repelling fleshy macroalgae recruits, and they can provide a suitable surface for coral larval settlement.[168] In the northern and central areas of the Reef, 30 species of crustose coralline algae have been identified; their diversity and relative abundance are greatest on mid and outer-shelf locations.[196] The abundance of crustose coralline algae varies latitudinally, with the northern Ribbon Reefs having, on average, five times more coverage than the southern Swain Reefs.[197] While there are some site-specific studies on crustose coralline algae, broadscale and long-term trends in its condition and abundance are poorly understood.

There is limited information to indicate a Region-wide increase in turf algae abundance following broad scale decline in coral cover. The condition and abundance of turf algae is likely to decrease over time if sedimentation increases, resulting in long, sediment-laden turfs, which deter fish feeding, coral settlement and productivity.[198] Nutrients, sediments, outflows from rivers and cyclones are significant drivers of algal turf composition.[199] Sediment levels in coastal algal turfs were more than ten times that of offshore reefs, and double that of inshore reefs.[23]

The most serious impacts to benthic algae as a group include sediment exposure and light limitation (from both natural and anthropogenic influences, such as dredging and disposal[200] and land-based run-off); increased sea temperatures[201] (which can cause bleaching of crustose coralline algae); and ocean acidification[202]. Benthic algae are a diverse group of species that provide important habitat for many organisms. Overall, benthic algal diversity has been maintained and abundance has increased in some areas.

2.4.4 Corals

The Region is home to more than 1200 species of hard (skeletonised) and soft corals[203,204,205], and this high diversity contributes to the outstanding universal value of the World Heritage Area.[28] Hard corals are the key habitat-forming species of coral reefs. These corals have microscopic algae, called zooxanthellae, living within their tissue that provide them with food produced during photosynthesis. Corals are mainly found in shallow waters (less than 30 metres), due to their dependency on light, but mesophotic reefs can be found down to 150 metres.[206]

Global warming has transformed coral species assemblages, with key coral species exhibiting significant declines

Corals exhibit a high degree of variation in growth rates and forms, including slow-growing boulder-shaped species (which grow at 1.3 centimetres per year)[207], and fast-growing branching species (which grow at 10–30 centimetres per year).[208] Corals tolerate a narrow range of temperatures and are adapted to their local conditions.[209] Slight increases in sea surface temperatures due to global warming can cause significant coral mortality.[88,91,141] Tabular and branching corals, such as acroporids and pocilloporids, are particularly important in creating three-dimensional structures that provide critical habitat to the majority of coral-reliant fish and invertebrate species.[83,210,211] These corals are also the most susceptible to disturbances, including bleaching due to thermal stress[212,213], breakage from cyclones[214], predation from crown-of-thorns starfish and *Drupella* snails[215,216], and coral disease[217].

Climate change, specifically temperature extremes, is the primary driver of coral degradation in the Region and has substantially altered the abundance and species composition of coral communities. Consecutive thermal stress events in 2016 and 2017 caused mass coral bleaching in the northern two thirds of the Region, resulting in unprecedented levels of coral mortality.[90] Acroporid and pocilloporid coral species, which dominate many shallow reefs, declined by more than 75 per cent on severely bleached reefs, resulting in the significant loss of three-dimensional structure.[91] Juvenile corals were generally less affected by bleaching than adults, with the exception of *Pocillopora* and merulinid corals.[218] Overall, juvenile *Acropora* and *Pocillopora* corals suffered greater mortality than juveniles of other corals.[218] As a result of mass mortality of adult corals, coral recruitment across the entire Region declined by 89 per cent in 2018 compared to recruitment levels before 2016. For acroporids, the decline was 93 per cent.[96] Recovery depends on successful recruitment of new corals, growth of existing corals and absence of further stressors (Section 2.3.5). Global warming has resulted in a five-fold increase in the frequency of severe coral bleaching events in the past four decades[99] and slowed the rate of coral recovery[219].

Cumulative impacts since 2014, such as unprecedented mass coral bleaching, crown-of-thorns starfish predation and regional cyclone damage, have caused widespread loss in populations of many coral species across the Region, with some species having deteriorated significantly.

Bleaching susceptibility varies among coral species, with branching and tabular varieties (bleached in the photo) more vulnerable to thermal stress and bleaching-related mortality than massive coral (unbleached underneath).

2.4.5 Other invertebrates

The Region is home to 32 invertebrate phyla (major groups), consisting of over 12,000 described species.[220,221,222] This biodiversity is nationally and internationally significant.

Small, mobile invertebrates often live in symbiosis with sedentary host invertebrates, such as corals, sponges and sea cucumbers (Section 3.4.6).[106,223] Some symbiotic invertebrates, such as those that live with coral hosts, are completely reliant upon their host for survival and are at high risk of population decline with any loss of coral habitat.[83] Other invertebrates, such as bivalves and sponges that bore into, and break down (bioerode), dead coral skeletons, benefit from habitat degradation. Invertebrates account for the greatest animal diversity and biomass in the Region[224,225], and are key elements of the food web[226]. They are important recyclers of nutrients[106], bioeroders[227] and providers of services vital to the health of other reef organisms.[83,228,229] Invertebrates are also a valuable source of food and medicine for humans.[229,230]

Rising sea temperatures due to global warming are affecting many invertebrate species

A range of factors directly affect invertebrates, particularly climate change.[109,229,231,232] Most invertebrate species are sensitive to changes in temperature.[233,234] For example, in 2016 mass mortality of shrimp and crabs attributed to temperature stress was observed in a shallow-water lagoon in the northern Region.[235] Ocean acidification also threatens calcifying invertebrates, such as foraminifera[236] and sea urchins[231,237]. Sponges appear to be an exception among invertebrates, exhibiting high tolerance of both ocean warming and acidification.[238] Pesticides and changes to salinity from freshwater inflow can have acute, lethal effects on many types of invertebrates, particularly crustaceans.[239,240] Overfishing and habitat destruction can cause rapid declines in invertebrate communities, as evidenced by the historical collapse of the black teatfish sea cucumber population (Section 8.3.3)[241,242] and more recently the saucer scallop stock (Section 5.4).[113] Nutrients and pollutants settling out from the water column can contaminate lagoon sediment and associated fauna.[108] Trawl discards of invertebrates remain largely unquantified, as there are no requirements to report discards of most bycatch (Section 5.4.1).[2] Some target species, such as mud crabs and blue swimmer crabs, are susceptible to local depletions from overfishing (Section 5.4.1).

The majority of invertebrates take refuge within the reef matrix to avoid predators. This coral crab hides between the branches of a Pocillopora coral.

Current knowledge of the condition and trend of invertebrates is limited, largely due to the sheer number of species and the variety of life history characteristics and habitat requirements. The majority of invertebrate species are cryptic, which means they are hidden from view and difficult to survey. Given the recent widespread reduction in coral habitat due to climate extremes[91], it is probable that many coral-reliant invertebrate species have been negatively affected.[83,243] Changes in invertebrate communities independent of coral loss have also been recorded along the entire Region, attributed directly to prolonged thermal stress.[244] Exposure to elevated nutrient levels, high sediment loads and freshwater is likely to have affected invertebrates distributed closer to shore. Given their exposure to a range of impacts (Section 8.3.1) and the widespread loss of coral reef habitat, it is likely that the condition of many invertebrate groups has deteriorated since 2014.

2.4.6 Plankton and microbes

Plankton and microbes are highly abundant and diverse; they include single-celled plants, bacteria, viruses, animals and animal larvae.[245,246] The density of plankton and microbes can exceed more than one billion microorganisms living in each litre of seawater, however, the number of species found within the Region is unknown.

Plankton and microbes are critical to ecosystem health and functioning.[247,248,249,250] Plankton are the primary food source for many animals and are the base of most marine food webs.[150] Zooplankton are an important food source for corals, particularly for bleached corals that may starve without their zooxanthellae.[251,252] Approximately half of global primary production is carried out by oceanic phytoplankton.[253] Microbes constitute the bulk of marine biomass and are significant contributors to metabolic activity, the carbon, nitrogen and sulphur cycles, and the exchange of trace gases that have direct impacts on local climate.[247,254] Microbes play an essential role in many ecosystem processes (Sections 3.3.1 and 3.4.1) and form symbiotic relationships with other organisms, such as corals, sponges and algae.[247,248,249,250] These relationships are specific and stable associations[255], and can assist organisms to acclimatise to prevailing environmental conditions.[256,257,258] Microbes are also agents of disease, which can be a sign of an imbalance in microbial communities (Section 3.4.1).

Plankton and microbes respond relatively quickly to changes in the environment, such as lowered salinity, temperature increases and elevated nutrients.[259] Changes in ocean conditions resulting from climate change are affecting their distribution and abundance.[260] For example, large changes in microbial community structure were seen in the Region during the extreme wet season of 2010–11, following riverine floods.[261] Sea surface temperatures have had large-scale effects on zooplankton[262,263], with declines of zooplankton biomass recorded during warmer El Niño conditions[264].

Despite a growing understanding of the importance of microbes and plankton to ecosystem health, they are overlooked in most large-scale monitoring programs and, therefore, remain a key knowledge gap.[265] Factors affecting these communities are increased temperature, elevated nutrients and reduced pH (for plankton with carbonate skeletons)[266], all of which are occurring in the Region. Localised plankton declines have been recorded in the central Region[267], and a higher incidence of coral and fish disease was reported after thermal stress (Section 3.6.1). It is likely that widespread thermal stress and ongoing poor water quality in some areas of the Region have led to a deterioration in the overall condition of plankton and microbes since 2014.

2.4.7 Bony fishes

Bony fishes (Class Osteichthyes) are fish with skeletons made of bone rather than cartilage. Approximately 1625 bony fish species are found in the Region, with the majority (1468) classified as coral reef species.[175] Bony fishes have high ecological and economic values (Section 5.4.2). They influence habitat structure and the flow of energy and nutrient cycling.[268] Bony fishes occur in a wide range of habitats, including coral reefs, shoals, seagrass meadows and open waters.

Coral-dependent fishes are declining

Some fishes, for example, small corallivorous fishes, depend heavily on coral reef habitats. Pelagic fishes associated with reefs (such as trevallies and scombrids) depend less on benthic habitat, but may decline in response to changes in their reef-associated prey.[269] Disturbances that deplete coral cover by as little as 10 per cent can reduce fish abundance across a range of species.[270] Declines in bony fishes following coral disturbance can manifest quickly (within six months) or take up to several years.[270] Changes in seagrass and mangrove habitats, which are important feeding, breeding and nursery grounds, can also influence the condition of bony fish and their recruitment.[64]

The full impacts of recent environmental disturbances to the Region's coral reef habitats (including the 2016 and 2017 mass coral bleaching events) on bony fishes are still being determined. Time-lags are expected in fish responses to habitat loss.[271] However, early indications are that coral bleaching has clearly affected bony fishes[272,273], including through decreased diversity and sub-lethal effects, such as reduced fitness.[272,273] Elsewhere, productivity of fisheries has been estimated to decline three-fold when habitat structure is lost following disturbance.[86] On the Reef, the full flow-on effect to fisheries is not yet understood and remains an area of research interest.

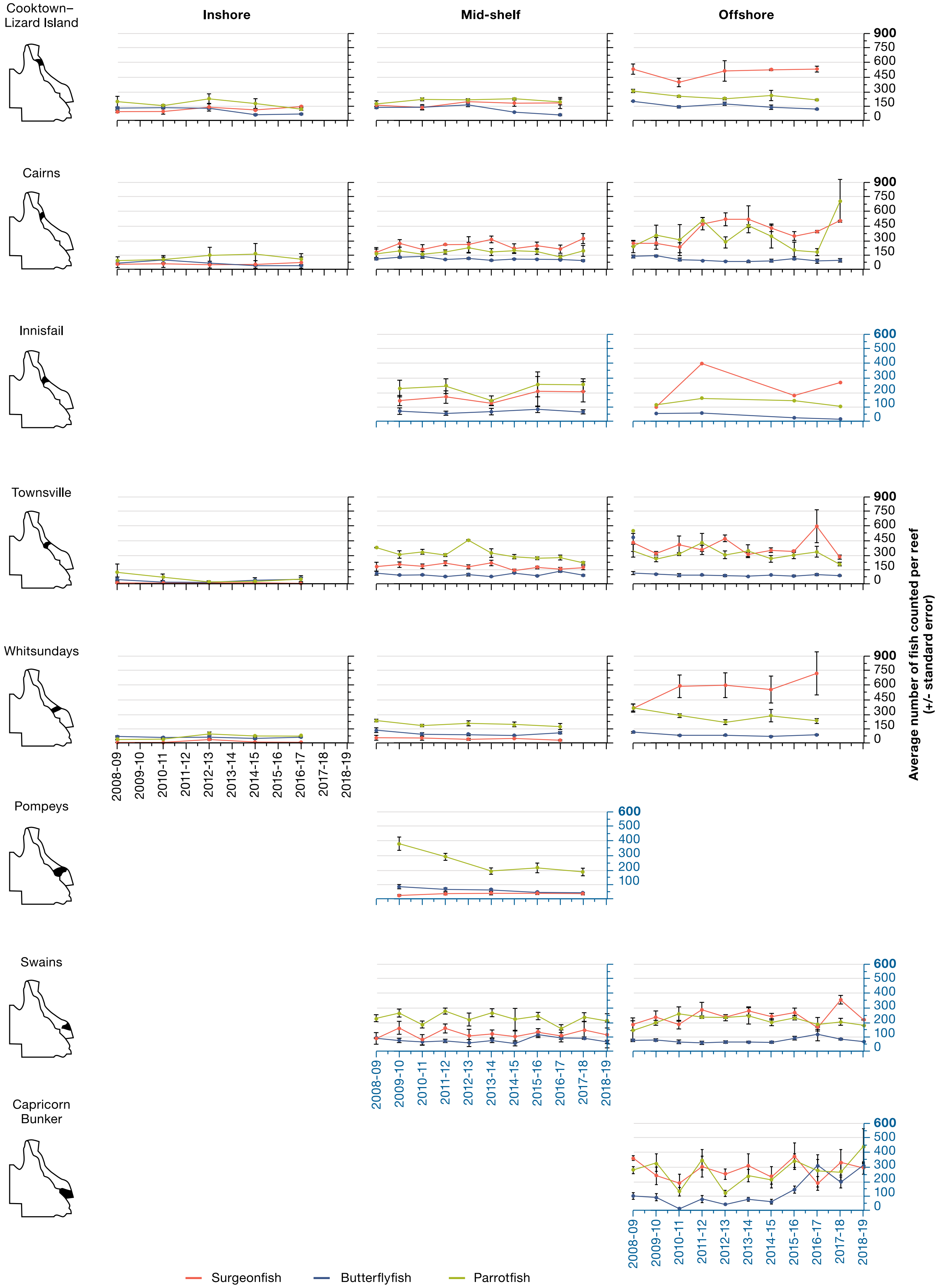


Figure 2.12 Abundance of some coral reef fishes, 2008–2019

Surgeonfish, butterflyfish and parrotfish are diverse bony fish groups present across the Region. Fish abundance is estimated by visual census of a total of fifteen 50 metre by five metre transects at each reef. Where possible, three or more reefs were surveyed at inshore, mid-shelf and offshore positions across the continental shelf. Note the differences in scale between the black and blue y-axes.

Source: Australian Institute of Marine Science Long-term Monitoring Program[282]

Long-term monitoring of three key fish groups (butterflyfish, parrotfish and surgeonfish) across the Region has identified some changes in mean abundance since 2009 (Figure 2.12). Butterflyfish, which rely heavily on coral and other invertebrates for food, showed small declines since 2016–17 at the Cooktown–Lizard Island, Innisfail (mid-shelf) and Townsville (mid-shelf) reefs and the Swain Reefs. Abundances of surgeonfish and parrotfish, which feed on a combination of algae and detritus, have been more variable over time. The greatest increases in parrotfish were observed offshore Cairns and the Capricorn Bunker group, while some declines were observed on reefs around Townsville and offshore Whitsundays. The greatest increase in surgeonfish abundance was observed offshore Whitsundays and Cairns in 2016–17 (Figure 2.12).

Climate change, over-fishing (including illegal fishing) and habitat alteration are the greatest current impacts on most fish species.[274,275,276] New research since 2014 has improved understanding of the effects of climate change on bony fishes.[277,278,279,280] Management tools, such as spatial zoning (including no-take areas), protect fish and contribute to the maintenance and recovery of target fisheries species through spillover of larvae from unfished to fished zones (Section 7.3.3 Box 11). Current extraction rates for some fished bony fish species are considered sustainable. However, there are concerns for others (Sections 5.4 and 8.3.4).

Little is known about the condition of most bony fish species on a Region-wide scale, given it is a highly diverse group. Monitoring ecological processes performed by bony fishes, such as herbivore feeding rates, can help diagnose problems early, before fish populations start to decline.[281]

Overall, some deterioration in the condition of bony fishes (as a group) has occurred, particularly in those dependent on coral and seagrass meadows for food, shelter or some part of their lifecycle. Current extraction rates are considered sustainable for some species, but may not be for others.

2.4.8 Sharks and rays

Chondrichthyan fishes have skeletons of cartilage, rather than bone; they include all sharks, rays, skates and chimaeras. Approximately 136 different species are known to inhabit the Region, 82 of which are sharks.[283] This has led to the Region being identified as a global hotspot of shark species richness, functional diversity and endemicity.[284]

The ecological roles and importance of different sharks and rays vary depending on abundance, body size, trophic level and how specialised their diet is.[285] Large apex predators, such as the great hammerhead shark and the tiger shark, are most likely to influence the population dynamics of prey species.[285] Smaller sharks, such as blacktip reef sharks, are functionally equivalent to other middle-order predators, such as coral groupers. Many species of sharks and rays are relatively long-lived, grow slowly, mature later, and produce few offspring; these traits make them particularly susceptible to overfishing.

Reef sharks patrolling the reef crest. © Matt Curnock

In the Region, at least 46 shark species are caught in the East Coast Inshore Fishery, with 17 species considered to be highly vulnerable to exploitation.[286] Green sawfish, the Australian blacktip shark, the pigeye shark, the grey, blacktip and whitetip reef sharks and hammerhead sharks are among the most vulnerable species that interact with fisheries.[287,288] Species richness and abundance of deep-water shark and ray species in the Region are naturally lower with increasing depth.[289] Eleven species of rays and skates have been identified as highly vulnerable to the East Coast Otter Trawl Fishery.[176] Deep-water species are more susceptible to overfishing than are shelf and pelagic species, because their populations take longer to recover from exploitation.[290] Large-bodied, shallow-water species of sharks and rays are the most vulnerable to depletion, with sawfishes being the most threatened.[291,292] Climate change also threatens shark and ray populations, with 30 species within the Region highly or moderately vulnerable to climate change, mainly freshwater/estuarine and reef-associated species.[293]

Sharks and rays are vulnerable to multiple threats, particularly from overfishing and climate change

In 2018, the scalloped hammerhead shark (*Sphyrna lewini*) was listed in the conservation-dependent category of threatened species under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth)[294] due to declines throughout its entire Australian distribution and continued threats posed principally by commercial fishing.

The population status of many species in the Region remains a knowledge gap, but modelling of mortality rates has predicted potential declines in reef-shark abundance.[295] Several species of sharks in the Region rely on coral reefs. A higher number of species of reef-associated sharks are found in areas of greater structural complexity (for example, rocky shoals and coral reefs) and their abundance is higher in areas with higher coral cover.[296] No-entry zones within the Region contain significantly more reef sharks than no-take zones and areas open to fishing.[297] A recent publication using analysis of the entire Queensland Shark Control Program dataset, which includes data from outside the Region, indicates that there may be declines in tiger, hammerhead, whaler and white sharks.[298] There are likely to be multiple causes of decline and further analysis is required. Declines in sawfish populations have occurred since 1970 across their entire range, including within the Region.[299] The conservation status and sustainability of some shark species in the East Coast Inshore Fishery remain uncertain and cause for concern[286], although the catch of some target species is well below that which can be sustained. Given the widespread loss of coral cover and ongoing fishing pressure, the condition of some shark and ray species may have deteriorated since the 2014 assessment. However, there is no consistent trend for sharks and rays as a group.

2.4.9 Sea snakes

Sixteen species of true sea snakes have been recorded in the Region, and 14 species maintain permanent breeding populations.[300] True sea snakes produce live young and are entirely marine, never venturing onto land. The Region is situated within the global hotspot of sea snake diversity.[301] Sea snake species within the Region are protected under both Queensland and Commonwealth legislation.

Life history characteristics of sea snakes, such as low reproductive output (two to three live young every couple of years), and low dispersal make them particularly vulnerable to threats.[301] As air-breathing organisms, sea snakes are susceptible to significant mortality when captured in trawl nets.[302] Two species, the ornate reef sea snake and the elegant sea snake, have been identified as being at high risk from otter trawling.[176] However, management changes in the trawl industry have reduced the capture of sea snakes by 60 per cent.[302] The spine-bellied sea snake and the elegant sea snake use shallow bays associated with freshwater inflows.[303] Inshore areas remain under pressure from direct or indirect anthropogenic impacts.[43]

While broad patterns in the distribution of sea snakes have been documented,[300,302] up-to-date information about the distribution and abundance of individual sea snake species remains limited. No regular population monitoring occurs, in part due to logistical difficulties associated with counting sea snakes.[304] Sea snakes within inshore regions of the central and southern Reef occur in relatively high abundance and diversity.[305] In the north, research station staff have anecdotally reported localised depletion at a site known for high sea snake abundance near Lizard Island. However, the cause is unknown. Unexplained declines have been documented for two species of sea snake in the southern Reef.[306]

Although trawl bycatch has been reduced, some localised depletions of sea snake populations have been recorded, probably due to other impacts, such as thermal stress. Overall, based on the evidence available, the condition of sea snakes has remained stable across the Region since the Outlook Report 2014 assessment.

2.4.10 Marine turtles

Six species of marine turtle occur on the Reef and all are listed as threatened under Commonwealth and Queensland legislation. The Region has globally significant nesting and foraging areas for green, loggerhead, hawksbill and flatback turtles.[307,308] Marine turtles provide a number of ecological services, including herbivory and seagrass dispersal (green turtles), and contribute to nutrient cycling and sediment production.[65,308,309,310] These iconic animals are also highly valued by Traditional Owners (cultural use), the tourism industry, visitors and residents.

Concerns are growing for the future of loggerhead, hawksbill and northern green turtles due to climate change and overseas fishing pressures

Ninety per cent of nesting by green turtles from the southern (Heron, Wreck and North West islands) and northern populations (Raine Island and Moulter Cay) occurs within protected areas.[311] The previously depleted southern population has more than doubled in the last 40 years[312], reflecting the value of large-scale habitat protection and the cessation of commercial harvesting in 1950[313].

Since the mid-1990s, concerns have been expressed about declines in nesting and hatchling success of green turtles nesting at Raine Island.[2,311] Extra management interventions implemented on some parts of the island since 2014 are slightly improving reproductive success.[27,314,315,316] Despite this, the previous period of low hatchling productivity is expected to cause a future decline in nesting turtle numbers on Raine Island because there will be fewer new adult females entering the population. Given an estimated 90 per cent of northern population females nest on Raine Island[317] or nearby Moulter Cay[318], there may be significant implications for the northern population as a whole. Warming temperatures are resulting in the feminisation of green turtles originating from nesting beaches in the northern Region, potentially leading to significant scarcity or absence of adult males in the future.[319]

A young flatback turtle. © Matt Curnock

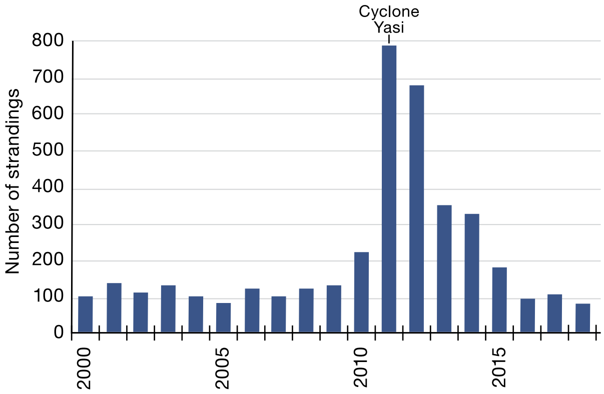


Figure 2.13 Green turtle strandings in the Region, 2000–2018
Green turtle strandings (dead or alive) in the Region from 2000 to 2018. Stranded turtles that were not identified to species level are not included in the graphed data, so the total is potentially higher than shown. Most records are from Cairns to the southern end of the Region. Cyclone Yasi and associated flooding occurred in early 2011 and led to widespread damage of inshore seagrass meadows (foraging habitats).
Source: Department of Environment and Science (Qld) 2018[337]

Loggerhead turtle nesting numbers declined at all eastern Australian nesting sites in the 1970s through to 2001. The positive management response in Australia to past issues (Section 8.3.5) is reflected in the increased numbers nesting at Woongarra coast (Mon Repos Beach) — from 118 nesting females in 1997 to 421 in 2017 (Figure 8.5).[320] However, recruitment of the Region's loggerhead turtles is being affected by overseas fisheries and marine debris, and this will subsequently affect nesting populations (Section 8.3.5).[321]

In 2016, the Torres Strait – northern Great Barrier Reef hawksbill turtle population was reclassified under Queensland legislation from vulnerable to endangered.[322] Hawksbill turtles are known to only nest north of Princess Charlotte Bay. Milman Island in the north of the Region is the only nesting site in Queensland for which there is sufficient information to allow trend analysis. Nesting numbers at Milman Island continue to decline, although more slowly than previously observed.[323]

Flatback turtles occur only on the continental shelf of Australia, Papua New Guinea and Indonesia. Key nesting sites for the Region's flatback turtles include Peak, Avoid, Curtis and Wild Duck islands (off central Queensland).[324] Lower density nesting occurs on beaches within the port limits of Port Alma and Port Curtis and around Mackay.[325] Some of these nesting sites are in the Region, while others are adjacent to it. At Peak Island, the nesting population appears to have stabilised, or is declining at a much slower rate.[326,327] At Curtis Island, the size of the nesting population has halved in the last decade.[326] There are insufficient long-term data to determine a clear trend for nesting at Avoid Island.[326,327]

The olive ridley turtle is not known to nest in the Region but it forages throughout the sub-tidal and non-reef habitats of the Region. Very limited information is available on the species' foraging habits. Leatherback turtles have not been recorded nesting in eastern Australia for 22 years.[328]

Rising air and sand temperature as a result of climate change are the most immediate and broadscale threats to marine turtles because the gender of hatchlings is determined by temperatures experienced within the nest.[329] Elevated air temperature has already strongly skewed the sex ratio in eastern Queensland foraging aggregations of hawksbill turtles towards females.[328] An increase in feminisation has also occurred for flatback turtles at Peak Island.[327,330]

Artificial light from urban and industrial areas can reduce nesting success and the number of hatchlings finding their way to the ocean.[331,332,333] Hotspots for elevated light include the Woongarra coast (outside the Region) (Section 8.3.5), Gladstone and Mackay.[327] Flatback turtle nesting areas on the east coast of Australia are experiencing a faster increase in light pollution than are nesting areas at other Australian locations.[332]

Smaller, oceanic-stage turtles are more likely to be affected by fragmented hard plastics in domestic and international waters than are turtles foraging along the coast.[334,335,336] Vessel strike and ingestion of fishing line and hooks are primarily experienced by green and loggerhead turtles. These impacts appear to be more often caused by recreational than commercial activities, at least in certain locations.[337,338,339] Hawksbill turtles are exposed to mortality from predation (for example by pigs, goannas and humans) and ghost net entanglement.[308]

Strandings of marine turtles can be related to food supply or occur due to marine debris ingestion and entanglement, vessel strike, interactions with fishing gear and disease.[334,337,338,340] In the last few years, green turtle strandings have returned to levels similar to those observed before the significant 2010–11 disturbances (cyclone Yasi and subsequent flooding) to seagrass beds (Figure 2.13, Section 2.3.4).

Overall, there has been recovery of the southern green turtle populations. However, there are growing concerns for the future of loggerhead, hawksbill and the northern green turtle populations due to a number of external pressures, including climate change and overseas fishing morality (in Chile and Peru). The recovery of flatback turtle population has no consistent trend.

2.4.11 Estuarine crocodiles

The estuarine crocodile (*Crocodylus porosus*) is the largest living reptile.[341] Crocodiles occur in most coastal waters of the Region, commonly in tidal reaches of rivers and along beaches and islands.[342,343,344] Adult crocodiles are important apex predators in the ecosystem[345], and their eggs and hatchlings are economically and socially important.[345]

North Kennedy, Normanby and Proserpine rivers support the highest estuarine crocodile population densities adjacent to the Region

Current condition and trend of crocodile populations remains an information gap. A three-year state-wide monitoring program to survey crocodile density along 28 waterways from Cape York to Gladstone began in 2017. Preliminary results of vessel-based spotlight surveys indicate an overall low density of crocodiles, averaging just one per linear kilometre, compared to five to 10 per linear kilometre in the Northern Territory.[343] The North Kennedy, Normanby and Proserpine rivers support the highest densities of crocodiles from Bundaberg to Cape York, ranging from an average of 2.3 to 5.1 crocodiles sighted per kilometre. No crocodiles were observed in the rivers south of the Fitzroy River.[343]

Illegal poaching, habitat loss and climate change are the main threats to crocodiles.[330,346,347] Coastal development encroaching on swamplands, mangroves and riverbanks threatens crocodile populations south of Cooktown. However, climate change will probably affect all populations. Because crocodiles are cold-blooded animals, their physiology is affected by air and water temperatures. Warmer temperatures increase metabolism and, therefore, decrease energy conservation.[348,349,350] Elevated water temperatures decrease diving times in juvenile crocodiles[351], and temperatures above 33 degrees Celsius decrease sustained swimming speed[352].

Crocodiles are important apex predators.
© GBRMPA

Because the sex ratio of hatchlings is temperature dependent and temperature plays an important role in embryo development and incubation time, climate change will influence population dynamics by exposing nesting sites to increased air temperatures.[353,354] More frequent encounters between humans and crocodiles has necessitated an increased focus on the removal of high-risk animals by authorities.[343] Climate change may contribute to a future increase in human-crocodile interactions, as crocodiles grow faster and to larger sizes in warmer temperatures.[354,355]

With no recently recorded impacts to crocodile populations, they have probably stabilised since the 2014 assessment.

2.4.12 Seabirds

The Region supports breeding populations of 20 seabird species.[356] Seabirds have profound influences on island ecosystems by bringing nutrients from sea to land, including guano and by-products of breeding (such as unconsumed regurgitate, dead chicks and eggs).[357] These nutrients may be vital to the fertility and biodiversity of some of the Region's islands and surrounding reefs.[30,358]

Breeding populations of six seabird species in the Region have declined, while one species has increased

Average Reef-wide trends indicate slight declines from 1980 to 2017 for breeding populations of six species: crested tern, brown booby, masked booby, common noddy, sooty tern and roseate tern.[359] However, trends were inconsistent across islands and cays within the Reef. The population of breeding red-tailed tropicbirds on Raine Island has increased, on average, by approximately 1.4 per cent per year since 1980.[359] Monitoring of trend and condition of the other 13 seabirds found in the Region remains a significant knowledge gap. The condition of seabirds in general remains poor and no consistent overall trend can be identified.

Raine Island is the only known breeding site in Australia for the critically endangered herald petrel (*Pterodroma heraldica*), which is rarely seen in the Region. In 2017, 26 birds were seen at Raine Island and one pair was observed breeding (the first confirmed breeding sighting since 1987).[360]

Changes in sea surface temperature affect food supplies for seabirds and can have implications at a population level.[361] Other threats to seabirds include, but are not limited to, commercial and recreational fishing impacts on prey species, direct disturbance by recreation and tourism visitors to islands, the introduction of exotic plants and animals[362,363], and ingestion (especially in inshore areas) and use in nesting of marine debris.[364,365,366]

Limited information exists on the populations of seabird species in the Region. Where information is available, the condition of most species is deteriorating.

Fluffy herald petrel chick on Raine Island. © Queensland Parks and Wildlife Service, photographer: G. Burrows

2.4.13 Shorebirds

Approximately 41 (80 per cent) of Australia's shorebird species are known to inhabit the Region and adjacent coastline.[367] Two of Queensland's five Ramsar sites (wetlands of international importance) are adjacent to the Region: Bowling Green Bay[368] and Shoalwater and Corio Bays[369]. These sites support internationally significant numbers of migratory shorebirds, including endangered curlew sandpiper, eastern curlew and Australian pied oystercatcher.

Long-term shorebird population trends have not been analysed specifically for the coastline adjacent to the Region. However, national level analysis provides an insight to the regional trends of many migratory and non-migratory species.[370,371] At a national level, 12 of 19 migratory shorebird species, all of which occur in the Region, declined significantly from 1973 to 2014[370], despite high levels of habitat protection in Australia.[372] Climate change and loss of intertidal habitats through pollution and degradation (for example, Yellow Sea tidal mudflats of East Asia) are primarily driving the decline.[370,371,373,374] Of the Region's seven non-migratory species whose populations were assessed at a national level, red-capped plovers, Australian pied oystercatchers and sooty oystercatchers were found to be stable or increasing from 1973 to 2014, whereas the other four species were declining.[370] Within the Region, the Mackay area appeared to be losing large numbers of multiple shorebird species. In contrast, Bushland Beach, Lucinda and Cape Bowling Green had the highest retention of shorebird species from 1973 to 2014.[370]

Shorebird populations face a number of threats, including habitat loss and degradation from coastal development, human disturbance, predation and disturbance by domestic and feral animals, commercial and recreational fishing impacts on prey species, and the introduction of exotic plants to important nesting locations.[367] These threats are generally heightened during and after migration or when non-migratory shorebirds are breeding and caring for their eggs and young. The major migration route, known as the East Asian – Australasian Flyway, is among the most highly threatened flyways in the world due to widespread declines in, and degradation of, habitat.[371,373,375] Climate change represents a significant threat to shorebirds, with increasing temperatures already causing earlier migration times[376], changes to egg-laying times, timing mismatches with food resources[377,378] and loss of habitat[379]. Coastal development and human disturbance within Australia can reduce local shorebird abundance[380], which could have important cumulative effects at the species level. These potential impacts highlight the importance of protecting habitat in the Region and Catchment.

The condition of shorebirds in the Region is difficult to determine due to limited Region-specific information, although significant declines across Australia have occurred.

2.4.14 Whales

Whales and dolphins belong to the group of marine mammals called cetaceans. They vary greatly in size, feeding habit and behaviour. There are two major groups (suborders) of cetaceans, the Mysticeti (baleen whales) and the Odontoceti (toothed whales and dolphins). Approximately 15 species of whales are known to occur within the Region. Humpback and dwarf minke whales (both baleen whales) are the most commonly encountered species. The first recorded sighting of a rare Omura's whale in the Reef was filmed in 2016.

Migratory baleen whales, such as the humpback whale, can move nutrients thousands of kilometres from productive feeding areas in the Southern Ocean to calving areas in the Region.[381,382] Little is known of the current condition and trend of the toothed whale species that visit the Region. Most are believed to be oceanic species that spend only short periods of time there. Whales are economically important to the Region, as reliable and extremely popular tourist attractions.[383,384]

The condition of most whale populations is unknown, however, humpback whales continue to recover strongly

All species of whales within the Region are protected by legislation. Since being protected from hunting in Australian waters in 1980, the eastern Australian humpback whale population has exhibited a strong recovery, with an annual growth rate of around 10–11 per cent.[385,386] The last survey, in 2015, recorded more than 24,000 whales; an estimated recovery of 58–98 per cent of the original population.[385] This rate of recovery suggested that the humpback whale population was likely to be more than 30,000 in 2018. As the population approaches its carrying capacity, estimated to be up to 40,000 whales, climate change, food availability and disease may become important limiting factors for the population.[387] Dwarf minke whales also migrate from the Southern Ocean to the north of the Region each winter, potentially for breeding.[388] While tourism interactions record the number of small dwarf minke whale aggregations, it is unknown how representative these numbers are of the overall population size.[383]

Although threats to individual whales while transiting through the Region include entanglements in nets, underwater noise and vessel strikes, the greatest threat to the population persistence of baleen whales is climate change and the related effect on their food sources outside the Region.[385,389,390,391] The increasing abundance of humpback whales and ships in the Region is likely to increase ship and vessel strikes (Section 5.8.3).[392]

Populations of whale species within the Region are believed to be currently stable, apart from humpback whales that are probably still increasing.

2.4.15 Dolphins

An estimated 18 species of dolphin occur in the Region. Dolphins are important top-level predators that feed on a variety of fish, crustaceans, shellfish and squid.[393] Dolphins can concentrate contaminants in their tissues; high levels of contaminants can be an indication of ecosystem stress.[394,395,396] Economically, dolphins are important to tourism and recreational users as iconic marine megafauna.

Four dolphin species reside in the Region year round. The spinner dolphin (*Stenella longirostris*) is found from the coast to the eastern boundary of the Region. The other three species — the Australian snubfin dolphin (*Orcaella heinsohni*), Australian humpback dolphin (*Sousa sahulensis*, formerly the Indo-Pacific humpback),[397] and the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) — inhabit inshore waters. Another 14 species are occasionally found on the outer waters of the Reef, but limited information exists for these species.

Two inshore dolphin species, snubfin and humpback dolphins, are particularly at risk

All dolphin species within the Region are protected by legislation. In 2015, Australian humpback and snubfin dolphins were listed as high-priority species for conservation under the Reef 2050 Plan.[9] No Region-wide abundance assessments exist for these two species. However, recent estimates indicate there are several, fragmented populations of each species (ranging from 70 to 150 individuals) along the Queensland coast, similar in size to populations found in other Australian states.[393,398,399,400] Population modelling shows that losing more than one dolphin per year from any of these isolated populations, as a result of human causes, is not sustainable.[399,401] Three snubfin dolphins and five Australian humpback dolphins were reported to have died between 2014 and 2017,[337] so it is possible that at least some of the isolated populations in the Region are in decline. However, it is unclear how accurately these observations reflect total mortality within the current population.

A small pod of snubfin dolphins socialising near Repulse Bay, south of Airlie Beach, as captured by a drone. © GBRMPA

Several anthropogenic processes cumulatively threaten dolphin populations, including vessel strikes, coastal development resulting in habitat degradation and modification, incidental capture in commercial set mesh nets, shark control nets set for safety (noting that, as of 2019, there are only two left within the Region and none within the Marine Park), water pollution and climate extremes.[401,402,403,404] The effects of thermal stress in 2016 and 2017 on the Region's dolphin populations are unknown. However, an unprecedented marine heatwave in Western Australia had long-lasting negative impacts on both survival and birth rates of a resident population of Indo-Pacific bottlenose dolphins; this was associated with loss of seagrass habitat and mass mortality of invertebrate and fish communities.[405] All three inshore species are vulnerable to human activities, such as habitat loss, vessel strikes, and incidental capture and drowning in mesh nets.[394,406] Offshore dolphin species are less likely to be exposed to nearshore threats, but remain vulnerable to anthropogenic climate change. Overall, due to multiple and cumulative threats, populations of dolphin species within the Region have probably deteriorated since 2014.

2.4.16 Dugongs

The dugong (*Dugong dugon*) is the only remaining species of the family Dugongidae. The Region is home to a globally significant population of dugongs recognised as contributing to the Reef's outstanding universal value.[28,407]

Dugongs are the only herbivorous mammals that are strictly marine, and they play a fundamentally important ecological role in the functioning of coastal marine habitats, particularly seagrass systems.[408,409,410] As large herbivores, dugongs consume a considerable amount of seagrass (approximately seven per cent of their body weight per day).[62] This consumption strongly influences the productivity of seagrass ecosystems, which in turn provides other ecosystem services, such as carbon sequestration and storage.[410] Individual dugongs can move several hundred kilometres in a few days, potentially supporting large-scale seagrass dispersal and thereby contributing to connectivity between seagrass meadows and aiding seagrass resilience and recovery.[65] Dugongs are also important cultural keystone species for local communities in the tropics.[411,412]

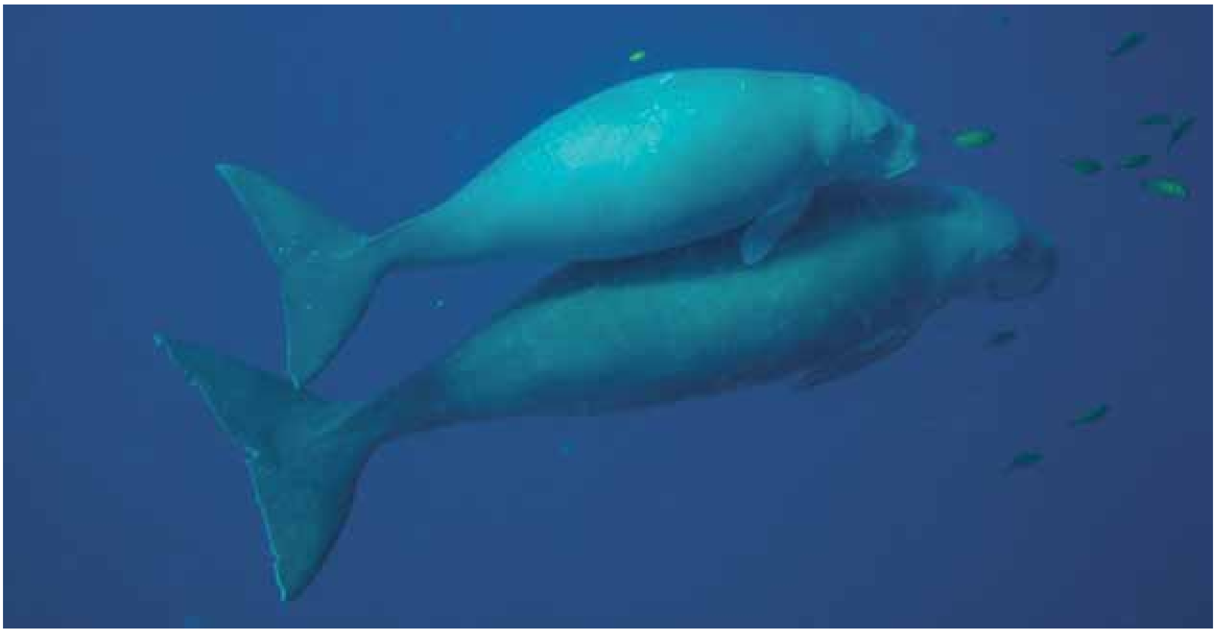
Dugongs occur along the length of the Region, and their abundance and distribution is monitored periodically. The nature and scale of human impacts on dugong populations and their habitats vary geographically. Two distinct areas are recognised: the remote coast (from Cooktown to the northern boundary of the Marine Park) and the urban coast (from Cooktown south to the southern boundary of the Marine Park). A series of aerial surveys conducted about every five years since the 1980s indicates the dugong population along the urban coast was significantly higher in 2016 than in 2011.[413] This difference is attributed to dugongs migrating into the area as the condition of seagrass communities recovered following flood and cyclone impacts in 2011.[59] The percentage of calves observed also increased from zero in 2011 to more than 10 per cent of the population in 2016.[413] Unsuitable weather caused cancellation of remote coast surveys planned for late 2018, and these will now occur in 2019.

Statistical analyses of the aerial survey data[414] suggest an overall decline in dugongs across the entire Region of 2.3 per cent per annum between 2005 and 2016. The probability that dugong abundance declined in the remote coast area between 2005 and 2013 is 0.79 (out of a possible 1.00), with an estimated decline of 3.1 per cent per year. For the urban coast area, the probability that the population declined over the same period is 0.69, with an estimated decline of 1.5 per cent per year.

In the southern Great Barrier Reef, more dugong calves were observed in 2016 than in 2011

Key impacts on dugongs include incidental drowning in commercial fishing nets, vessel strikes, habitat degradation and poaching.[415] Loss or degradation of seagrass habitats, due to prolonged periods of rain, floods or cyclones, can severely and acutely deplete the populations, because the reduced food availability delays reproduction and ultimately causes starvation.[62,416] Climate change is a threat to dugong populations, since it affects coastal environmental conditions and flood events, both of which affect dugongs and the seagrass habitats they rely upon.[62,417]

Although the Region's dugong population exhibits an overall long-term decline, there has been some recent recovery for the urban coast dugong population since 2014.



A dugong mother and calf swim near Low Isles. © Chris Jones

2.5 Assessment summary — Biodiversity

Paragraph 54(3)(b) of the *Great Barrier Reef Marine Park Act 1975* requires *'… an assessment of the current biodiversity …'* within the Great Barrier Reef Region.

This assessment is based on two assessment criteria:

- habitats to support species
- populations of species and groups of species.

2.5.1 Habitats to support species

Grading statements — habitats to support species

Very good	Good	Poor	Very poor	Borderline
All major habitats are essentially structurally and functionally intact and able to support all dependent species.	There is some habitat loss, degradation or alteration in some small areas, leading to minimal degradation but no persistent, substantial effects on populations of dependent species.	Habitat loss, degradation or alteration has occurred in a number of areas leading to persistent, substantial effects on populations of some dependent species.	Widespread habitat loss, degradation or alteration has occurred in a number of areas leading to persistent, substantial effects on many populations of dependent species.	Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.

Trend since last report

↑	Improved
↔	Stable
↓	Deteriorated
–	No consistent trend

Confidence

●	Adequate high-quality evidence and high level of consensus
◐	Limited evidence or limited consensus
○	Inferred, very limited evidence

Grade and trend 2009	Grade and trend 2014	Grade and trend 2019	Confidence Grade	Confidence Trend	Criterion and component summaries
Good	Good ↓	Poor ↓			**Habitats to support species:** The condition of habitats overall is poor at a Region-wide scale, because habitat loss, degradation or alteration has occurred in a number of areas leading to persistent substantial effects on populations of some dependent species. There is a high level of variability in the scale and condition of all habitats assessed, and data for the majority of habitats are limited. For many habitats considered in good condition overall, condition is usually lower closer to the coast and in the vicinity of developed areas. The isolation of *Halimeda* banks and continental slope from the mainland, and their depth, contribute to their very good condition. Extreme sea surface temperatures and localised flood plumes have affected many habitats, particularly seagrass meadows and the water column, and caused widespread deterioration in coral reef habitats.
Good	Good ↓	Good ↔	◐	◐	**Islands:** Localised damage to some islands has occurred from severe weather, temperature extremes and pests. Recovery from past impacts is occurring and monitoring of island condition is increasing.
Good	Good ↔	Good ↔	◐	◐	**Mainland beaches and coastlines:** Some beaches and coastlines have been modified as a result of natural processes, coastal development and climate change. However, most remain in a relatively natural state.
Good	Good ↔	Good ↔	◐	◐	**Mangrove forests:** Cyclones have caused localised habitat loss and degradation; recovery is occurring.
Good	Poor ↓	Poor –	●	●	**Seagrass meadows:** Degradation of inshore seagrass meadows has occurred in a number of areas and recovery has been slowed by a number of disturbances. The absence of seed banks and low reproductive effort have resulted in many seagrass meadows being vulnerable.
Good	Poor ↓	Very poor ↓	●	●	**Coral reefs:** Multiple severe disturbances have caused widespread damage and loss of coral reef habitat in a number of areas. Coral recruitment has declined significantly. Evidence of cascading effects on coral dependent species, such as fish and invertebrates is emerging.
Good	Good ↔	Good ↓	◐	○	**Lagoon floor:** Some areas of the lagoon floor have been exposed to prolonged thermal stress, impacts associated with dredging and disposal, bottom trawling, shipping and potentially damaging cyclonic waves.
Good	Good ↔	Good ↓	◐	○	**Shoals:** Underwater mapping has increased understanding of shoal extent but not condition. Since 2014, over 10 per cent of shoals have been exposed to potentially damaging cyclonic waves and many have been exposed to prolonged thermal stress.

Grade and trend			Confidence		Criterion and component summaries
2009	2014	2019	Grade	Trend	
Very good	Very good ↔	Very good –	○	○	***Halimeda* banks:** Improved spatial analysis has increased understanding of the spatial coverage of *Halimeda* banks. Understanding its ecological role and condition remains limited. Exposure to potentially damaging cyclonic waves and thermal stress has occurred since 2014, but impacts are inferred to be limited given their isolation and depth.
Very good	Good ↓	Very good ↔	○	○	**Continental slope:** Much of this habitat remains undisturbed and minimally affected. The upper continental slope around the Swain Reefs is exposed to high levels of trawl effort. Clarification on the extent of this habitat has resulted in a grade of very good.
Good	Good ↓	Good (borderline Poor) ↓	◐	◐	**Water column:** The water column has deteriorated in some inshore areas due to the impacts of land-based run-off. Alteration of the water column may have occurred in a number of areas following record-breaking temperature extremes potentially leading to substantial effects on some species. The condition of water column habitat is good borderline poor.

2.5.2 Populations of species and groups of species

Grading statements — populations of species and groups of species

Very good
Only a few, if any, species populations have deteriorated as a result of human activities or declining environmental conditions.

Good
Populations of some species (but no species groups) have deteriorated significantly as a result of human activities or declining environmental conditions.

Poor
Populations of many species or some species groups have deteriorated significantly as a result of human activities or declining environmental conditions.

Very poor
Populations of a large number of species have deteriorated significantly.

Borderline
Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.

Trend since last report

- ↑ Improved
- ↔ Stable
- ↓ Deteriorated
- – No consistent trend

Confidence

- ● Adequate high-quality evidence and high level of consensus
- ◐ Limited evidence or limited consensus
- ○ Inferred, very limited evidence

Grade and trend			Confidence		Criterion and component summaries
2009	2014	2019	Grade	Trend	
Good	Good ↓	Poor ↓			**Populations of species and groups of species:** The majority of species or groups of species have declined, mainly due to human activities and climate change impacts. Findings reflect both ongoing effects of past significant population declines (for example, from historic commercial harvesting) and impacts on the habitats they depend on. Deterioration (to varying extents) has now occurred throughout the Region, not just the southern two thirds, and is particularly evident in coral species. Some species (such as humpback whales and some turtle populations) show continuing recovery from historical declines.
Very good	Very good ↔	Very good ↔	◐	◐	**Mangroves:** The diversity and abundance of mangrove species are being maintained, with several new species being recorded in the Region.
Good	Poor ↓	Poor ↔	◐	◐	**Seagrasses:** Inshore seagrass community composition continues to change in many inshore meadows as the habitat recovers from past disturbances.
		Good	◐		**Benthic algae:** Overall benthic algal diversity appears to be maintained and abundance has increased in some areas, resulting in good condition across the Region. However, some species of coralline algae were affected by thermal stress in 2016 and 2017 and are showing signs of stress from ocean acidification. Turf algal condition is also deteriorating in some inshore locations due to sedimentation. A trend cannot be provided due to macroalgae and benthic microalgae being combined in 2019.
Good	Good ↔				**Macroalgae:** Combined into benthic algae assessment.
Very good	Very good ↓				**Benthic microalgae:** Combined into benthic algae assessment.
Good	Poor ↓	Very poor ↓	●	●	**Corals:** Unprecedented mass coral bleaching due to global warming, outbreaks of crown-of-thorns starfish and cyclone impacts have reduced coral diversity and abundance, with widespread loss of key habitat-forming coral species at many locations.

Grade and trend			Confidence		Criterion and component summaries
2009	2014	2019	Grade	Trend	
	↓	↓	○	○	**Other invertebrates:** Prolonged thermal stress, substantial loss of coral habitat, poor water quality and fishing have probably adversely affected many invertebrate species across a range of habitats. Populations of bioeroding species may have increased with more dead coral substrata available in affected areas.
	↓	↓	○	○	**Plankton and microbes:** There is little information on plankton and microbe populations in the Region. Changes in water temperature and water quality are likely to be negatively impacting plankton and microbial communities.
	↓	↓	◐	◐	**Bony fishes:** Little is known about the condition of most bony fish species on a Region-wide scale given it is a highly diverse group. Some coral-dependent fishes have decreased in areas affected by mass bleaching events. Some herbivore populations have remained stable or increased in some areas. Current extraction rates for some fished bony fish species are considered sustainable, however, there are concerns for other species. There is likely to be a lag in detecting effects on bony fishes following multiple impacts on their habitat.
	↓	–	◐	◐	**Sharks and rays:** Quantitative information does not exist for most species of sharks and rays in the Region; some species have declined, others recovered and trends for most species are unknown. Fishing (and incidental catch) and climate change are the primary threats to sharks and rays, with at least 17 species considered highly vulnerable to exploitation and 30 species at risk from climate change.
	↔	↔	○	○	**Sea snakes:** The trawl fishery continues to kill sea snakes through bycatch. Management changes in the trawl industry have reduced capture. Localised depletions have been reported. Condition information is a knowledge gap because no ongoing monitoring occurs.
	–	–	●	◐	**Marine turtles:** Heightened concerns exist for the future of loggerhead, hawksbill and northern green turtle populations. The southern green turtle population continues to recover. The trend for flatback turtles is not clear.
	↑	↔	◐	◐	**Estuarine crocodiles:** Estuarine crocodile population density across the Region is estimated to be low. Climate change may be altering the sex ratios of hatchlings and increasing the maximum size of adults.
	–	–	◐	◐	**Seabirds:** Limited information is available on the condition and trend of seabirds. Reef-wide trends indicate slight declines in six seabird populations between 1980 and 2017. The population of one species is increasing.
		–	○	○	**Shorebirds:** Population estimates for the Region's shorebirds are not differentiated from the national level analyses, making condition assessments difficult for the Region. Large numbers of multiple shorebird species have declined in the Mackay area, whereas other areas have retained populations of shorebird species.
	↑	↔	◐	◐	**Whales:** Populations of whale species within the Region are believed to be currently stable. Humpback whales have recovered strongly. Climate change is the greatest threat to baleen whale populations and the related effect on their food sources outside the Region.
	↓	↓	○	○	**Dolphins:** Data on the Region's dolphins are very limited. Offshore dolphin species are considered more stable as they are less likely to be exposed to human-related threats than inshore dolphin species. Concerns continue for the condition of Australian humpback and snubfin dolphins (both inshore species), which may be in decline due to human-related mortality.
	↓	↑	●	●	**Dugongs:** The Region is home to globally significant populations of dugongs. Over the entire Region there is a high probability that the dugong population declined between 2005 and 2016. Along the urban coast, from Hinchinbrook south, the breeding rate has improved since the impacts of cyclone Yasi and widespread flooding in 2011.

2.6 Overall summary of biodiversity

The Region is one of the world's most diverse and remarkable ecosystems and contains the largest coral reef system in the world. This biodiversity is a critical component of the Reef's outstanding universal value and natural heritage value. Biodiversity was assessed in terms of habitats and populations of species.

The Region is one of the world's most diverse and remarkable ecosystems and contains the largest coral reef system in the world

Across the entire Region, the condition of habitats (as a group) was rated poor, compared with a rating of good in 2014. This deterioration reflects that habitat loss and degradation or alteration in a number of areas have had persistent and substantial effects on populations of some dependent species. The significant and large-scale impacts on coral reef habitats and coral species from extreme sea surface temperatures due to global warming has resulted in these components transitioning from poor to very poor condition for the first time in the history of Outlook reporting. Exposure to high sea surface temperatures and severe cyclones are also likely to have influenced the condition of other habitats, such as the lagoon floor, shoals and the water column, which are rated good but deteriorating.

Coastal habitats, including mangroves, islands and mainland beaches and coastlines, remain in good condition across the Region. However, confidence in these grades is limited given a lack of broadscale quantitative data and ongoing monitoring. Many habitats have declining trends, and the two key habitats where confidence in grades is adequate (seagrass meadows and coral reefs) are rated as being in poor and very poor condition, respectively.

Significant and large-scale impacts on coral reefs from extreme ocean temperatures has resulted in this habitat transitioning from poor to very poor condition

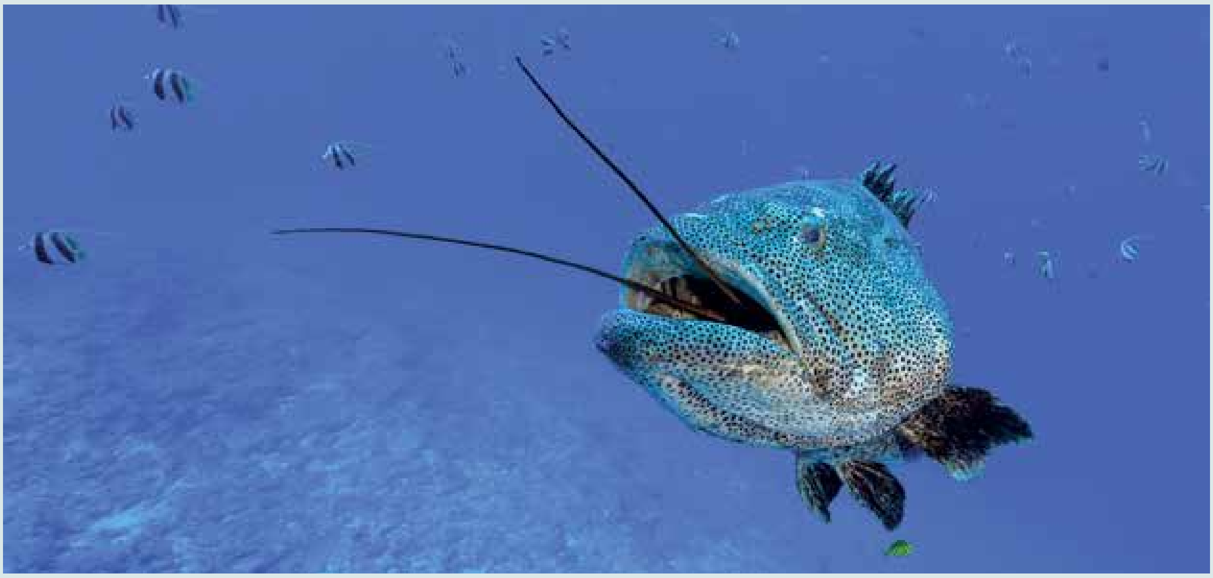
The condition of the Region's species is also of concern, with the overall assessment of species' populations deteriorating from good in 2014 to poor. Condition declined in most of the assessed species components, and over half are graded as being in poor or very poor condition. Species assessments reflect both long-lasting effects of significant past population declines (for example, from historical commercial harvesting) and effects of deterioration of the habitats they depend on. There are a few instances where species have improved in condition. Humpback whales and the southern population of green turtles continue to recover, and the breeding rate of urban coast dugongs has improved since the impacts of the cyclone and flooding in 2011.

Humpback whales and the southern green turtle population continue to recover

For both habitats and species, grades provided are for the entire Region. The size of the Region is extensive and variability in condition exists. For example, reefs that escaped impacts of bleaching, cyclones and crown-of-thorns outbreaks remain in good condition.

Key knowledge gaps remain for many species and habitats that are not comprehensively monitored. The lack of information on most groups of species is concerning, because declines may not be evident until critical thresholds are exceeded. Condition is inferred for some of the deeper and less accessible habitats, such as *Halimeda* banks, the continental slope and lagoon floor, because these habitats are not frequently monitored and large knowledge gaps remain.

The Region has experienced an unprecedented level of widespread cumulative stress since 2014. Further deterioration in the condition of habitats and species is likely in future if threats persist and recovery windows are no longer adequate.



Groper swallowing a crayfish. © Tane Sinclair-Taylor