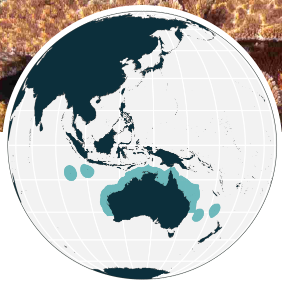

John Brewer Reef, Great Barrier Reef
Credit: Victor Huertas



AUSTRALIA

Authors

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Traditional Owner acknowledgement

The authors recognise Aboriginal and Torres Strait Islanders as the Traditional Owners of the land and sea Country on which we work. We recognise their enduring cultural connections to land, water, and community, and their leadership, knowledge, and ongoing stewardship of the reef systems described in this report.

We pay our respects to their Elders, past and present, and extend that respect to all First Nations peoples.

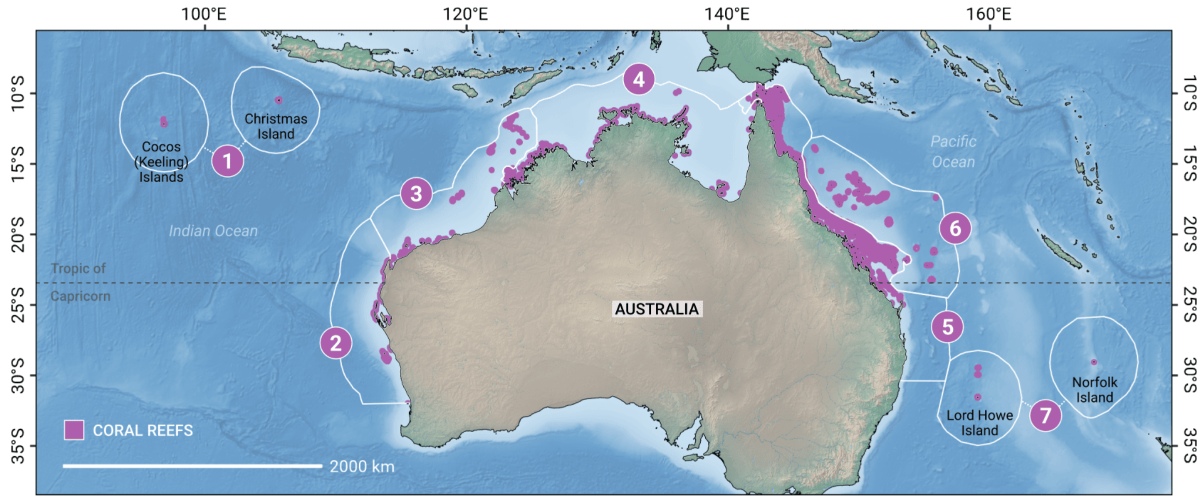
The data analysed in this study were collected from coral reef systems across many places that are part of the lands and Sea Country of Aboriginal and Torres Strait Islander peoples. The authors sought to acknowledge the Traditional Owners associated with these monitoring locations. However, it was not possible within the scope of this report to verify a complete and accurate list. To avoid the risk of omission, misidentification or misattribution, we have used a broader acknowledgement here. We recognise this as a limitation of the current chapter and an important area for improvement in future GCRMN Australia reporting.

INTRODUCTION

Australia hosts one of the world's most extensive and diverse coral reef assemblages. These coral reefs span more than 20° of latitude along the east and west coasts, from the tropical reefs of the Torres Strait and north-west shelf, such as the Rowley Shoals, to temperate reefs at Lord Howe, Norfolk, and the Houtman Abrolhos Islands [103]. This broad geographic range supports a continuum of reef assemblages, from species-rich tropical coral communities to low-diversity, high-latitude systems shaped by strong seasonal variability. Reef geomorphology is equally diverse, including oceanic atolls in the Indian Ocean, seamounts in the Coral Sea rising from abyssal depths, the extensive continental shelf barrier reef system of the Great Barrier Reef, and turbid-water fringing reefs along continental margins. Three of Australia's reef systems have been recognised as World Heritage Areas: Ningaloo Reef, the world's largest fringing reef; Lord Howe Island, which supports one of the southernmost coral reefs; and the Great Barrier Reef, the largest coral reef system on Earth. Together, Australia's reefs form interconnected ecological networks that support biodiversity, fisheries, coastal protection, and cultural values.

Recent national reef-mapping initiatives identified more than 21,000 reef structures within Australia's exclusive economic zone [104], highlighting the scale and complexity of the systems encompassed by the Australia GCRMN region. The region extends over a maritime area of approximately 5 million km^2, ranging across 20° of latitude and 70° of longitude (Figure 2.1.1) and includes at least 43,000 km^2 of coral reef, representing approximately 17% of the world's coral reef extent. This makes Australia the third-largest GCRMN region by reef extent, and the country with the largest national extent of coral reef globally [2]. Capturing long-term trends in reef condition across such varied and often remote systems is logistically and methodologically demanding. As a result, the regional and subregional summaries presented here do not include all reefs and sampling years, and may smooth or obscure important local-scale dynamics, including pulse disturbances and subsequent recoveries.

The GCRMN Australia region is divided into seven subregions (Figure 2.1.1), which vary markedly in coral reef extent (Table A.1) and mapping accuracy (see Box 3). As a result, their contributions to regional trends in hard coral and macroalgal cover are not equal. Subregion 5, which includes the Great Barrier Reef, Torres Strait and South East Queensland, contains 81.6% (34,503 km^2)



▲ **Figure 2.1.1.** The distribution of coral reefs within the Australia region and respective subregions. White polygons and numbers represent subregions. Subregion 1 = Cocos Keeling and Christmas Island, Subregion 2 = Central West Australian Shelf, Subregion 3 = Northwest Australian Shelf, Subregion 4 = Northern Australia, Subregion 5 = Eastern Australian shelf / Great Barrier Reef, Subregion 6 = Coral Sea, Subregion 7 = Lord Howe and Norfolk Islands. Coral reefs are delineated with a 20 km buffer to enhance interpretation, and only coral reefs within the region are represented. The scale bar provides distance at the equator and may not accurately represent distance over the entire latitudinal range of the region.

of Australia's mapped reefs and strongly influences regional model outputs. In contrast, subregion 7, which includes Lord Howe Island, Norfolk Island, and Elizabeth and Middleton Reefs, comprises just 0.3% (126 km^2) and has minimal influence on regional trends (Table A.1).

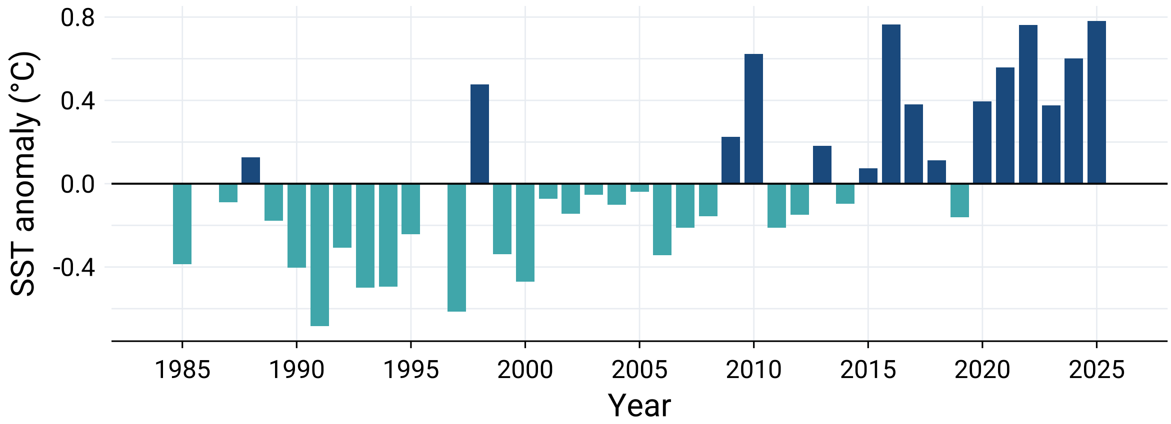
In Australia, over a million people live within the Great Barrier Reef catchment and an estimated two million benefit from Australian reefs through tourism, recreational and commercial fisheries, and reef science and management [16, 105]. Overall, 37% of Australia's population is located within 100 km of a coral reef, the highest proportion of all GCRMN regions [2], which may help explain why coral reefs are a defining element of Australia's national identity [106]. Equally important is their deep and enduring cultural significance for Australia's First Nations peoples, whose custodianship and knowledge of coral reefs extend back millennia. These long-standing relationships with Sea Country represent the oldest continuous reef monitoring system on Earth, with knowledge about reefs and their changes embedded in stories, practices, and cultural governance that continue to inform contemporary reef stewardship [24].

THREATS AND DISTURBANCES

Heat stress

On average, Australian reefs experience slightly cooler temperatures than most GCRMN regions because they span a broad latitudinal gradient, with a long-term mean satellite-derived sea surface temperature (SST) of 26.4 °C across reefs over the past 40 years. Between 1985 and 2025, average regional SST increased by 0.78 °C (0.19 °C per decade; Table A.3).

Over the 40-year record, the severity, spatial extent, and duration of annual heat stress events increased (Figure 2.1.2). Between 1986 and 2024, up to 80% of coral reefs in Australia accumulated Degree Heating



▲ **Figure 2.1.2.** Annual mean sea surface temperature (SST) anomalies (°C) over the coral reefs of the Australia region from 1985 to 2025. SST anomalies were calculated based on the long-term average over the period 1985–2025. Positive values (red bars) indicate SST warmer than the long-term average, whereas negative values (blue bars) indicate SST cooler than the long-term average. Derived from NOAA Coral Reef Watch data (Skirving *et al.* [107]; see Materials and Methods).

Weeks (DHW) over 4°C-weeks in a single year, with the highest value recorded in 2024 (Figure 2.1.3). The proportion of reefs experiencing severe heat stress ($\geq$ Alert Level 2) has increased since 2016 (Figure 2.1.3).

Periods of elevated heat stress have led to several subregional or widespread mass coral bleaching events across Australian reefs over the reporting period, including in 1998, 2002, 2004 (largely restricted to the Coral Sea Marine Park), 2011–2013 (primarily central Western Australia and the Northern Territory), 2016–2017, 2020–2022 and most recently during 2024–2025; the impacts of the latest event are still being assessed (see Box 2).

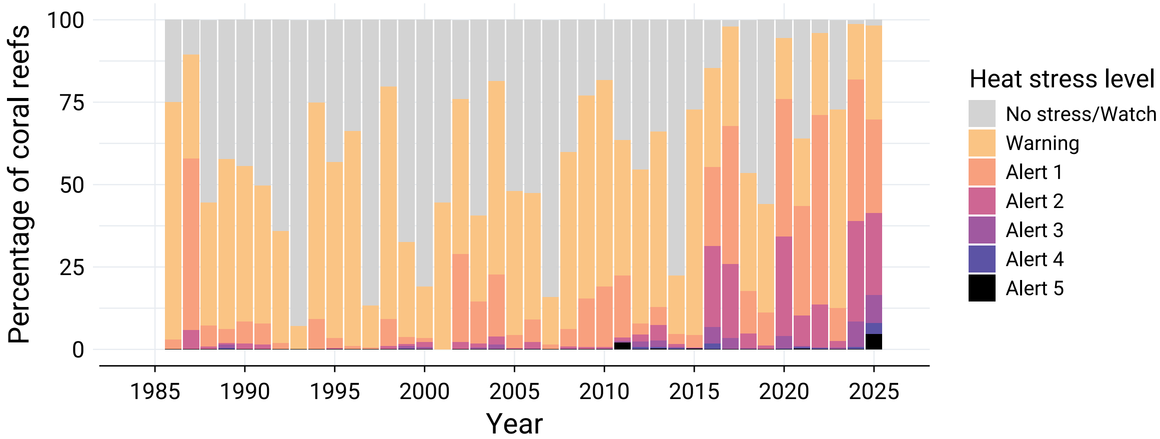
Cyclones

Across Australia, severe tropical cyclones have caused major structural damage to coral reefs, with the most frequent and severe impacts in mid-latitudes ($\cong$12–22°S). From 1980 to 2025, a total of 191 cyclones passed within 100 km of coral reefs within the region (Figure 2.1.4). Swells generated by more distant cyclones, not captured in this metric, as well as seasonal and monsoonal storms, may have also affected coral reefs [108].

The Eastern Australian Shelf has experienced episodic but severe structural damage from cyclones, while the Central West Australian Shelf has experienced more frequent cyclonic events. Major cyclones on the Eastern Australian Shelf (cyclones Larry 2006, Hamish 2009, Yasi 2011) caused extensive coral mortality and declines in hard coral cover [109] (Figure 2.1.5). On the Northwest Australian Shelf several cyclones have caused moderate or severe damage. On the Central West Australian Shelf, cyclones Vance (1999), Seroja (2021) and Isla (2023) caused severe damage to Pilbara and Ningaloo reefs. Cyclone Seroja was notable for its unusually southerly track, damaging reefs at the Houtman Abrolhos Islands (28.5°S), which are rarely exposed to intense cyclones.

Coral predators

Australian reefs have experienced periodic outbreaks (also referred to as “irruptions”) of the coral-eating crown-of-thorns starfish (*Acanthaster* cf. *solaris*, CoTS). Since the 1960s, four major outbreaks (beginning 1962, 1979, 1993 and 2010) have occurred on the Eastern Australian Shelf, with a fifth



▲ **Figure 2.1.3.** Percentage of the coral reefs within the Australia region experiencing heat stress levels per year, from 1986 to 2025. No stress/Watch (DHW = 0); Warning (possible bleaching, $0 < \text{DHW} < 4$); Alert 1 (reef-wide bleaching, $4 \leq \text{DHW} < 8$); Alert 2 (reef-wide bleaching and mortality of heat-sensitive corals, $8 \leq \text{DHW} < 12$); Alert 3 (multi-species mortality, $12 \leq \text{DHW} < 16$); Alert 4 (severe multi-species mortality, $16 \leq \text{DHW} < 20$); and Alert 5 (near-complete mortality, $\text{DHW} \geq 20$). Derived from NOAA Coral Reef Watch data (Skirving *et al.* [107]; see Materials and Methods).

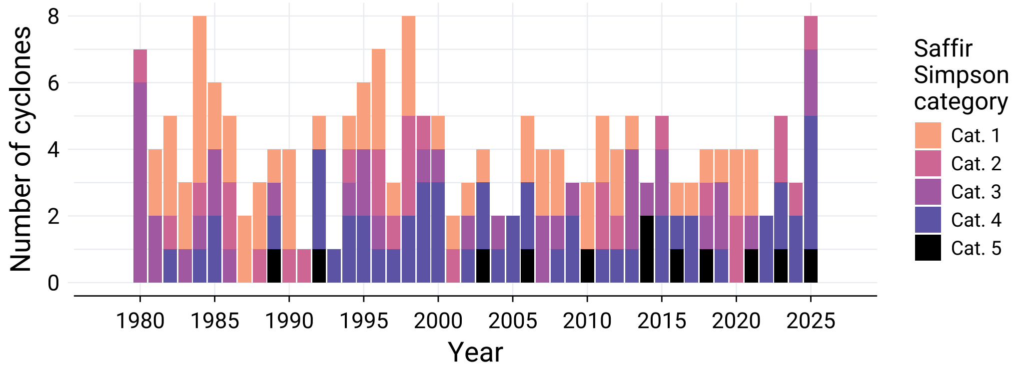
wave now emerging [110]. These outbreaks typically originate in the northern Great Barrier Reef and spread southwards, contributing substantially to regional coral loss [111]. In other subregions, only localised CoTS aggregations have been reported, although outbreak-level densities were recorded locally on Elizabeth and Middleton Reefs in the early 1980s and on the Central West Australian Shelf in 2014 [112]. Outbreaks of the corallivorous gastropod *Drupella* spp. occurred on the Central West Australian Shelf in the late 1980s and early 1990s [113]. Densities remained low thereafter, although observations following the 2025 bleaching suggest localised aggregations on surviving corals.

Water quality

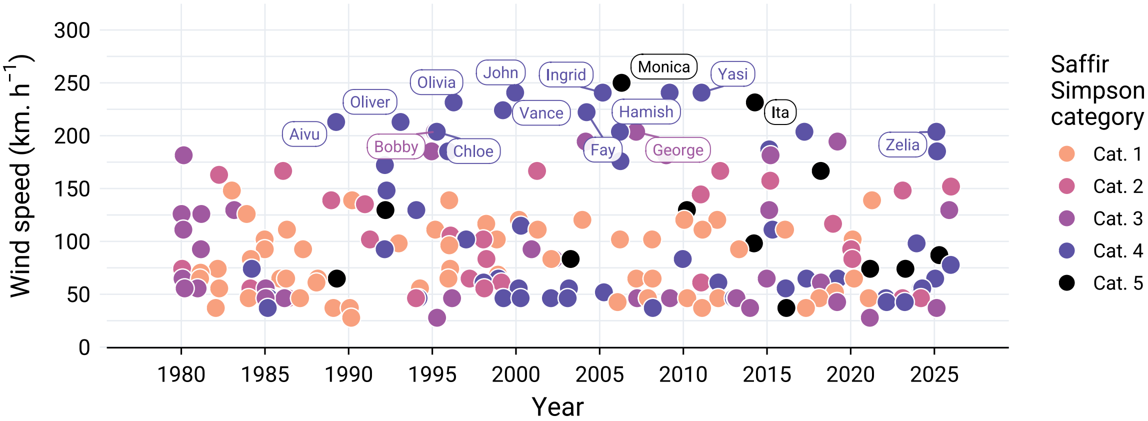
Water quality pressures vary among subregions. On the Eastern Australian Shelf, land-based runoff transports sediments, nutrients and pesticides to inshore reefs, degrading inshore ecosystem condition and limiting recovery after disturbances [114, 115]. Since European settlement, land use change has increased river loads of fine sediments and dissolved inorganic nitrogen by approximately 1.4–5 and 1.5–3 times, respectively [114]. Extreme rainfall and flooding may further intensify these pressures. Some coastal Western Australian reefs are occasionally affected by episodic flood events and localised dredging operations [116].

Other disturbances

Direct pressures to Australian coral reefs from coastal development, dredging, port maintenance and other local impacts (*e.g.* oil contamination, plastics, marine debris, ship groundings and overfishing) remain relatively low by global standards but are increasing in areas [117]. Management actions, including zoning, fishery controls, crown-of-thorns control and water-quality improvement programs can reduce local pressures and support recovery, but their benefits are increasingly constrained by recurrent climate-driven disturbances.



▲ **Figure 2.1.4.** Number of cyclones that passed within 100 km of the coral reefs of the Australia region from 1980 to 2025. Colors correspond to the Saffir–Simpson category of the cyclone along its entire track. Derived from IBTrACS data (Knapp *et al.* [118]; see Materials and Methods).



▲ **Figure 2.1.5.** Maximum sustained wind speed of cyclones that passed within 100 km of a coral reef in the Australia region between 1980 and 2025. Colors correspond to the Saffir–Simpson category of the cyclone along its entire track. However, the values of sustained wind speed are extracted from the nearest cyclone position from a coral reef. For this reason, some sustained wind speed values are below the lower threshold of category 1 Saffir–Simpson scale (*i.e.* 119 $km.h^{-1}$). Derived from IBTrACS data (Knapp *et al.* [118]; see Materials and Methods).

STATUS OF CORAL REEFS IN THE REGION

Across the last four decades hard coral cover in the Australia region has been impacted by numerous disturbances. However, the reefs have generally been resilient, with rapid increases in hard coral cover following disturbance. Macroalgae have rarely proliferated on coral reefs in the region, with hard coral cover largely replaced by turf algal cover. However, as the rates of coral loss and sometimes recovery have increased in more recent years, the volatility of benthic cover dynamics in this region appears to reflect an escalating disturbance regime [119].

Hard coral cover

Median hard coral cover across the Australia region ranged between 20% and 34% over the past four decades, with cycles of disturbance-driven decline and recovery (Figure 2.1.6A). Prior to the early 2000s, variability was largely driven by impacts from cyclones and by CoTS on the Eastern Australian Shelf, whereas mass bleaching has become the dominant cause of coral decline over the past decade [73].

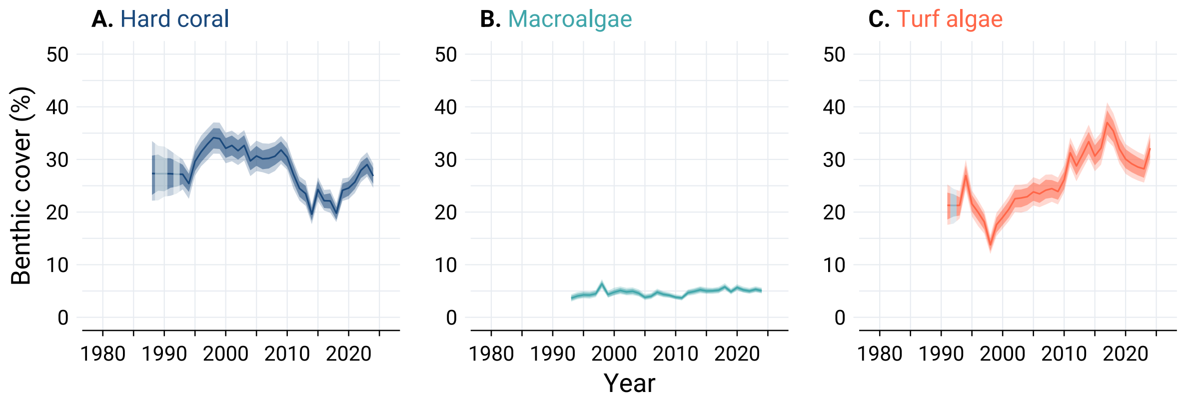
Prior to 1993, estimates of hard coral cover were sparse and unreliable. Regional hard coral cover increased to 34.1% (credible interval at 95% [CrI $_{95\%}$]: 31.1 – 37.0%) in 1998, the highest on record for the region, before declining to 29.7% (CrI $_{95\%}$: 26.8 – 32.5%) in 2004 following coral bleaching in the Eastern Australian Shelf and Northwest Australian Shelf, coupled with local impacts from multiple cyclones. Hard coral cover then remained relatively stable until 2010, after which it declined rapidly to 19.6% (CrI $_{95\%}$: 17.7 – 21.4%) by 2014, primarily due to CoTS and two cyclones on the Eastern Australian Shelf, and mass coral bleaching in the Central West Australian Shelf.

Hard coral cover returned to 24.3% (CrI $_{95\%}$: 22.0 – 26.6%) in 2015, before further mass bleaching events across most subregions and localised cyclone impacts reduced regional cover to 19.8% (CrI $_{95\%}$: 18.1 – 21.7%) in 2018. Cover then increased steadily to 29.0% (CrI $_{95\%}$: 26.7 – 31.4%) by 2023 during a period when disturbances causing extensive coral mortality were limited, although localised bleaching and cyclone impacts occurred in some subregions.

From 2024, severe heat stress and widespread coral bleaching and mortality were recorded in at least five of the seven subregions. The impacts of this most recent global bleaching event are not accounted for in this report, as the analysis includes data only to the end of 2024. However, a decline in hard coral cover was already evident in 2024. Summer temperature anomalies for this event were unprecedented in at least 400 years [120], and the 2024–2025 event is expected to represent the most severe mass bleaching event on record for the Australia region (see Box 2).

Macroalgal cover

Macroalgal cover is generally low across the Australia region (Figure 2.1.6B), with higher levels often limited to coastal reef habitats. For example, on the Great Barrier Reef [83] and in Western Australia, macroalgal cover is typically limited to inshore reefs, where more turbid, nutrient-rich waters favour macroalgal growth compared to other reefs in the region.



▲ **Figure 2.1.6.** Modeled temporal trends of benthic cover in the Australia region from 1980 to 2024 for hard coral (A), macroalgae (B), and turf algae (C). The solid line represents the estimated median benthic cover while darker and lighter ribbons represent 80% and 95% credible intervals, respectively. Grey areas represent periods during which no field data were available.

Between 1988 and 2024, macroalgal cover ranged from 3.6% to 6.3%, and has remained relatively stable since 1998. Despite recurrent disturbances and substantial declines in hard coral cover, consistently low macroalgal cover provides no evidence of widespread coral-macroalgal phase shifts across the Australia region.

Turf algal cover

In the Australia region, turf algal cover has generally varied inversely with hard coral cover, ranging from 13.8% ($CrI_{95\%}$: 12.0 – 15.6%) in 1998 to 37.0% ($CrI_{95\%}$: 33.6 – 40.9%) in 2017, with the most recent value in 2024 being 32.1% ($CrI_{95\%}$: 29.3 – 35.1%) (Figure 2.1.6C). There was a 4.6 percentage point increase in turf algal cover from 2012 to 2014, coinciding with the absolute loss of 4.9 percentage points in hard coral cover. Conversely, turf algal cover declined by 3.3 percentage points between 2018 and 2024, while hard coral cover increased by 7.1 percentage points over the same period.

Since 2011, turf algae have been the dominant benthic group on coral reefs in the Australia region, with median turf algal cover exceeding that of hard corals by 1–16% in all but one year, although the evidence is limited for some years (Figure 2.1.6). By contrast, during the preceding 23 years, turf algal cover exceeded that of hard corals in only a single year. The occupation of space by turf algae following coral loss represents a natural transitional stage on healthy reefs, as short turf algae generally do not inhibit coral recruitment [121]. In many cases, increased turf cover reflects repeated disturbances rather than shifts in selective pressures [122]. However, alterations to key reef processes (*e.g.* herbivory or sediment deposition) can promote the development of longer turfs, which can trap sediment and hinder coral recruitment and recovery (see Case study 1).

STATUS OF CORAL REEFS IN THE SUBREGIONS

Australia 1 - Cocos Keeling and Christmas Island

The remote Cocos (Keeling) atoll and Christmas Island volcanic seamount (>970 km to its northeast) occur in Australia's external territories in the Indian Ocean, ~2100 km from mainland Australia. Reefs in this region are generally characterised by high hard coral cover and have shown an overall upward trajectory since monitoring began in 1997 (Figure 2.1.7A), despite periodic heat-stress events and chronic pollution at some sites on Christmas Island [123]. The only major decline occurred during a marine heatwave at Christmas Island in 2016, when hard coral cover declined from 47.5% ($CrI_{95\%}$: 36.3 – 59.4%) in 2015 to 28.4% ($CrI_{95\%}$: 19.4 – 38.2%) in 2017. Hard coral cover then increased to 55.8% ($CrI_{95\%}$: 43.7 – 65.7%) in 2023, among the highest recorded in the Australia region.

Australia 2 - Central West Australian Shelf

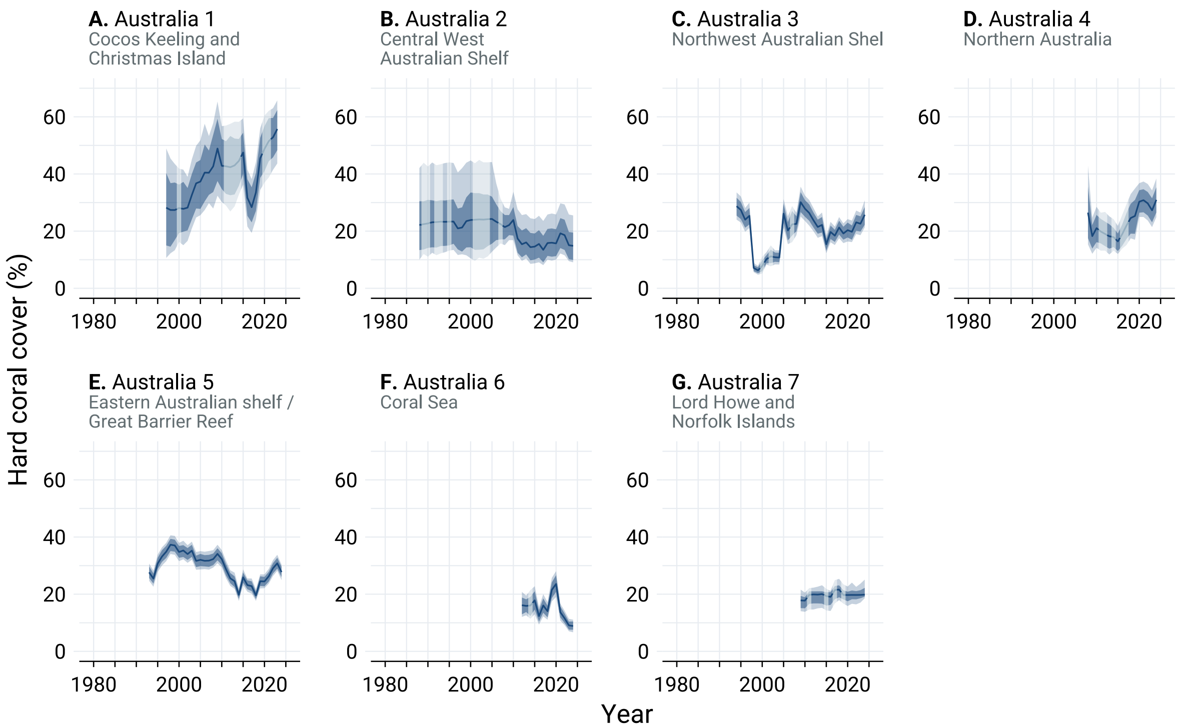
Coral reefs in this subregion span two World Heritage Areas across a tropical-temperate transition zone. Ningaloo Reef is the world's longest fringing reef, while the Houtman Abrolhos Islands have the southernmost coral reefs in the Indian Ocean. Coral monitoring began in 1988 with estimated cover being relatively stable at 21.0–24.5% until 2010. However, considerable variation around the estimated cover reflects non-continuous data collection in the Houtman Abrolhos and Shark Bay ecoregions, particularly prior to 2008. Hard coral cover decreased from 23.9% ($CrI_{95\%}$: 16.8 – 33.8%) in 2010 to 15.4% ($CrI_{95\%}$: 9.6 – 25.6%) in 2012 following a marine heatwave and mass bleaching that affected Ningaloo and Shark Bay [124, 125]. Hard coral cover has since fluctuated between 13.4% and 19.2% (Figure 2.1.7B).

Australia 3 - Northwest Australian Shelf

Coral reefs in this subregion range from inshore turbid reefs to clear-water oceanic atolls near the continental shelf edge. Many reefs were affected by a marine heatwave in 1998, particularly two oceanic atoll systems, causing a subregional decline in hard coral cover from 25.4% ($CrI_{95\%}$: 21.1 – 30.0%) in 1997 to 6.3% ($CrI_{95\%}$: 4.7 – 7.9%) in 1999; the lowest on record [126]. Hard coral cover took more than a decade to recover, reaching a peak of 30.1% ($CrI_{95\%}$: 24.8 – 35.7%) by 2009. Cover then gradually declined to 15.4% ($CrI_{95\%}$: 12.4 – 18.9%) by 2015 following recurrent marine heatwaves and coral bleaching, particularly during 2011–2013 when some inshore reefs were affected. Subregional cover gradually increased to 25.7% ($CrI_{95\%}$: 20.8 – 30.8%) by 2024 (Figure 2.1.7C), as recovery across the subregion outpaced the impacts of local marine heatwaves and cyclones, including multiple bleaching events on the Northwest Australian Shelf from 2016.

Australia 4 - Northern Australia

Coral reefs in this subregion persist in extreme environmental conditions, including high turbidity and tidal ranges of up to 11 m that regularly expose intertidal reefs [127]. Prior to 2020, the percentage cover of hard corals ranged from 16.4% to 26.5%. However, data used in this analysis before 2020 were limited to sparse surveys during a single year across different locations, making early trend estimates less reliable.



▲ **Figure 2.1.7.** Modeled temporal trends of hard coral cover in Australia subregions from 1980 to 2024. The solid line represents the estimated median hard coral cover while darker and lighter ribbons represent 80% and 95% credible intervals, respectively. Grey areas represent periods during which no field data were available.

From 2020 to 2024, repeated monitoring of sites was conducted along the Bonaparte Coast (north Kimberley), and subregional cover remained relatively stable at around 29.8% ($CrI_{95\%}$: 24.0 – 36.7%) (Figure 2.1.7D).

Australia 5 - Eastern Australian Shelf

Hard coral cover across eastern Australia's tropical and subtropical reefs — including the Torres Strait, Great Barrier Reef and South East Queensland — has fluctuated over the past four decades, reflecting an environment increasingly characterised by short recovery windows between acute disturbances and rising pressures associated with coral bleaching [128]. Hard coral cover increased from 1994 to a peak in 1998 (Figure 2.1.7E), before entering a prolonged period of decline caused by cyclones, marine heatwaves, CoTS outbreaks and, in some areas, flood-related water quality impacts. These pressures were particularly pronounced on the Great Barrier Reef during the early to mid-2010s. Although hard coral cover increased from 2018, this recovery was reversed due to marine heatwaves in 2024, the impacts of which are not included here.

Australia 6 - Coral Sea

The Coral Sea subregion comprises 32 widely dispersed reef systems within the Coral Sea Marine Park, an area spanning nearly one million square kilometres and extending over 1,000 km from the Australian mainland. These reefs occur on seamounts rising from deep-water plateaus and, due to their isolation, experience limited direct human pressures such as fishing and terrestrial runoff. They are, however, increasingly exposed to climate-driven disturbances.

Overall, hard coral cover remained relatively stable from 2012 to 2018, ranging from 12–18% ($CrI_{95\%}$: 9.4 – 22.8%) (Figure 2.1.7F), but with reductions in cover due to substantial heat stress and bleaching in the central Coral Sea in 2016 and 2017 [129]. Hard coral cover subsequently recovered, peaking at 23.6% ($CrI_{95\%}$: 19.0 – 28.0%) in 2020, before rapidly declining to 8.9% ($CrI_{95\%}$: 6.7 – 11.1%) in 2024 due to severe heat stress and widespread bleaching across much of the region [130].

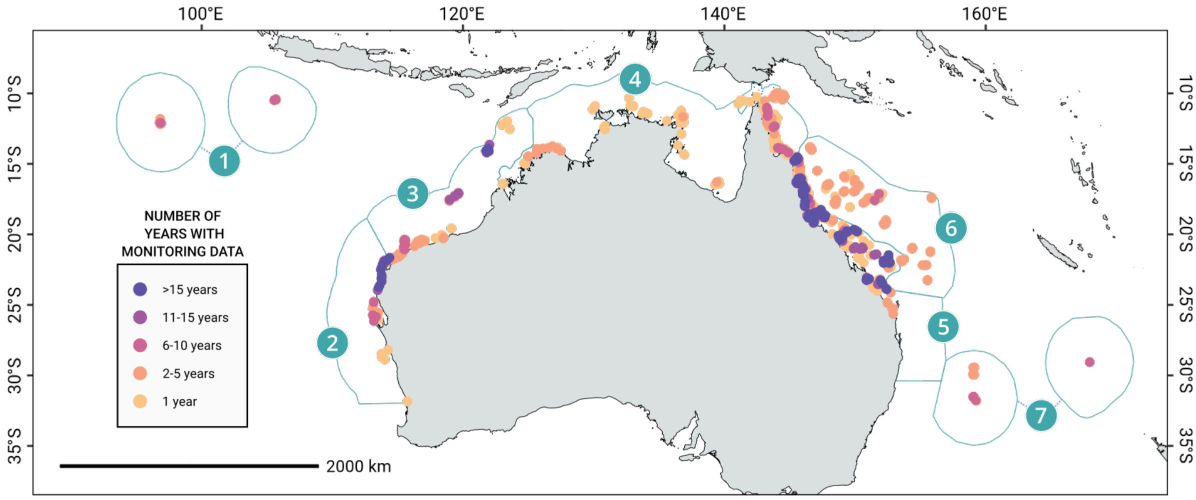
Australia 7 - Lord Howe and Norfolk Islands

The world's southernmost coral reefs, Norfolk and Lord Howe Island coral reef ecosystems occur within Australia's Temperate East Marine Park, where subtropical coral communities develop on shallow and submerged reef systems.

Overall, hard coral cover has remained stable at ~20% since monitoring began in 2009 and was estimated at 18.8% ($CrI_{95\%}$: 11.5 – 29.5%) in 2025 (Figure 2.1.7G). Despite severe bleaching (up to 53%) at some sites at Lord Howe in 2019 and 2024, and bleaching in 2020 and 2024 coupled with pressure from catchment runoff at Norfolk Island, no decline in hard coral cover was detected. This temporal stability is likely due to the proximity of reefs to cooler, deeper water and the cooling effect of cyclones, which reduced heat stress and aided recovery from bleaching.

DESCRIPTION OF MONITORING DATA

Temporal trends in benthic cover for the Australia region were estimated using 14 datasets encompassing 2,645 monitoring sites. These data include 13,211 in-water surveys conducted between 1988 and 2025, with 90% of surveys taking place after 2001 (Figure A.1).



▲ **Figure 2.1.8.** Spatio-temporal distribution of benthic cover monitoring sites across the Australia region and respective subregions. Light blue polygons and numbers represent subregions. Subregion 1 = Cocos Keeling and Christmas Island, Subregion 2 = Central West Australian Shelf, Subregion 3 = Northwest Australian Shelf, Subregion 4 = Northern Australia, Subregion 5 = Eastern Australian shelf / Great Barrier Reef, Subregion 6 = Coral Sea, Subregion 7 = Lord Howe and Norfolk Islands. The scale bar provides distance at the equator and may not accurately represent distance over the entire latitudinal range of the region.

Survey effort was unevenly distributed geographically (Figure 2.1.8). Of all the surveys conducted between 1988 and 2025, 71.4% (representing 58.5% of surveyed sites) occurred in the Eastern Australian Shelf (subregion 5), whereas only 1.2% (2% of sites) were conducted in Northern Australia (subregion 4) (Table A.4). This concentration of long-term monitoring in the Eastern Australian Shelf, particularly on offshore reefs, drives the regional patterns in hard coral cover and biases the contribution of other benthic groups. For example, lower macroalgal cover typical of offshore reefs may be overrepresented relative to inshore and turbid fringing reef habitats that have received less monitoring effort.

Monitoring efforts were also biased through time, with sparse and discontinuous data from the 1980s–2000s limiting our confidence in historical estimates in many reefs and some subregions (Figure 2.1.7). Much of the effort was again concentrated on the Great Barrier Reef, with 220 of the 241 long-term (>15 years) monitoring sites on the Eastern Australian Shelf (Figure 2.1.8).

The uncertainty in historic data highlights the need for sustained investment in long-term monitoring around Australia, which is increasingly critical in our rapidly changing environment. As data from the fourth global bleaching event continue to be analysed, forecasts indicate an extreme El Niño in 2026 that could elevate bleaching risk in 2026–2027. Assessing the impacts on Australian coral reefs, identifying potential refugia and tracking recovery all depend on regular, comparable and rigorous in-water surveys. The monitoring data presented here represent a substantial expansion from the 2020 report, increasing from 372 to 2,645 sites: a seven-fold increase in spatial coverage. As a result, Australia's proportional contribution to the global GCRMN dataset has more than doubled, from 3.1% to 6.7%. Nevertheless, this contribution remains low relative to Australia's share (~17%) of the world's coral reefs.

Data were contributed by a diverse range of organisations, including three citizen science programs, four universities and five government agencies, highlighting the collaborative commitment to reef monitoring across sectors. However, significant geographic gaps persist, particularly in northwest and northern Australia. Monitoring in these regions is logistically challenging due to remoteness, high turbidity and safety constraints associated with in-water surveys. Addressing these gaps will require sustained investment, stronger partnerships with local ranger groups and Traditional Owners, and increased adoption of remote and autonomous monitoring technologies to support surveys in inaccessible areas. Recognising and incorporating Indigenous stewardship is essential to building a more representative, inclusive and regionally balanced understanding of coral reef conditions across the Australia region.

CONCLUSIONS

Australian coral reefs remain in relatively good condition in an international context, with many regions continuing to support high hard coral cover and ecological processes that facilitate recovery following disturbance. However, these ecosystems are facing mounting pressure from climate change, with marine heatwaves and mass coral bleaching events increasing in frequency, scale and severity, alongside ongoing impacts from crown-of-thorns starfish outbreaks, cyclones, flood plumes, disease and other local pressures. Many Australian reefs have demonstrated a capacity to recover when given sufficient time between major disturbances. However, the increasing frequency and overlap of disturbance events are reducing opportunities for recovery, and there is no guarantee that historical patterns of recovery will continue under future climate conditions. Importantly, the findings presented here do not fully capture the ecological consequences of the 2024–2025 global bleaching event, the most widespread and severe bleaching event recorded in Australia.

As climate-driven disturbances intensify, long-term monitoring is becoming increasingly important for detecting change, understanding recovery trajectories, identifying emerging risks and informing management responses. Continued investment in monitoring, including expansion of its spatial and ecological coverage, will be essential to support the stewardship of Australia's diverse reef ecosystems in a rapidly changing climate.

DATA CONTRIBUTORS

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Access to online supplementary materials

The modelled benthic cover data, detailed outputs from the data analyses, and the CRediT author contribution statement are available on Zenodo.

CASE STUDY 1

Algal phase-shifts on coral reefs and the role of turfs

Author

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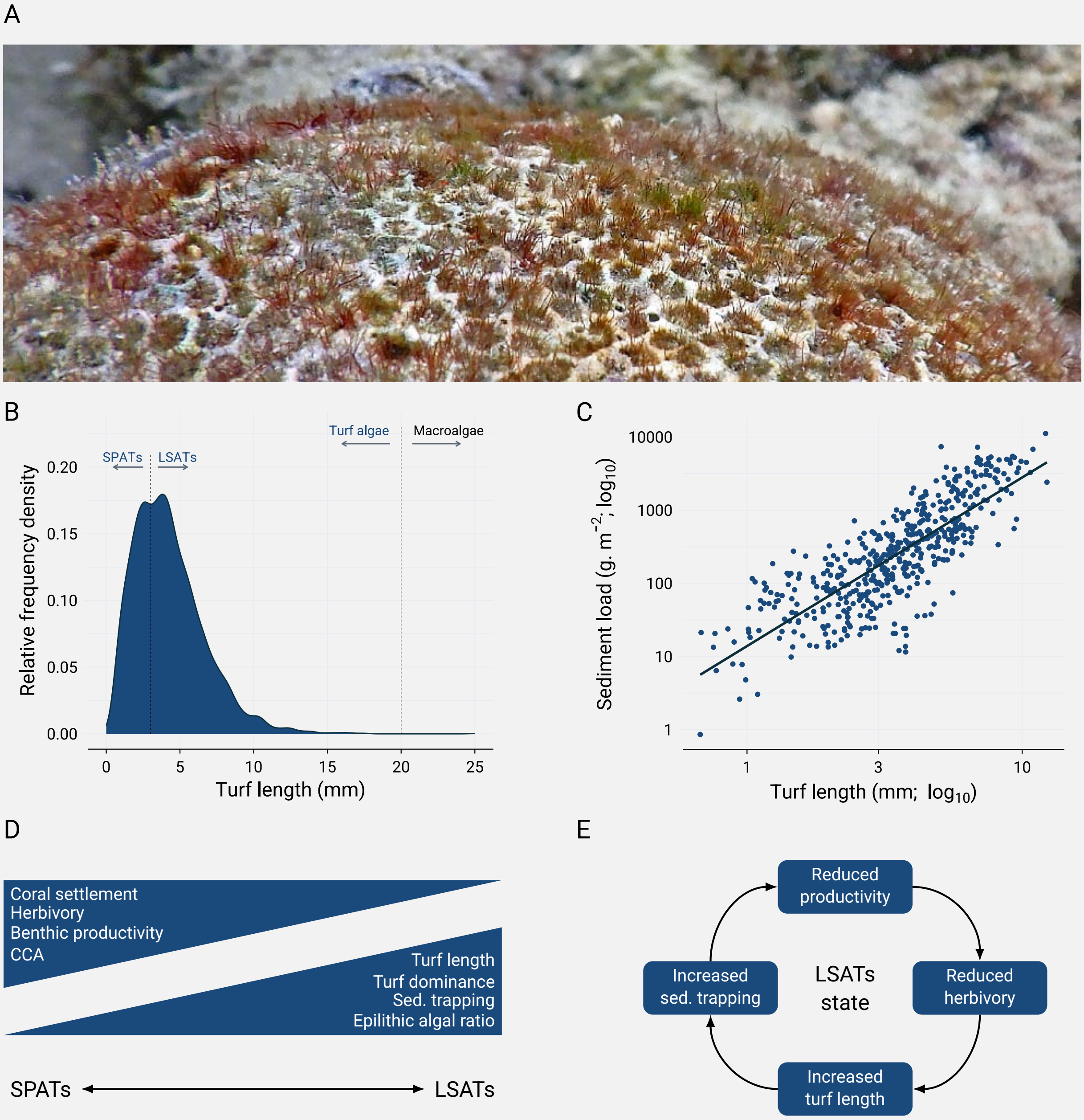
The decline of hard corals on the world's reefs is generally associated with an increase in various groups of algae, especially fleshy macroalgae and turfs. The inverse relationship between coral cover and different algae is underpinned by both indirect (*e.g.* a stressor such as increased sea surface temperature results in coral mortality, creating space and enabling an increase in turfs [131]) and direct (*e.g.* fleshy macroalgae outcompete coral via allelopathic effects [132]) mechanisms. In extreme cases, change in reef condition manifests as a "phase-shift" (*i.e.* a change in the equilibrial community in response to environmental change [133]). On coral reefs, the transition from a hard-coral-dominated state to one dominated by fleshy macroalgae exemplifies a phase-shift [134]. However, this form of phase-shift is relatively rare and often limited to specific contexts (*e.g.* high nutrient inputs and reduced herbivory [135]) or biogeographic locations (*e.g.* the Caribbean [136]). More commonly, a decline in hard corals is associated with a rise of turfs [122].

Turfs are highly abundant on reefs globally, however they are often poorly defined and widely overlooked [137]. Here, turfs are defined as short ($<$ 2 cm) multispecies assemblages of algae and cyanobacteria (Figure C1.1A). At such lengths, the algae and cyanobacteria that comprise turfs are not readily identifiable in situ; with the term "turf" facilitating rapid categorisation in the field. Importantly, this definition is also informed by 1000s of quantitative measurements, with 99.98% of these falling within this 2 cm threshold (Figure C1.1B). Despite this short stature, the structure and composition of turfs at the scale of millimetres can have fundamental implications for the functioning of coral reefs.

Turfs form an ecological interface that directly interacts with a range of processes that are central to coral reef functioning and resilience. Emerging evidence suggests many of these processes are directly mediated by the structure and composition of turfs at the scale of millimetres. For example, a 5 mm increase in turf length can mean a $>$ 1,000% increase in trapped sediments (Figure C1.1C). These sediments can re-shape coral reef functioning as they reduce herbivory rates by 70–90% [138, 139], benthic productivity yields to fishes by 95% [140], and coral settlement rates by 90–99% [141, 142] (Figure C1.1D).

The capacity of turfs to trap sediments is key to how they shape ecosystem functions. Terms such as "short productivity algal turfs" (SPATs) and "long sediment-laden algal turfs" (LSATs) have been coined to recognize this variation [139]. A turf length of ~3 mm and associated sediment load of ~100 g.m^{-2}, represents the nominal transition between SPATs and LSATs. However, strictly defining a threshold is difficult as the state of turfs spans a continuum from crustose coralline algae (CCA) with short sparse turfs through to LSATs, with this continuum recently captured via the development of the epilithic algal ratio (Figure C1.1D, [143]). Given the high cover of turfs on coral reefs, a subtle, but potentially major, form of phase-shift appears to be a change in the state of the turf itself from SPATs to LSATs. The strong feedback processes involved in this shift (Figure C1.1E) underscore the need for better consideration of turfs in coral reef research, monitoring, and management. In this respect, the current *Status of Coral Reefs of the World* report has taken fundamental steps forward, specifically considering divisions between major algal groups at a global scale. This report, therefore, generates knowledge that is vital to understanding coral reef change at regional and global scales.



▲ **Figure C1.1.** Short productive turf growing on dead coral (A). The frequency distribution of turf length (B, *n* = 6,133 measurements), showing the approximate transition point between short productive algal turfs (SPATs) and long sediment-laden algal turfs (LSATs) at ~3 mm. The positive relationship between turf length and the load of accumulated turf sediments (C, *n* = 497). Key processes and benthic characteristics that can vary along a gradient of turf states (D). An example of a feedback loop which may stabilise an LSAT state (E). Data were based on those compiled in Tebbett *et al.* [122], with additional data from Tebbett *et al.* [143, 144].

CASE STUDY 2

Beyond coral cover: A new framework to assess the condition and resilience of coral reef habitats

Authors

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Introduction

Ecosystem management aims to maintain healthy and resilient ecosystems over time. These attributes can be summarised under a general term widely used in management, *ecosystem condition*, which defines the overall quality of an ecosystem relative to a reference state. However, measuring ecosystem condition remains a challenge.

Hard coral cover is a widely used indicator of coral reef condition because it is easily measured and understood by a non-technical audience and has been consistently collected worldwide over decades. Nonetheless, a comprehensive assessment of coral reef condition requires (1) indicators that describe the multiple processes driving the resistance and recovery capacity, (2) habitat-specific thresholds that define their reference condition, (3) accounting for their spatial and temporal dynamics, and (4) summarising information to classify habitat condition and assess management effectiveness strategies.

This case study outlines a newly developed framework that integrates five indicators derived from conventional monitoring metrics to assess and communicate the condition of coral reef habitats (Table C2.1). Collectively, these indicators assess the resilience capacity of coral reefs, assist in interpreting monitoring data, support the evaluation of management targets and provide a prognostic assessment of ecosystem condition using reference values (for more information see Gonzalez-Rivero *et al.* [145]).

Two examples from the Great Barrier Reef

Drawing on over three decades of monitoring data from the Australian Institute of Marine Science in the Great Barrier Reef (GBR), the following examples demonstrate the value of considering multiple indicators for assessing reef condition.

The fringing reefs of Snapper Island, northern GBR were severely impacted by a cyclone (2014) and bleaching (2017), leaving coral cover low by 2018 (Figure C2.1A). The framework analysis, conducted for 2018, shows underperformance relative to baselines, with high macroalgal prevalence, low juvenile coral abundance, and taxonomic compositional changes, indicating a compromised reef condition in 2018 ("Warning II"; Figure C2.1B). Indeed, continued monitoring until 2023 showed only slight recovery (Figure C2.1A, grey lines). In contrast, while Lady Musgrave Reef, southern GBR, was also heavily impacted by disturbances in 2008–2010, it maintained expected values for most indicators after the impact, despite low coral cover, suggesting a less compromised condition ("Watch"). Six years post-impact, the reef had regained high coral cover, demonstrating strong resilience (Figure C2.1C, grey lines).

▼ **Table C2.1.** List of indicators included in the framework with a brief rationale for their inclusion.

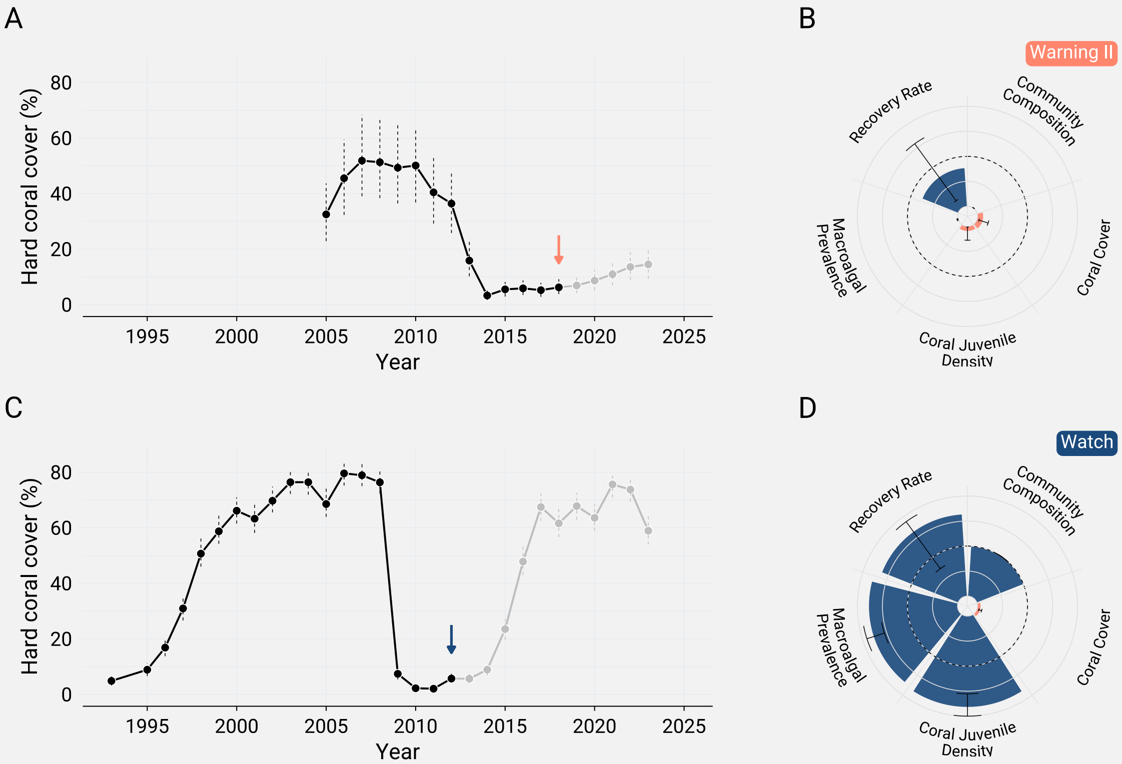
Indicator	Metric	Ecological interpretation	Reported by the GCRMN
Coral cover	Proportion of the reef substrate covered by hard corals	Represents key functional attributes, including reef accretion, structural complexity, abundance of coral-dependent species, and larval production	Yes
Macroalgal prevalence	Proportion of macroalgae relative to total algal cover	An increasing prevalence of macroalgae indicates increased competition for space, reduced herbivory intensity, and/or increased turbidity and nutrient availability	Yes*
Community composition	Relative abundance of benthic taxa within a reef	Indicates changes in the taxonomic representation of the benthic community that may impact ecological functions, successional dynamics, and vulnerability to further disturbances	No
Recovery rate	Change in hard coral cover over time from repeated surveys	Slowing recovery rates are early warnings of an impaired capacity of coral reef habitats to withstand current and future pressures	No
Coral juvenile density	Abundance of hard coral juveniles relative to the available area for recruitment	Represents the ability of coral larvae to settle and survive, thereby sustaining population recovery and long-term reef persistence	No

**Functional groups of algae, including macroalgae, turf algae and crustose coralline algae, have recently been incorporated in GCRMN reports.*

Conclusions and recommendations

Coral reefs are intricate and dynamic systems at the frontlines of climate change. Recognising their complexity while finding effective ways to communicate their condition and resilience is crucial to inform timely and effective conservation efforts. The framework offers a practical way to increase the relevance of monitoring to management, especially for local and regional decision-making. It applies monitoring data analysis for prognostic assessments of coral reef condition, facilitating the prioritisation of reefs for conservation and helping explain complex responses of these ecosystems to disturbances. Importantly, the proposed framework can utilise available data and expertise within a region (sensu Gudka *et al.* [146]), if monitoring remains consistent over time.

Currently, changes in key coral reef attributes besides live hard corals and macroalgae cannot be reliably assessed globally, such as in the GCRMN reports, due to limited indicator data [1]. Therefore, implementing this framework more widely would require strengthening coral reef monitoring (see Obura *et al.* [147]). Over the medium term, collectively advancing towards higher-quality, repeatable and more comprehensive monitoring will be essential to inform conservation in a rapidly changing world.



▲ **Figure C2.1.** Prognostic assessments of coral reef condition in the Great Barrier Reef, including temporal trends in coral cover and indicator values for habitat condition, were evaluated for specific years (represented by the arrows) at Snapper Island (A and B) and Lady Musgrave Reef (C and D). Indicator values below the reference threshold (dashed line) are shown in red, and those at or above are shown in blue. The grey lines in the temporal coral cover plots show the observed trajectories after the evaluated year.

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