Australian Government
Great Barrier Reef
Marine Park Authority

Reef Authority

Great Barrier Reef
Outlook Report 2024



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Letter of Transmittal

The Hon Tanya Plibersek MP
Minister for the Environment and Water
Parliament House
Canberra

Australian Government
Great Barrier Reef
Marine Park Authority

Dear Minister

I am pleased to provide the Great Barrier Reef Outlook Report 2024 to you as Minister for the Environment and Water and, through you, to the Australian Parliament and the people of Australia.

The Great Barrier Reef Outlook Report 2024 has been prepared by the Great Barrier Reef Marine Park Authority based on the best available information and covers the period January 2019 to December 2023. It fulfils the requirements of Section 54 of the *Great Barrier Reef Marine Park Act 1975* (Cth). The report includes nine assessments covering biodiversity, ecosystem health, heritage values, commercial and non-commercial use, factors influencing the Reef's values, existing protection and management, resilience, risks and the long-term outlook for both the ecosystem and heritage values. The contents of the report were independently peer reviewed.

The legislation requires that an Outlook Report be prepared every five years. As in Outlook Report 2009, 2014 and 2019, this report identifies that the Great Barrier Reef Region faces significant pressures ranging in scale from local to global. Climate change remains the greatest threat to the Great Barrier Reef.

The Great Barrier Reef retains its outstanding universal value as a World Heritage Area. While its natural beauty and phenomena endures, its integrity is being increasingly challenged. Cumulative pressures, predominantly from climate change, combined with the time required for the recovery of key habitats, species and ecosystem processes continue to affect the overall health of the Great Barrier Reef. Recent recovery in some ecosystem values demonstrates that the Reef is still resilient, but its capacity to tolerate and recover is jeopardised by a rapidly changing climate, with implications for Traditional Owners, Reef-dependent communities and industries.

The arrival of El Niño climate conditions in mid-2023 highlighted the narrowing of critical recovery windows for the Reef's health. It brought record global temperatures on land and in the oceans and, by the end of summer 2023-24, the now-familiar sight of mass coral bleaching. The full impacts of this latest mass coral bleaching event are still being determined.

Even with the recent management initiatives to reduce threats and improve resilience, the overall future outlook for the Great Barrier Reef is very poor. These findings will be best addressed through urgent national and global action to deliver on international commitments that would limit temperatures to 1.5˚C of warming—or as close as possible. Across the Region and at local scales, it is imperative that everything possible is done to create recovery windows for the Reef. Improving water quality and enhancing on-ground management actions are critical to addressing compounding threats and supporting Reef resilience.

I commend this Outlook Report to you for tabling in both Houses of the Australian Parliament.

Yours Sincerely,



Ian Poiner
Chair
Great Barrier Reef Marine Park Authority

Acknowledgements

The *Great Barrier Reef Outlook Report 2024* was prepared by the Great Barrier Reef Marine Park Authority with assistance and contributions from many others.

The Reef Authority acknowledges the expertise, wisdom, and enduring connections that have informed the guardianship of the Reef for millennia. We pay our respects to the Traditional Owners as the first managers of this Land and Sea Country, and value their traditional knowledge which continues to inform the current management and stewardship of the Reef for future generations.

Many Traditional Owners and custodians of the Region's Land and Sea Country shared stories with the Reef Authority to inform the assessment. These stories were gathered and prepared by Winangali Pty Ltd, Indigenous engagement consultants.

A number of Australian and Queensland government departments and agencies provided information, expertise and comment throughout the development process.

Many Great Barrier Reef scientists willingly contributed their knowledge and information, both formally through an expert elicitation workshop and informally by reviewing information used in the Outlook Report to ensure the correct interpretation of results. The expert elicitation workshop was independently facilitated by Science into Action (Anthony Boxshall) and Scientell (Simon Torok).

The independent assessment of the existing measures to protect and manage the Great Barrier Reef was conducted by BMT Pty Ltd (Ingrid Baker, Ann Peterson, Lydia Tobin, Beth Toki and Jeremy Visser).

Finally, the contents of the Outlook Report were formally peer reviewed by Professor Nicholas Graham, Dr Rosemary Hill, Professor Peter Mumby, Professor Hugh Possingham and Professor Stephen van Leeuwen.



Nautilus Shell Artwork © 2023 by Laurence Gibson, Yalanji Arts, Mossman Gorge

Executive Summary

The window of opportunity to secure a positive future for the Great Barrier Reef (the Reef) is closing rapidly. The Reef remains a vast and spectacular ecosystem and one of the most complex natural systems on Earth. Recognised for its outstanding universal value as a World-Heritage-listed property, it transcends national boundaries and is a source of pride for the Australian public. It supports the livelihoods and wellbeing of its Traditional Owners and coastal communities by providing material, spiritual and cultural sustenance and drawing visitors from across the world. It delivers ecosystem services that support the economic prosperity of tourism, fishing and other industries that depend on the Reef.

A wealth of habitats, species and genetic riches underlie the Reef's resilience, and — thanks to decades of effective protection and management — its natural beauty and natural phenomena endure. Nevertheless, the ratcheting pressures brought about by climate change, combined with chronic and legacy impacts, are undermining the Reef's resilience. The Region's overall long-term outlook remains one of continued deterioration due largely to climate change.

Urgent action to deliver on international commitments that would limit temperatures to 1.5 degrees Celsius of warming—or as close as possible—remains critical. This would deliver the best possible future for the Reef and the livelihoods that depend on it. But global action is currently falling short of what is needed. New ways of thinking are needed to complement existing management in charting a positive path forward for the Reef and its dependent communities.

The Great Barrier Reef Outlook Report 2024 has been prepared by the Great Barrier Reef Marine Park Authority based on the best available information. Prepared every 5 years, Outlook Reports provides a summary of the long-term outlook for the Reef based on its condition, use, influencing factors, management effectiveness, resilience and risks. It fulfils the requirements of Section 54 of the *Great Barrier Reef Marine Park Act 1975* (Cth). The reporting period generally includes data from January 2019 to December 2023 and, where possible, compares it with historical trends.

2024 opens a new chapter for the Reef. Future warming already locked into the climate system means that further degradation is inevitable. This is the sobering calculus of climate change. Every increment of additional global warming will further compromise the Reef's unique biodiversity, with continuing consequences for cultural heritage, social and economic benefits, and the broader ecosystem services of the Reef.

Over the past 5 years, the condition of natural values of the Great Barrier Reef Region (the Region), including species, habitats and ecosystem processes has varied, with both improvements and deteriorations documented. Overall, the condition of habitats remains poor on a Region-wide scale, in large part due to the ongoing vulnerability of coral reef habitats.

Despite widespread coral bleaching in 2020 and 2022, the absence of mass mortality from the bleaching — along with relatively little cyclone damage and effective management of crown-of-thorns starfish — allowed for recovery of fast-growing corals across much of the Region. This resulted in an improved overall condition of coral reef habitats from very poor to poor (borderline good), but this varies across the Reef. The condition of seagrass meadows has also improved since 2019 to good (borderline poor) condition, reflecting the recovery from past flooding impacts in some areas. Other habitats remain in good or very good condition.

Improvements in the condition of some species did occur in the reporting period (2019 to 2023). Widespread recovery of corals, typically led by a few fast-growing species, led to an improved condition for this group from very poor to poor. Some taxa, such as seabirds, sharks and rays, dugongs, and seagrasses, have shown a mix of recovery and decline across different species and populations. Most populations of marine turtles have declined. Many of the species showing declines are listed as threatened or protected species under various State and Commonwealth legislation.

The Region relies upon the healthy functioning of a range of physical, chemical and ecological processes, and connection to functioning coastal ecosystems. The conditions of most processes are similar to those reported in 2019, with continued deterioration of several key processes influenced by climate change and land-based runoff.

While recent recovery in some ecosystem values demonstrates that the Reef is still resilient, its capacity to tolerate and recover is jeopardised by a rapidly changing climate. Outlook Report 2024 reports on the past five years to December 2023. The subsequent events of early 2024 provide a stark illustration of warnings articulated since the first Outlook Report was released in 2009. The arrival of El Niño climate conditions in mid-2023 brought record global temperatures on land and in the oceans and, by the end of summer 2023–24, the now-familiar sight of mass coral bleaching. Although the full impacts of this latest mass coral bleaching event are still being determined, the event highlights the narrowing of critical recovery windows for the Reef's health.

Many of the Region's heritage values, particularly Indigenous heritage, are inseparable from the condition of the ecosystem and are vulnerable to the same threats. The living heritage of First Nations people across the Region remains resilient. Agency and access by First Nations people to manage their Country is fundamental to the condition of ecosystem and heritage values. Strengthening Traditional Owner involvement in the management of Sea Country is vital. Managing agencies can continue to build an enabling environment for Traditional Owners to protect Land and Sea Country through implementation of co-management principles. The *Reef 2050 Traditional Owner Implementation Plan* is a critical part of this pathway forward. Other heritage values, including social, aesthetic and scientific, are considered in good condition overall . While the property's outstanding universal value as a World Heritage Area remains whole and intact, its integrity continues to be challenged.

The Reef ecosystem, the people who use and depend on it, and human wellbeing are deeply interconnected. Understanding the relationships and feedback loops between the Reef's ecological and social systems is crucial. As the Reef changes, it will pose unprecedented challenges to dependent communities and industries, and require changes in the way people interact with, and derive benefit from, the Reef. The Reef remains a significant economic resource for industry, regional Queensland communities and Australia. The COVID-19 pandemic affected most Reef-dependent industries due to national and international border closures and impacts to market chains. Tourism visitation was greatly reduced during this time but is starting to recover. Reductions in international trade and exports affected the commercial fishing, shipping and port industries. In contrast, recreational use of the Region is understood to have increased.

The Region is influenced by activities occurring within and adjacent to the Region and is protected and managed by a partnership between many government agencies, Traditional Owners, stakeholders and community members. Effective management of the Region is a complex task given the range of threats and their variation across space and time. An independent review found the Region continues to be well managed, with the *Reef 2050 Long-term Sustainability Plan* improving jurisdictional consistency, coordination and resourcing. Direct use of the Region is also generally well managed reflecting, in part, the maturity of many management systems. Management of the Reef's values in relation to climate change and coastal development remains subject to significant challenges.

Climate driven disturbances are compounding the cumulative effects of chronic impacts (such as unsustainable fishing, pollution and sedimentation), acute disturbances (such as cyclones), and outbreaks of crown-of-thorns starfish. Building on efforts to reduce greenhouse gas emissions, management actions need to continue to address compounding threats and support the Reef's natural resilience. Actions must capitalise on recovery windows and maximise the Reef's inherent capacity for regeneration and change.

It is vital to identify and protect places (including climate refugia), habitats, species and ecosystem processes that are critical for resilience. Well-targeted culling of crown-of-thorns starfish can promote resilience in coral reef habitats by preventing severe coral losses from predation and protecting the supply of juvenile corals to damaged reefs. Multi-agency efforts to explore tangible and scalable reef interventions may lead to a suite of other innovative and targeted measures that could provide options for management in future.

Meeting water quality improvement targets is a crucial step towards a more resilient Reef. Poor water quality continues to affect many coastal and inshore areas of the Reef. Since 2019, water quality has continued to improve slowly reflecting modest improvements in agricultural land management practices and land-based runoff.

Sustainable fisheries and healthy fish populations are critical to maintaining a healthy ecosystem and a functioning Reef. Ongoing reform under the *Queensland Sustainable Fisheries Strategy 2017-2027* has led to important improvements in fisheries management. Notably, the incidental catch of species of conservation concern is likely to go down due to implementation of the planned phase-out of gillnets in the Reef by 2027. However, fishing activities continue to have a high impact on the Region's values. Some stocks, such as saucer scallops and Spanish mackerel, remain depleted and outcomes from fisheries reforms are yet to be fully realised. Key gaps in understanding relate to recreational fishing, discarded catch and bycatch, and independent validation of fishing data.

A vigilant, proactive and optimistic approach to management remains crucial. The Reef may be forever changed, but it has various possible futures. Choices made today can lead to vastly different outcomes — the path that unfolds will be shaped by the actions of many.

Difficult choices and trade-offs will need to be met head on and more often. Managers must take a clear-eyed approach, making decisions in the face of uncertainty and responsibly evaluating outcomes. Decisions should be based on the best available evidence, apply a risk-based approach, and acknowledge the realities of a changing Reef. Effective decision making depends on decision support tools that leverage emerging technologies and incorporate monitoring data, outputs from models, cultural science, and field intelligence.

Strong and effective actions are urgent at global, regional and local scales. Broad, multijurisdictional management actions that involve the community and behaviour change will be important in maintaining resilience of social heritage values. The health of the Reef ecosystem will continue to have both impacts on, and benefits for, the community and human wellbeing. Society will need to play a pivotal and urgent role in mitigation and adaptation to support the Region's resilience.

The Great Barrier Reef is one of the best managed reef systems in the world. While coral reefs across the globe are facing urgent and present threats from a warming climate, the Reef's diversity of habitats, species and genetic riches uniquely position it to retain resilience in the face of change. The future Reef will be altered by climatic changes already in motion, but just as every increment of warming compounds impacts, every effective action taken now contributes to a more positive long-term outlook.

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Coral reefs are an iconic habitat of the Great Barrier Reef © Johnny Gaskell 2018

About this report



Chapter 1

About this report



About this report



Tourists enjoy the Great Barrier Reef. © Chloe Schauble 2023

"One of my main reasons for working on Country is I reckon my grandmother would be very proud. She fought for the land for a very long time and I want to make sure I keep doing the same in my way. Hopefully, by doing this work I can keep the bloodline on Country and to learn the new and old ways."

— Stirling King, Traditional Owner and Indigenous Ranger

The Gunggandji-Mandingalbay Yidinji Land and Sea Rangers (GMY Rangers) group is shaping up to be an accomplished and highly qualified team of Indigenous rangers — caring for their Sea and Land Country, in dual World Heritage Areas in Yarrabah, near Cairns in Far North Queensland. The GMY Rangers are willing storytellers — stories woven into their experiences of caring for their Sea Country.

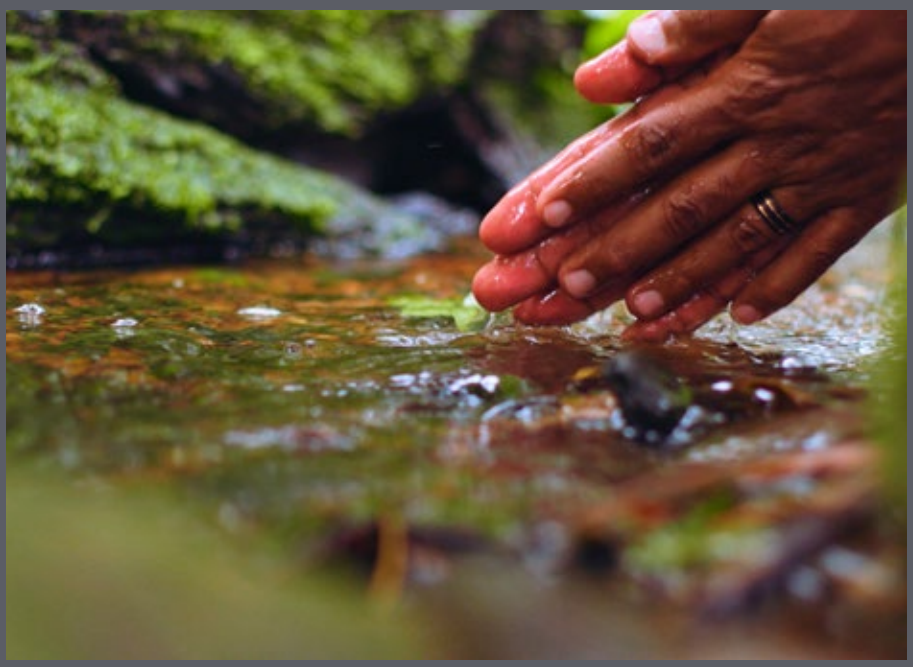
Stirling King, Traditional Owner and Indigenous Ranger, is eager to share the creation myth of the Yidinji people of how the Great Barrier Reef was formed after Bhiral, The Creator, threw lava from the sky. As the story goes, Bhiral was angered after two brothers went out fishing, and speared a particular fish that they had been told not to hunt.

"I like sharing my culture. I'm proud and I am getting better at doing so many things. I like making spears and showing school groups how to use them. I feel good about my culture and Country."

— Rakim Schieber, Trainee Indigenous Ranger

This is a Sea Country home to a diversity of species: such as seagrass, butterflies, moths, bats, stingrays, dugongs and crocodiles that are being monitored by the GMY Rangers program. Stirling sees protection of land and sea, biodiversity and culture as paramount.

Source: Caring for Sea Country — Traditional Owner Stories from the Great Barrier Reef [1]



Catchment to Reef: water connects people, places and ecosystems. © Commonwealth of Australia (Reef Authority) 2024

1.1 Background

The Great Barrier Reef Marine Park Authority (the Reef Authority) prepares a Great Barrier Reef Outlook Report (Outlook Report) for the Great Barrier Reef Region (the Region) every five years. The *Great Barrier Reef Marine Park Act 1975* (Cth) (the Act) and the associated regulations specify what the report must contain and the relevant statutory timeframes (Appendix 1).

The Outlook Report underpins decision making for the long-term protection of the Great Barrier Reef (the Reef). Its purpose is to provide an accountable and transparent assessment of the overall performance of measures to protect and manage the Reef. The report provides a summary of the long-term outlook for the Reef based on assessments of condition, use, influencing factors, management effectiveness, resilience and risks.

The Outlook Report is a key input to Reef management, the review of the *Reef 2050 Long-Term Sustainability Plan* (Reef 2050 Plan)[2] and reviews of zoning plans. It also plays a significant role in informing Australia's reports to the World Heritage Committee addressing the state of conservation of the Great Barrier Reef World Heritage Area. The first Outlook Report was released in 2009[3], the second in 2014[4] and the third in 2019.[5]

The Act does not provide for the Outlook Report to include recommendations about future protection or management initiatives. Rather, the report provides an evidence-based assessment that identifies future trends, risks and threats, to inform future protection and management initiatives. The Outlook Report 2024 builds upon previous reporting, predominantly since 2019. While much of the report's assessment focuses on retrospective performance over a five-year period, a forward-looking long-term outlook is also provided (Chapter 10).

1.2 Scope

The jurisdictional scope of the report covers the entire Region (Figure 1.1). The Commonwealth has jurisdiction over most of the Region which covers approximately 346,000 square kilometres, from the tip of Cape York in the north to past Lady Elliott Island in the south.[6] Mean low water is the landward boundary and it extends seaward at a distance between 70 and 250 kilometres to the eastern border with the Coral Sea Marine Park.[6] It excludes the Torres Strait Region. The Region's boundary is slightly larger than the Great Barrier Reef Marine Park (the Marine Park) and it includes the air above to a height of 915 metres, the subsoil beneath the surface of any land to a depth of 1000 metres, and about 70 Commonwealth Islands.[7] The State of Queensland has jurisdiction over the majority of islands in the Reef (approximately 980 islands) which are, therefore, not included formally within the Region. However, where it is relevant to the health of, or factors influencing, the Reef ecosystem and its heritage values, the report looks beyond the Region's jurisdictional boundaries and includes information about adjacent islands, neighbouring marine areas and the Great Barrier Reef river catchments (the Catchment). Jurisdictional differences between the various areas described in the report are outlined in Table 1.1 and Figure 1.2. Additional information on jurisdictions, governance arrangements and management responsibilities is provided in Section 7.1.1.

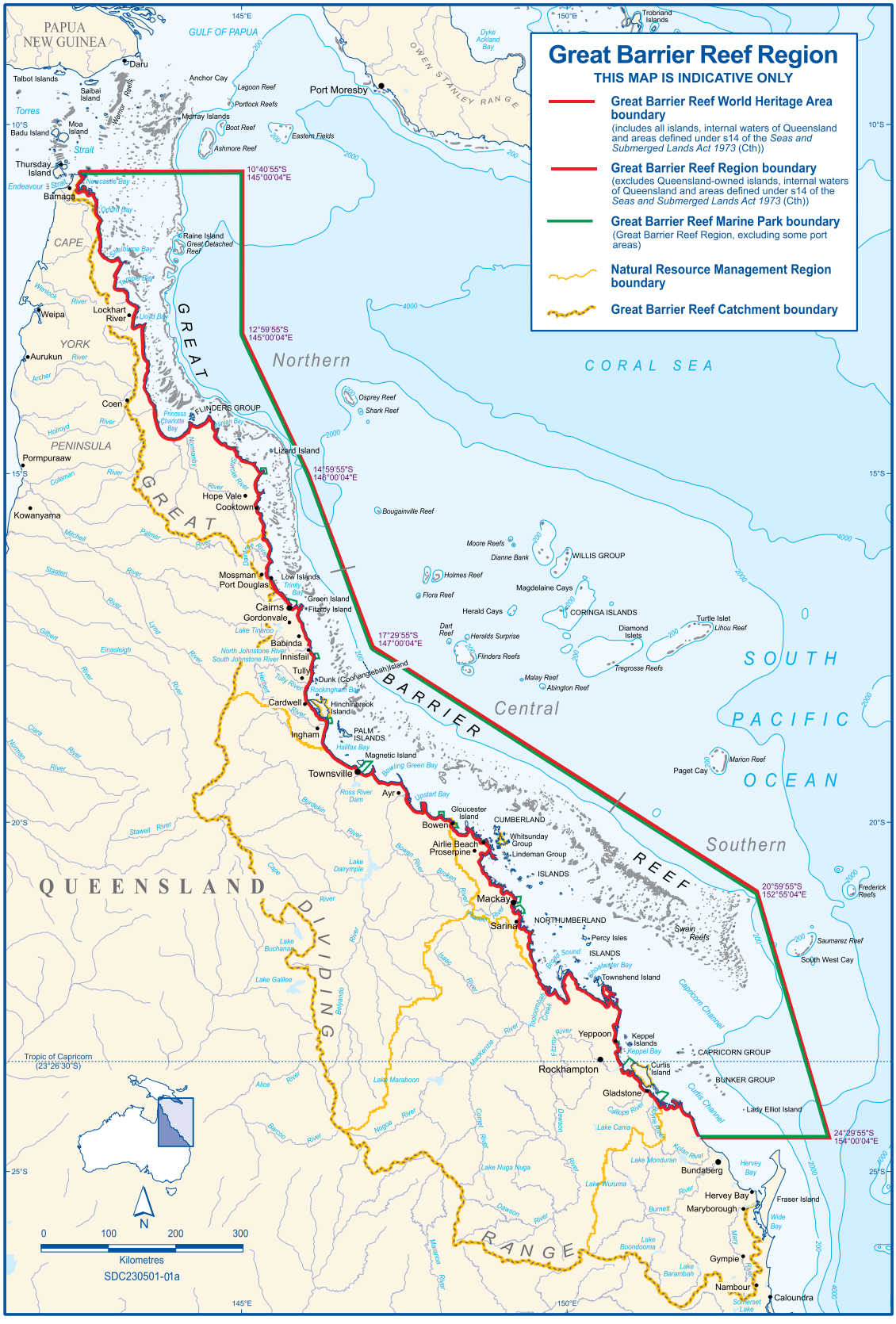


Figure 1.1 Great Barrier Reef Region and Catchment

Table 1.1 **Differences between the Great Barrier Reef Marine Park, Region, World Heritage Area and Catchment**

The square kilometres of each area is an approximation only. Terms relating to ports are described in Section 5.7.

Great Barrier Reef Marine Park	Great Barrier Reef Region	Great Barrier Reef World Heritage Area	Great Barrier Reef Catchment
Declared in sections between 1979 and 2001; amalgamated into one section by proclamation in 2004	Established 1975	Inscribed 1981	
344,400 km^2	346,000 km^2	348,000 km^2	424, 000 km^2
Includes: • approximately 70 Commonwealth islands • all waters seaward of low water mark (excluding Queensland internal waters and trading ports)	Includes • approximately 70 Commonwealth islands • all waters seaward of low water mark (excluding Queensland internal waters) • 12 coastal exclusion areas (12 trading ports) and maritime port infrastructure	Includes • all islands within outer boundary (approximately 1050), comprising approximately 70 Commonwealth islands and approximately 980 Queensland islands • all waters seaward of low water mark (including* Queensland internal waters) • 12 coastal exclusion areas (12 trading ports) and maritime port infrastructure	Includes: • 35 river basins that flow into the Great Barrier Reef Region • six natural resource management regions: Cape York, Wet Tropics, Burdekin, Mackay-Whitsunday, Fitzroy and Burnett-Mary • land-based port infrastructure
Does NOT include: • internal waters of Queensland • Queensland islands (approximately 980) • 12 coastal exclusion areas (trading ports)	Does NOT include: • internal waters of Queensland • Queensland islands (approximately 980)		Does NOT include: • land seaward of low water mark • maritime port infrastructure



This map shows examples of the differences between the boundaries of the Marine Park, Region and World Heritage Area. It also includes a Queensland island (Goold Island) that is positioned within, but not part of, the Region.

*This text has been updated subsequent to tabling of the Great Barrier Reef Outlook Report 2024.

The Outlook Report assesses all parts of the ecosystem within the Region, ranging from species and habitats to key ecosystem processes. For the purposes of the report, the ecosystem components within the Region are collectively referred to as the Great Barrier Reef ecosystem or simply the Great Barrier Reef. The report also assesses all aspects of the Region's heritage values, including Indigenous and historic values and its world heritage value.

The Reef was inscribed on the World Heritage List in 1981 for all four natural criteria (Table 4.1). The assessment of the condition of the Region's world heritage value, in Chapter 4, is directly informed by Chapters 2 and 3, which provide grades for a suite of natural heritage components. In addition, Appendix 3 presents a matrix describing how the components assessed in this report correspond with the attributes (outstanding features) that comprise the statement of outstanding universal value.

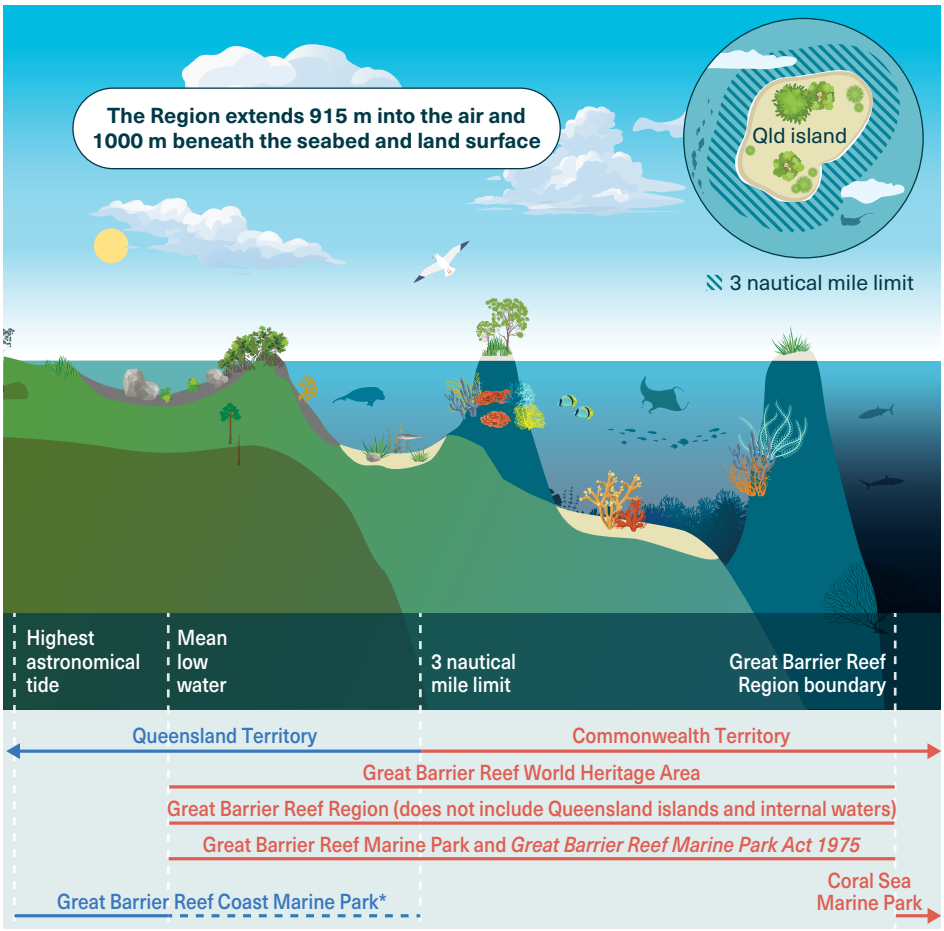


Figure 1.2 **Jurisdictional boundaries**

The Commonwealth and the State of Queensland have jurisdiction over various parts of the Region (red and blue lines, respectively). An intergovernmental agreement ensures integrated field management of the Great Barrier Reef Marine Park and the abutting Great Barrier Reef Coast Marine Park through joint management of marine parks and island national parks. The Queensland territory extends from the mainland to the three nautical mile limit. The Queensland territory includes Queensland-owned islands that lie within the Region, as well as the three nautical mile area surrounding Queensland-owned islands within the twelve nautical mile limit of the mainland (inset image).* The land boundary for the Great Barrier Reef Coast Marine Park may be high water or highest astronomical tide depending on location pursuant to the Marine Parks (Declaration) Regulation 2006. The dotted lines indicate the possible extent of the relevant legislation or jurisdiction (for example depending on species or fishery). Additional information on jurisdictions and management responsibilities is provided in the expanded version of this diagram in Section 7.1.1.

1.3 Structure

The Outlook Report 2024 looks back over the past five years and collates a Region-wide assessment of the current condition of the Reef's ecosystem and heritage values. The report is structured around the nine assessments required by the Act and its regulations, with each assessment forming a chapter of the Report (Figure 1.3). Chapters fall into three main themes: (i) values; (ii) threats, management responses, resilience and risk, and (iii) the long-term outlook for the Region. Chapters 2 to 5 focus on the current condition of the values of the Reef and trends to date. Future trends in the condition of the values depend on the drivers influencing them, which are discussed in later chapters.

Each chapter has case studies relating to a particular section of the report. These case studies provide further information, highlighting specific bodies of work, events or updates from previous reports.

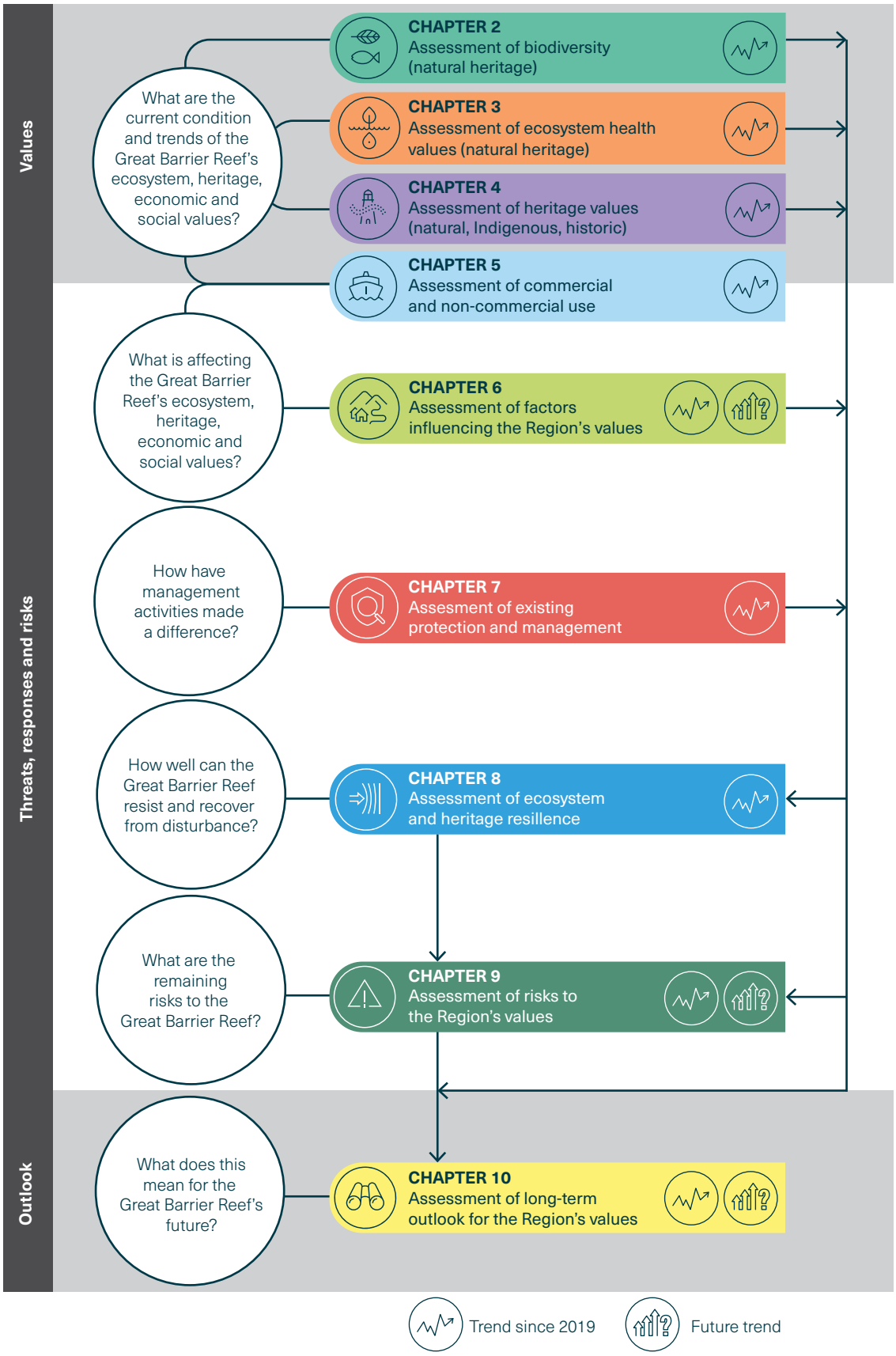


Figure 1.3 **Assessments within the Outlook Report 2024**

Each of the assessments required under the Act and relevant regulations forms a chapter of the report. The assessments relate to the condition of the Region's ecosystem and its heritage value and examine threats, responses and risks. These then inform an assessment of the likely outlook for the Region's values.

1.3.1 Human dimensions within the Outlook Report

The Reef ecosystem and the people who use it are strongly interconnected. A way to understand this connection is to consider that humans are a part of, not separate from, nature: a social–ecological system. First Nations peoples view health of the environment and health of people as inextricably linked — healthy Country means healthy people (Section 4.3).

How humans derive wellbeing from nature feeds back into how humans behave towards the environment.[8] Human wellbeing can be described in five inter-related themes: healthy, secure, sustainable, cohesive and prosperous.[9] Ecosystems play a critical role in underpinning many constituents of human wellbeing (Figure 1.4).

A healthy and functional Reef ecological system provides material and non-material benefits to people that results in wellbeing outcomes. Social heritage values related to aspects of wellbeing are described in Section 4.5.1 as including: access; aesthetics; appreciation, understanding and enjoyment; human health; personal connection; equity (intra- and intergenerational); empowerment; and employment and income. More details about the direct and indirect use aspects of those values can be found in Chapter 5 (Commercial and non-commercial use). Non-use aspects are mostly described in sections of Chapter 4 (Heritage values).

People's wellbeing derived from benefits can influence their attitudes and values. Ultimately this affects their behaviours and actions towards the Reef to maintain or enhance benefits.[8] For example, best practice behaviours and stewardship actions, but also compliance or non-compliance with rules and regulations.

Understanding of the relationships and feedback loop between the Reef's ecological and social systems is crucial to guide the long-term protection and conservation of the environment, biodiversity and heritage values of the Great Barrer Reef Region and to allow for ecologically sustainable use.

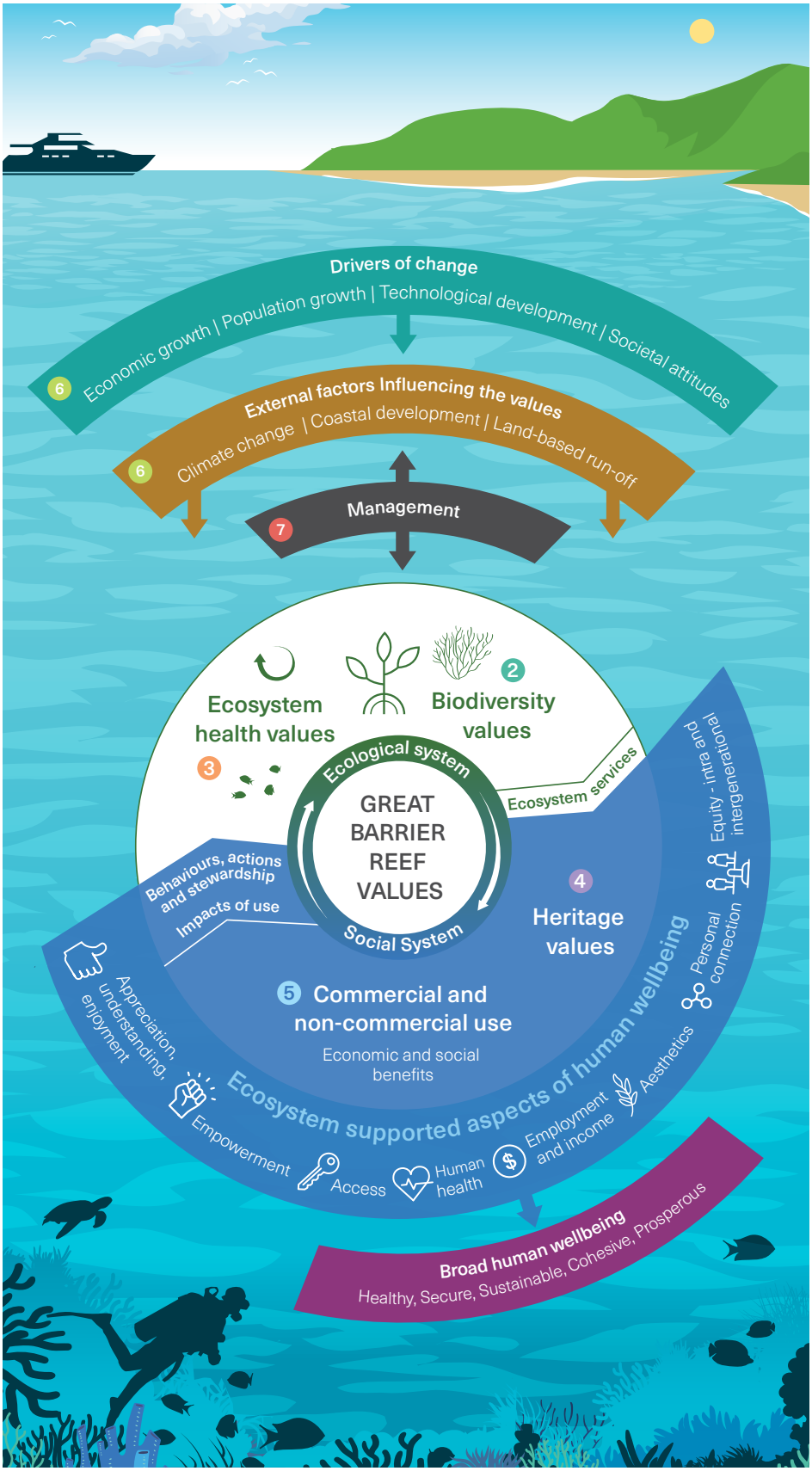


Figure 1.4 **Human dimensions of the Great Barrier Reef for the Outlook Report**

Numbered circles link parts of the diagram to relevant chapters in the Outlook Report. Management encompasses a broad range of considerations, including governance and institutions, environmental regulation, on-ground actions, engagement, knowledge integration and innovation (Chapter 7).

1.4 Assessment approach

For each of the required statutory assessments (Appendix 1), specific criteria and grading statements guide the analysis of available evidence and provide transparency (Figure 1.5 and Table 1.2). For example, the assessment of biodiversity (Chapter 2) uses two assessment criteria: (i) habitats to support species, and (ii) populations of species or groups of species. Each assessment criterion comprises several components (Table 1.2).

Based on analysis of the evidence available, at the scale of the Region, each component receives an assessment grade (Section 1.4.1) and trend (Section 1.4.2) since the Outlook Report 2019. The component results are then combined to inform the grade for the overarching criterion (Figure 1.6). Determination of both criteria grades and component level grades are guided by reference to standard grading statements (Section 1.4.1). Criteria and component assessments are presented in a table in the assessment summary at the end of each chapter. For 2024, regional scale grades (i.e. for portions of the Region) have been added for coral reef habitats.

To maintain the comparative value of the Outlook Report over time, changes to the assessed components have been limited to instances where they significantly improve the validity or utility of the assessment (Appendix 2).

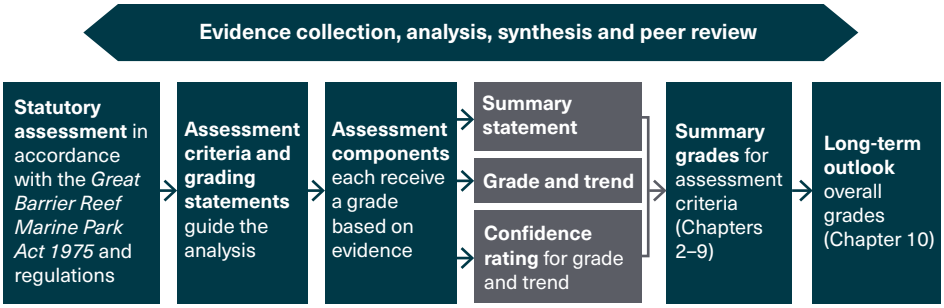


Figure 1.5 **Assessment approach to determine final grades**
The required assessments are based on the best available evidence. Availability and quality of evidence is variable across assessments. Grades are standardised against grading statements presented with each assessment summary.

Table 1.2 Assessment criteria and their components

Each chapter of the report contains assessments of a specific set of criteria (bold text) and components (bullet points).

Chapter 2: Biodiversity

Habitats to support species
- Islands
- Mainland beaches and coastlines
- Mangrove forests
- Seagrass meadows
- Coral Reefs
- Lagoon floor
- Other banks and shoals
- *Halimeda* bioherms and meadows
- Continental slope
- Water column

Populations of species and groups of species
- Mangroves
- Seagrasses
- Benthic algae
- Corals
- Other Invertebrates
- Plankton and microbes
- Bony fishes
- Sharks and rays
- Sea snakes
- Marine turtles
- Estuarine crocodiles
- Seabirds
- Shorebirds
- Whales
- Dolphins
- Dugongs

Chapter 3: Ecosystem health

Physical processes
- Currents
- Cyclones and wind
- Freshwater inflow
- Sediment exposure
- Sea level
- Sea temperature
- Light

Chemical processes
- Nutrient cycling
- Ocean pH
- Ocean salinity

Ecological processes
- Microbial processes
- Particle feeding
- Primary production
- Herbivory
- Predation
- Symbiosis
- Recruitment
- Reef building
- Competition
- Connectivity

Coastal ecosystems that support the Great Barrier Reef
- Saltmarshes
- Freshwater wetlands
- Forested floodplains
- Heath and shrublands
- Grass and sedgelands
- Woodlands and forests
- Rainforests

Outbreaks of disease, introduced species and pest species
- Outbreaks of disease
- Outbreaks of crown-of-thorns starfish
- Introduced species
- Other outbreaks

Chapter 4: Heritage values

Natural heritage values – world heritage and national heritage values
- Natural beauty and natural phenomena
- Major stages of the Earth's evolutionary history
- Ecological and biological processes
- Habitats for conservation of biodiversity
- Integrity
- Natural heritage values

Indigenous heritage values
- Cultural practices, observances, customs and lore
- Sacred sites, sites of particular significance and places important for cultural tradition
- Stories, songlines, totems and languages
- Indigenous structures, technology, tools and archaeology

Historic heritage values – Commonwealth heritage values
- Commonwealth heritage values

Historic heritage values
- Commonwealth lightstations
- Other historic lightstations and lighthouses
- Historic voyages and shipwrecks
- World War II features and sites
- Other places of historic significance

Heritage – other
- Social heritage value
- Aesthetic heritage value
- Scientific heritage value

Chapter 5: Commercial and non-commercial use

Economic and social benefits
- Commercial marine tourism
- Defence activities
- Fishing
- Recreation (not including fishing)
- Research and educational activities
- Ports
- Shipping
- Traditional use of marine resources

Impacts of use on the Region's values
- Commercial marine tourism
- Defence activities
- Fishing
- Recreation (not including fishing)
- Research and educational activities
- Ports
- Shipping
- Traditional use of marine resources

Chapter 6: Factors influencing the Region's values

Impacts on ecological values
- Climate change
- Coastal development in the Catchment
- Land-based run-off
- Direct use

Impacts on heritage values
- Climate change
- Coastal development in the Catchment
- Land-based run-off
- Direct use

Impacts on economic values
- Climate change
- Coastal development in the Catchment
- Land-based run-off
- Direct use

Impacts on social values
- Climate change
- Coastal development in the Catchment
- Land-based run-off
- Direct use

Chapter 7: Existing protection and management

Elements of the management cycle
- Understanding of context
- Planning
- Financial, staffing and information inputs
- Management systems, processes and governance
- Delivery of outputs
- Achievement of outcomes

Individual management topics
- Commercial marine tourism
- Defence activities
- Fishing
- Ports
- Recreation (not including fishing)
- Research and educational activities
- Shipping
- Traditional use of marine resources
- Climate change
- Coastal development in the Catchment
- Land-based run-off
- Biodiversity values
- Heritage values
- Community benefits of the environment

Chapter 8: Resilience

Ecosystem resilience
- Coral reef habitats
- Seagrass meadow habitats
- Black teatfish (sea cucumber)
- Coral trout
- Loggerhead turtles
- Urban coast dugongs
- Humpback whales

Heritage resilience
- Social heritage value
- Indigenous heritage value
- Historic heritage value

Chapter 9: Risks to the Region's values

Overall risk to the ecosystem (natural heritage values)
Overall risk to the heritage values (Indigenous, historic and other)

Chapter 10: Long-term outlook

Outlook for the Region's ecosystem
Outlook for the Region's heritage values

1.4.1 Assessment grades and grading statements

A series of condition grading statements standardise the allocation of grades for each criterion and all components examined in an assessment. A four-point grading scale has been used since 2009 and is continued for consistency. An example is shown in Figure 1.5. There is no option for 'moderate', so a decision is required about whether a component is in a positive or negative state. This application is consistent with the Australian State of the Environment Report.[10]

The grade allocated is a 'grade of best fit', based on a qualitative assessment of the available evidence and scaled to the Region (or Catchment for coastal ecosystem and coastal development). It is not a comparison of the Region in relation to other tropical and sub-tropical ecosystems around the world. It is recognised that the condition grade of a component may not be consistent across the entire Region. Where important subregional differences in condition and trend are supported by evidence (for example, corals), they are identified in the discussion and graphics within the main text of the chapter and considered in the grade and trend.

1.4.2 Assessment of trends and confidence

A trend reflects how a component has changed in condition over the past five years. Trends are assessed in relation to the assessment of the corresponding component in the Outlook Report 2019 as well as other available information on the trend in that component, if available. Previous grades (2009, 2014 and 2019) and trends (2014 and 2019) are included in the assessment summary tables.

Chapters relating to factors that influence the Region's values, risks and long-term outlook contain forward-looking assessments. In these chapters (6, 9 and 10), trends in criteria and components are forecast for the next five years and beyond.

Trends are categorised as either: improved, stable, deteriorated or no consistent trend. The category 'no consistent trend' is applied to a component when the available information is too variable to determine a trend. The terms 'improved' and 'deteriorated' are replaced with 'increased' and 'decreased' in assessments of impacts, threats and risks (Chapters 6 and 9).

Outlook Reports are evidence-based and peer-reviewed. To support transparency and reliability of the current grades, a level of confidence is provided. The categories used are:

- adequate high-quality evidence and high level of consensus
- limited evidence or limited consensus
- inferred, very limited evidence.

For components where the confidence level is 'inferred, very limited evidence', the assessment grade should be treated with some level of caution given it is based on a limited amount of published peer-reviewed literature. Inferred assessments may also be based on knowledge from managing agencies, Traditional Owners, topic experts and informed stakeholders. Confidence levels are not provided for criteria assessments, as aggregating across components is difficult and there can be a high level of variability. A confidence level is also not provided for the assessment of existing protection and management (Chapter 7) because this assessment is conducted by independent assessors and confidence levels are not currently part of that methodology.[11]

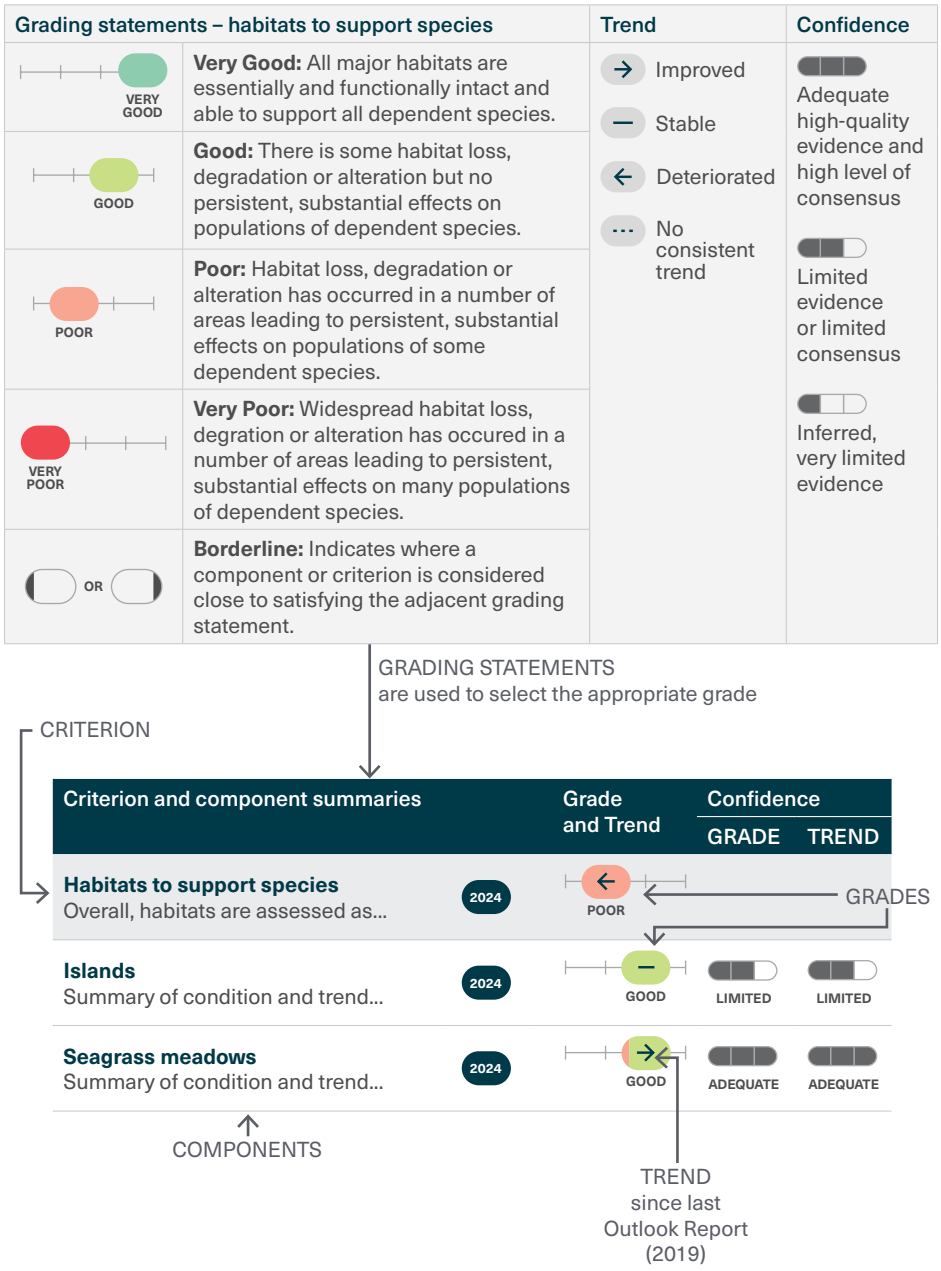


Figure 1.6 **Grades for criteria are informed by grades for components**

This figure shows an example from an assessment table for one of the biodiversity assessment criteria and illustrates the relationship between findings for a criterion and findings for its components. The grades for individual components (in this example, islands, seagrass meadows and mangrove forests) are key in informing the grade for the criterion (in this example, habitats to support species). Ultimately, both the criterion and component level assessments are guided by the relevant set of grading statements.

1.5 Evidence used

The Outlook Report contains brief background information on the Region, its ecosystems, heritage values, use and management, and the key evidence for the assessment required under legislation.

The information featured in this Outlook Report is a portion of all that is known about the Region with a focus on research and information sources from the past five years. The reporting period generally includes data from January 2019 to December 2023 and, where possible, compares it with historical trends. Evidence is drawn from the best available published science, data sets and knowledge based on:

- relevance to the required assessments
- duration of study
- extent of area studied
- reliability (such as consistency of results across different sources, peer review and rigour of study).

The Outlook Report is based on the best available evidence

Published peer-reviewed literature from technical experts is prioritised for most assessments. Long-term data sets and peer-reviewed monitoring program reports are considered highly persuasive evidence. Statistics from government-managed entities (for example, Australian Bureau of Statistics, Australian Maritime Safety Authority) are integral to the analysis in several chapters. Consultant reports may also be considered as part of the available evidence, but do not hold as much weight (particularly if not peer-reviewed).

The perspectives and knowledge of First Nations peoples have been incorporated through co-produced place-based stories, participation in workshops and, where available, published literature and reports (Section 1.7).

In some cases, information that became available in early 2024 has been included, where it was considered to make a significant difference to a key finding of the Outlook Report. Sources for the evidence used in each chapter are cited in the text. Web addresses provided in the report's references list were correct at the time of writing. Despite the volume of information available, many aspects of the Region — its values, uses and threats, in particular cumulative effects — remain poorly understood. Significant information gaps are noted in the text.

1.6 Terminology

Studies used in this Outlook Report vary in the spatial scales they cover. While only one grade is given for the Region, information available about a component (for example, seagrasses) may differ on a regional scale. The report attempts to discuss and summarise regional differences in condition and trends — however, there is no standard way of dividing up the Region when interpreting the data.

Where evidence covers larger areas, for ease of reading and comparison, results are summarised into three regional marine areas (or 'thirds of the Reef'): northern, central and southern (Section 2.3.5). Their boundaries are not precisely defined, but the northern area extends from the tip of Cape York to approximately Port Douglas (which marks the division between the less-developed and developed catchments adjacent to the Region). The central area extends from the northern area south to the Whitsundays area. The southern area extends south of the Whitsundays area to the Region's southern boundary near Baffle Creek (north of Bundaberg). The term 'southern two thirds of the Region' is often used to describe the combined central and southern areas.

Great Barrier Reef Marine Park 'management areas' are sometimes used to describe the main zoning sections within the Region: Far Northern (or far north), Cairns–Cooktown, Townsville–Whitsunday and Mackay–Capricorn. Within the Catchment and inshore locations, sectors are described by natural resource management regions: Cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary.

The Region is defined by the Act, whereas the Catchment is managed by multiple jurisdictions and is not specifically defined by Queensland legislation. The Catchment (Figure 1.1) encompasses the 35 river basins flowing into the Region.

Across the Region, the term 'inshore' may be applied differently for water quality, biodiversity and ecosystem health components. Inshore areas broadly correspond to enclosed coastal water bodies and open coastal waters adjoining intertidal areas and habitats adjacent to the coast, and inshore from mid-shelf reefs. Areas beyond are generally referred to as 'offshore'. For coral reefs, the term 'outer shelf' refers to reefs along the edge of the continental shelf and 'mid-shelf' refers to reefs between inshore areas and the outer shelf.

1.7 Developing the report

This Outlook Report has been prepared by the Reef Authority, with contributions of evidence from a number of Australian and Queensland government agencies, researchers from a range of institutions, industry data-holders and Traditional Owners.

Aboriginal and Torres Strait Islander peoples are the Traditional Owners of the Great Barrier Reef Region. Incorporation of the perspectives and knowledge of Traditional Owners has been enhanced in recognition of their deep connection and role in the conservation and ecologically sustainable use of the Reef. Every chapter begins with a Traditional Owner story from the Great Barrier Reef about caring for Land and Sea Country. A First Nations business worked with Traditional Owner communities and leaders along the Reef to develop these place-based stories for the report.[1] Enabling even greater Traditional Owner involvement in providing and considering evidence used in Outlook Report assessments will further enrich future reports.

The outcomes of an expert elicitation workshop[12], involving more than 45 scientists, Traditional Owners and other stakeholders, contributed to the biodiversity, ecosystem health and heritage value assessments (Chapters 2, 3 and 4). The outcomes also informed the forward-looking risk and resilience assessments (Chapters 8 and 9). The methodology for the expert elicitation workshop was modelled on similar workshops used for previous Outlook Reports.[4,5]

Five independent consultants specialising in protected area management, monitoring and evaluation, public policy and governance assessed the effectiveness of existing protection and management arrangements for the Region's ecosystem, its heritage value and, where relevant, the Catchment.[11] This independent assessment of management effectiveness also incorporated evidence from structured interviews with partners and stakeholders. The assessment identified gaps, improvements and deficiencies, and produced a comparative analysis with the 2009, 2014 and 2019 assessments. The assessors' report forms the basis of the assessment of existing measures to protect and manage the Region (Chapter 7).[11]

Five expert reviewers, appointed by the Australian Minister for the Environment and Water, independently reviewed the draft Outlook Report. These reviewers are recognised national and international experts with biophysical, heritage and/or socio-economic expertise and achievement, including conducting high-level policy and scientific reviews. Their comments were considered and incorporated into the final report.

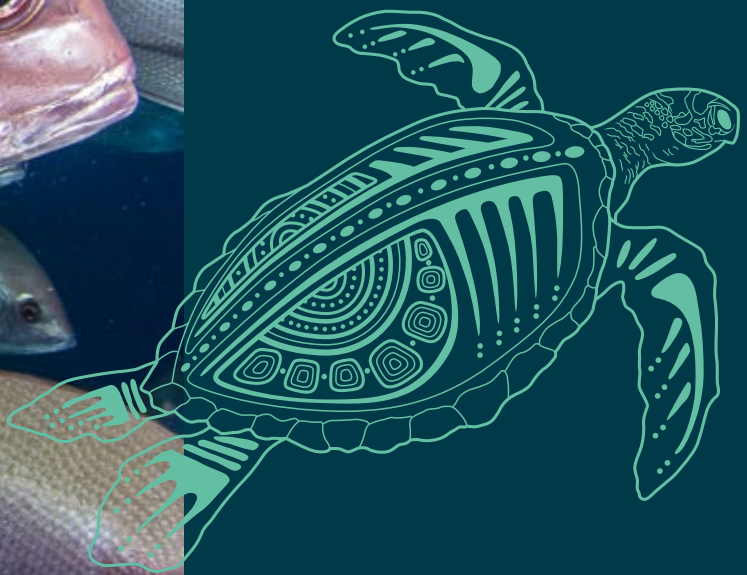


School of crimson snapper (*Lutjanus erythropterus*). © Matt Curnock 2020



Chapter 2

Biodiversity



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* (Cth)



Black-naped terns on the beach. © Queensland Government. Photographer: Matt Wright 2023

Seagrass and seagrass meadows are the unsung heroes of the Great Barrier Reef. They are essential habitats for marine species such as dugong and sea turtles, that also hold totemic value for Traditional Owners. On Gunggandji-Mandingalbay Yidinji (GMY) Sea Country, Indigenous rangers are learning western science and combining it with their own traditional knowledge systems and applying this on their Sea Country.

"You don't realise how much turtles and dugongs need seagrass, and the fact that there are four different types of seagrass on our Country, it is up to us to see the other side. We can all learn a lot from each other.

"We want seagrass healthy for our next generation, as a main food supply. And it would be good to see turtles and dugongs, stingrays coming back in more numbers. With turtles and dugongs, you don't realise how much they need seagrass, the seagrass environment is changing, the wet and dry seasons are changing. We can't rely on the old ways as much as we used to because of how climate is not following its normal habits"

— Stirling King, GMY Traditional Owner and Indigenous Ranger with the GMY Land and Sea Ranger program

A Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) survey and training program, part of the Healing Country Project, includes surveying, recording, and mapping deep water seagrasses in GMY Sea Country. GMY Indigenous rangers are becoming skilled and knowledgeable across traditional knowledges and learning from western science. The holistic approach that combines all knowledges across ecosystem health, marine science and environmental management is building personal and community capability.

"The seagrass mapping plays a big part in getting dugong and turtles back. It is about community, and getting kids involved now with Sea Country and culture — it is nice to be on Country with my people"

— Meegan Fourmile, GMY Traditional Owner and Indigenous Ranger with the GMY Land and Sea Ranger program

Source: Caring for Sea Country — Traditional Owner Stories from the Great Barrier Reef [1]



The green sea turtle is a totem animal for some Traditional Owners. © Matt Curnock 2022

2.1 Background

Biodiversity refers to the variety of living things in an area, including plants, animals and microbes, and their unique genetic information.[14] It is a fundamental component of ecosystem resilience (Chapter 8). The Great Barrier Reef is the largest coral reef ecosystem in the world and remains one of the world's most diverse and remarkable ecosystems. The biodiversity of the Reef underpins its rich and complex ecosystem, conferring a range of benefits to the Reef itself and to the industries and communities that depend on it for their livelihoods and wellbeing.

The Reef remains one of the world's most diverse and remarkable ecosystems

The Reef is not just a natural wonder, recognised for its outstanding universal value as a World Heritage–listed property. It is also a place of spiritual and cultural importance to the First Nations peoples who have lived in the Region for thousands of years.[15,16] The many and varied forms of life that make up the Reef have sustained Traditional Owners for millennia, and they carry special significance expressed through song, dance, music, and cultural artefacts (Chapter 4).

A place of spiritual and cultural importance to First Nations peoples

Despite its importance and the wealth of information available for some species and habitats, knowledge of much of the biodiversity on the Reef,[17] and in tropical marine ecosystems more generally, remains limited.[18,19] Rapid advances in technologies, including genome sequencing, are beginning to shed light on the unknown biodiversity of the Reef (see Box 2.1).

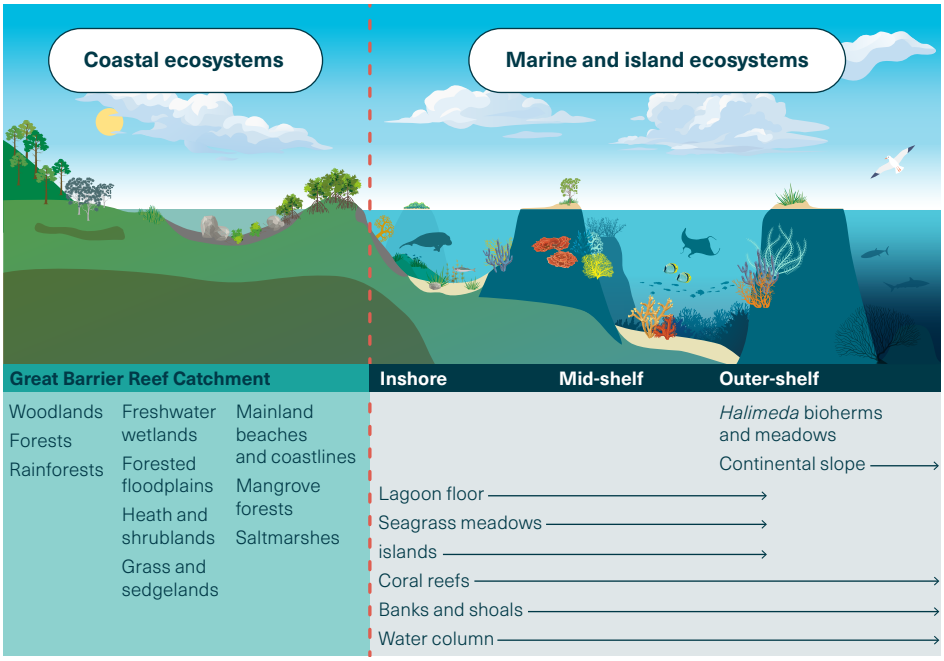


Figure 2.1 **Major habitats that comprise the overarching ecosystems of the Reef and Catchment**
A wide variety of habitats make up the Reef's coastal and marine ecosystem. The most pronounced variation is across the continental shelf from the inshore coastal habitats, such as mangroves and beaches,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

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 is important to note that these habitats and processes function at a hierarchy of scales,[33,34] in both space and time. Consideration has been given to the relevance of observed change over the past 5 years in the context of variability expected over widely varying timescales, from days to the many centuries over which the modern Reef has formed. Beaches, coastlines, and island habitats outside the Region are considered to the extent that they influence the values within the Region. Assessments of condition and trends in condition for coastal ecosystems that support the Reef are presented in Chapter 3.

BOX 2.1

The genomics revolution: insights into Great Barrier Reef diversity and resilience

Continuing rapid advances in genomics (sequencing and analysing an organism's genetic code) are providing new insights into biodiversity and the ability of species to cope with the impacts of climate change.[14] For example, genomic studies are revolutionising the way scientists understand the relationships of corals with their symbiotic microorganisms.[20] Genomic techniques are being used to challenge traditional understanding of coral taxonomy, and they have led to the discovery of new species, including cryptic species that are morphologically indistinguishable from previously recognised corals.[21] These findings suggest that coral diversity is even greater than previously thought.[22]

Environmental DNA (eDNA) analysis is a molecular technique that involves collecting samples from physical environments and using genetic markers to identify the presence of distinct species. eDNA is an emerging tool with wide-ranging applications.[14,23] Examples include the monitoring of rare, cryptic, and elusive species[23] (such as assessing benthic species of the lagoon floor[24]) and the potential early detection and monitoring of invasive species[25] (such as invasive ants on Reef islands).[26] These techniques may allow researchers to assess species assemblages quickly and relatively inexpensively. However, limitations on their application remain[23] because an adequate library of well-curated reference sequences for most species is currently lacking, and there are constraints in current genomic methods and analyses.[14,27]

Genomic data are also providing insights into the potential impacts of climate change on corals by identifying the way corals respond to stress at the molecular level[28] and the ability of corals to adapt in the face of rapid environmental change.[29] This is enabling the identification of coral species and populations with greater resistance to environmental stressors.[30,31] These resilient organisms could be vital to ensure the survival of coral reefs in a changing climate and in the development of new approaches to coral conservation and restoration.[32]

2.2 Legacies and shifted baselines

Assessing the current condition and trends in condition of key habitats and species involves considering ongoing impacts from a variety of historical activities and land use changes, as well as people's altered perceptions of their state over time. This section discusses these legacy impacts and shifted baselines.

2.2.1 Legacy impacts

Legacy human-use impacts encompass activities that caused significant environmental change in the past and continue to have major effects today, such as historical land clearing, coastal development and overfishing.[35] Legacy infrastructure that has modified the movement of water and species between the Reef and its Catchment continues to affect species and habitats [36] (Sections 3.4.10, 3.5, and 6.4.2). Historical commercial exploitation can also have ongoing effects on populations. Some species that were commercially exploited in the past have recovered well, such as humpback whales.[35] Populations and habitats can take decades or longer to fully recover to their pre-disturbance state, and some have been irrevocably altered.[37] Species and habitats that have yet to recover from historical disturbances include dugongs, some marine turtles, and certain islands that were cleared and mined for guano. For example, after 100 years of European settlement, many Reef islands still require active pest management programs to treat the legacy of pests introduced more than a century ago,[38] although contemporary impacts of recent pest re-incursions can confound the effects of historical introduction.



Legacy human-use impacts continue to have major effects today

Certain legacy impacts to inshore reefs and other habitats are linked to eroded topsoil and sediment particles originating from Catchment areas that have been transported and deposited in the Reef lagoon since European settlement [39] (Section 6.5). During this time, suspended sediments entering the lagoon are estimated to have increased up to five-fold, largely due to human influences.[40] These sediments carry a historical record of human activities and land use changes within the Catchment.[41] They also represent a large reservoir of nutrients, organic matter, fine particles, and other pollutants, such as pesticides that continue to affect inshore ecosystems [42] (Section 3.3.1 and 6.5.2).

Climate change is now part of a suite of legacy impacts, shaping ecosystem compositions and resultant biodiversity, ecosystem functions and services. Warming oceans are leading to novel ecosystem compositions as different species thrive or fail and species range shifts occur.[43] In some of these situations returning ecosystems to historical baselines may no longer be possible.

2.2.2 Shifting baselines

Human activity has caused significant environmental change for millennia [44,45] and this process has accelerated with a growing human population and burgeoning resource use over the past two centuries.[46,47,48] The long history of impacts can make it difficult to identify suitable baselines, or starting points, from which to assess environmental change.[49] Shifting environmental baselines can occur when, as generations pass, there is a perception that the current or recent past condition of habitats or species represents a natural state despite progressive degradation.[50] This is especially the case where historical or anecdotal information is not effectively considered.[50] In this way, progressive degradation, such as large declines in species diversity over long periods of time [50,51] or

the current pace of global warming,[52] may not be accurately recognised. Shifting baselines can present challenges for sustainably managing commercial species [53] and for restoring degraded ecosystems.[54]

For all these reasons, it is important to acknowledge the risk of using a shifted baseline to underpin a current assessment. Determining the condition of ecosystems or populations of species back through time is often complicated by the patchiness of records or reliance on anecdotal evidence. Without systematic monitoring and careful consideration of natural drivers, it can be challenging to determine whether local declines represent longer-term trends or regional-scale change.[55]



Perceptions of ecosystem condition can be skewed by shifting baselines

In many parts of the world, coral reefs have experienced significant depauperation compared to their historical condition, including declines in coral diversity and cover.[56,57] Although wide-scale systematic monitoring of - shallow-water coral reefs in the Reef has only been conducted since 1983,[58] longer-term declines in indicators such as coral cover have been demonstrated at some locations through multiple lines of evidence, including coral and sediment cores.[59] Combining scientific and traditional knowledge helps to promote a more holistic understanding of environmental changes, and has been demonstrated to improve environmental assessment and management.[60] Careful analysis of evidence from archival sources and scientific records (as well as anecdotal information) can provide important insights into the past and help avoid shifting baseline syndrome. The case of giant grouper illustrates this point.[51]

Reaching up to 400 kilograms and more than 2.5 metres in length,[61] the giant grouper is the largest bony fish occurring in the Region. Typically solitary, the species occurs naturally at low abundance across its range.[62] Although protected in Australia since 1994, the species was once highly prized in recreational fisheries and continues to be fished across other parts of its distribution.[63] Despite anecdotal and short-term evidence of severe localised depletions, relatively little is known of the species' life history or historical abundance. The global population trend for this species is downwards, noting data deficiencies.[62] More locally, shifting baselines may be helping to mask population trends in giant grouper, given the lack of data and limited intergenerational memory on past abundances (aside from that held by Traditional Owners).

In an attempt to shed light on historical baselines, recent research reconstructed giant grouper population trends in Queensland from fishing records reported in newspaper archives.[51] The study reveals a significant decline in the relative abundance of giant grouper between 1860 and 1958. This is based on a decrease in probability (dropping from 81 per cent to 2 per cent) of catching giant grouper in a popular recreational fishery over that period.[51] This study highlights the importance of archival sources in uncovering historical population trends and assisting in detecting shifting baselines.

The assessments below consider available evidence for each habitat and species component, including recent information and historical trends where available.

2.3 Condition and trend — habitats to support species

Ten habitats are graded in terms of current condition and changes over the past 5 years with respect to impacts on dependent species. *Halimeda* bioherms and meadows, and continental slope habitats, remain in very good condition. Islands, mainland beaches and coastlines, mangrove forests, lagoon floor, and other banks and shoals, are assessed to be in good condition, and seagrass meadows have improved to good (borderline poor) since 2019. Coral reefs have improved to poor (borderline good), and the grades for component regions indicate that condition generally decreases from the north to the south of the Region.

The full assessment summary is in Section 2.5.1.

This section assesses the current condition (and trends in condition) of key habitats in the Region, from the tropics to the subtropics and from the coast to the continental slope and deep ocean. The depth and breadth of available biodiversity information varies enormously between components of the Reef ecosystem. In remote, deep and inaccessible areas, new examples of habitat are still being discovered (Figure 2.2). Investments in established and emerging technologies (Section 6.2.3) are helping researchers to document the extent and biological richness of these lesser-known habitats.[64]

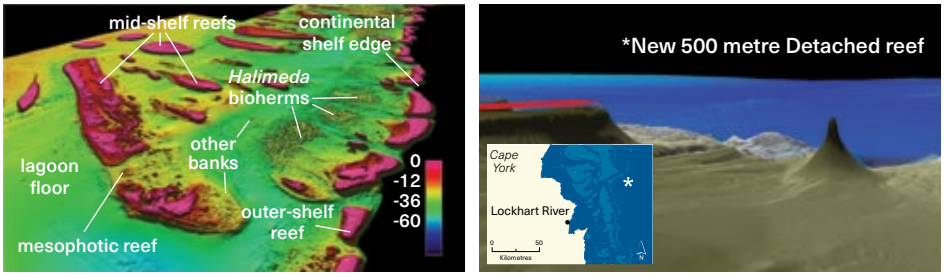


Figure 2.2 **Reef geomorphological features**
Left: A three-dimensional image of the Ribbon Reefs in the northern Great Barrier Reef identifying different habitat types. Right: A 500-metre-tall detached coral reef, which rises to 40 metres below sea level, was discovered off Cape York in October 2020. Sources: Dr Robin Beaman, James Cook University and Schmidt Ocean Institute

2.3.1 Islands

The Great Barrier Reef World Heritage Area includes approximately 1050 islands, consisting of continental islands (617), reef islands or coral cays (more than 300), and mangrove islands.[65] There are 70 Commonwealth islands in the Region, and the remainder are under Queensland Government jurisdiction or a range of other tenures.[66] About 470 of the Reef's islands are protected as Commonwealth islands or National Parks. This assessment considers all these islands because of their connection to, and influence on, the values of the Region.

The Reef's islands support unique flora and fauna and are critical to the life cycles of many species, for example, by providing internationally significant nesting sites for 4 species of marine turtle (Section 2.4.10) and supporting breeding colonies for 21 seabird species (Section 2.4.12).[66] They function as important refuges because islands are often

isolated from impacts present on the mainland and serve as key links connecting coastal and offshore ecosystems.[66,67] Ongoing regional ecosystem mapping and fauna surveys since 2019 [68,69,70,71,72] are adding to a rich baseline understanding of island ecosystems.[66,73] There is growing evidence that islands with nesting seabirds support more-resilient coral reefs, with improved coral growth and recovery rates linked to supply of seabird-derived nutrients.[74]

Islands serve as key links connecting coastal and offshore ecosystems

The Reefs' islands hold a deep history of stewardship by Traditional Owners, as evidenced by numerous cultural and archaeological sites,[75] and continue to be a critical component of the living cultural landscape for many groups.[76,77,78] For example, Jessie Island and Sisters Island, offshore from Cowley Beach, are important story places for the Mandubarra people. These sites are increasingly being documented and mapped to preserve and share this heritage.[76]

Since 2019, [146] islands, or parts thereof, amounting to 1508 hectares (15.08 square kilometres), have been added to Queensland's protected area estate, and more are on the way.[79,80,81,82,83] While these islands are not technically part of the Region, they have important influence on condition and connectivity for its habitats and species. Active efforts to acquire and bring more island area into Queensland's protected area estate and rehabilitation of degraded areas are reducing legacy impacts and providing additional protection for vulnerable species.[72,84,85,86,87]

Threats to island habitats include legacy impacts of historical guano mining; invasive plants and animal pests, such as goats, pigs and rats (Section 3.6.3); wildfires; impacts from direct use such as vegetation clearing; the degradation of cultural heritage (Indigenous and European); and plastic pollution transported from local and distant sources (Section 6.5.1).[72,88] Between January 2019 and October 2023, [55] of the more than 1000 islands within the Region were affected by fire including prescribed burns and wildfires.[89,90] During the same period, 26 wildfires burned within protected areas and forests on islands.[90] Preventing and eradicating highly invasive species (Section 3.6.3), such as yellow crazy ants,[91,92,93] contribute to improved biodiversity outcomes for island-dependent species in the Region.



Cockermouth Island near Mackay. © Mark Fitz 2023

Climate change is an important persistent threat. Rising sea and air temperatures, changes in cyclonic activity and otherwise amplified disturbance regimes, sea-level rise, and inhibition of reef-building processes, all present threats to island species and ecosystems.[94,95] Low-lying reef islands can be particularly vulnerable to rising sea levels and increased storm intensity, through impacts on water tables, island over-wash and erosion, and sand supply,[96,95] with consequential effects on vegetation[97] and species such as marine turtles.[65] Reef islands are dynamic landforms subject to the interplay between the living and non-living forces that shape them. Responses to climate change are likely to be complex and vary between islands (Section 6.3.2).[96,98] Efforts to document the detailed responses of reef islands to sea-level rise are underway using new data sources including drone technology, but detailed trend analysis is not yet available. Analysis of satellite images shows that island coastlines within the Region have been less stable in the past few years (2019 to 2022), compared to long-term average values (1988 to 2022): the proportion of island coastlines that are eroding has increased (Figure 2.3).[99] The significance of this in the context of natural long-term change is not yet clear.

Use of continuously evolving technologies (Section 6.2.3), such as acoustics and drones for seabird and marine turtle monitoring, is improving data collection and enhancing understanding of island resources.[66,100]

The condition of islands varies considerably across the Region and between island types. Some islands have experienced localised damage from severe weather and the accumulation of plastic pollution. Improvements have occurred on others due, for example, to pest eradication. Monitoring of island condition is increasing, and work is underway to assess the response of coral cays to sea-level rise.

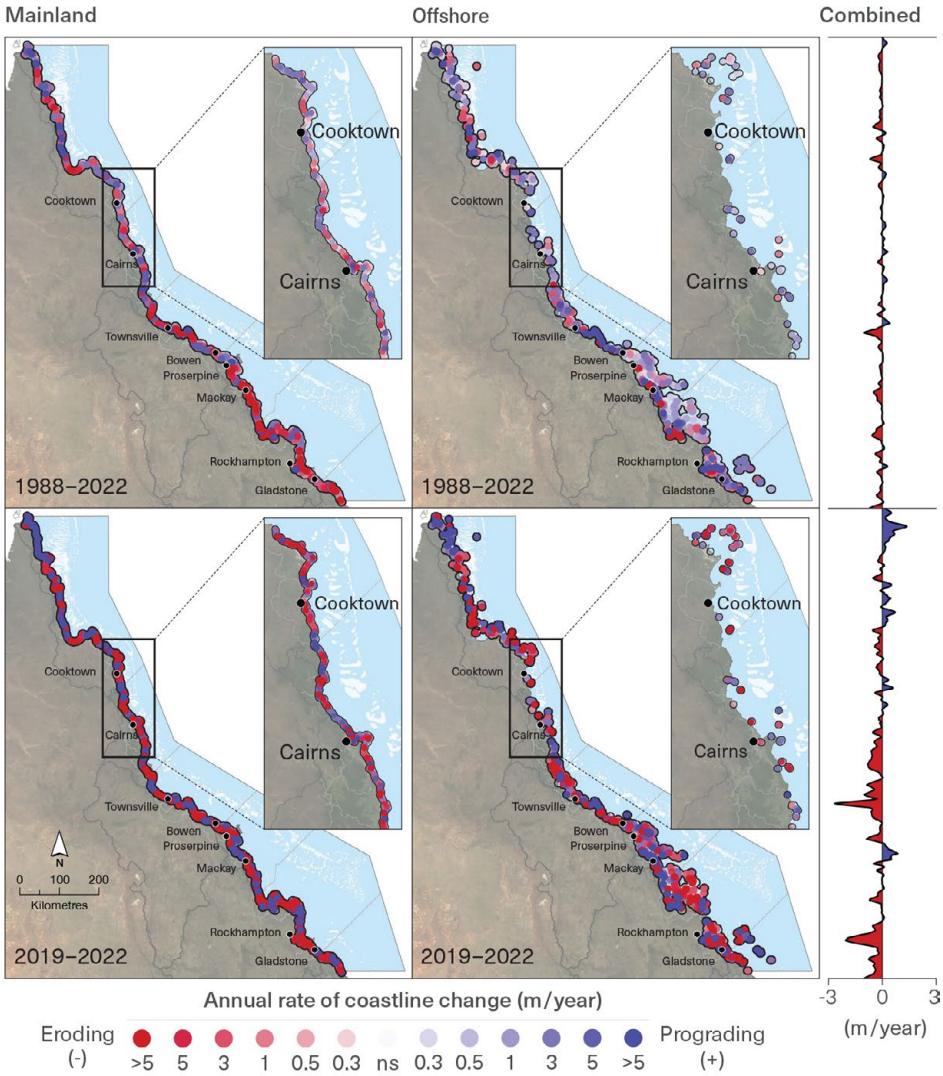
2.3.2 Mainland beaches and coastlines

The Reef's mainland coastline spans approximately 2300 kilometres of the Queensland coast. This assessment considers a range of coastal types including sandy beaches, rocky shores, estuaries, and tidal flats. The Region's mainland beaches and coastlines have aesthetic value and are readily accessible, providing an array of recreational opportunities that contribute to the local economy. Mainland beaches support seabird and turtle nesting as well as important migratory shorebird habitat.[101,102] They also include many sites of cultural and spiritual significance to the Reef's Traditional Owners.

The Region's coastline is monitored to measure shoreline trends, erosion and hazard lines, beach fluctuations, and storm demand (the removal of sand from beaches during storms).[103] Many factors contribute to the complex equation of whether a particular beach will recede or grow.[104] In general, beaches that are receding have a deficient supply of coarse sediments, such as sand and shingle, while other beaches build seaward where there is abundant supply of these sediments from the adjoining nearshore zones.[103] Understanding of the movement of mainland beaches and coastlines at scale has advanced considerably since 2019 with the availability of new data sources, improved remote sensing techniques, and increased computing power for analysis.[105,106] Analysis of satellite images shows that mainland coastlines within the Region have been less stable in the past few years (2019 to 2022) than the long-term average (1988 to 2022).[99] These changes are largely driven by higher recent rates of coastal erosion, possibly linked to the influence of La Niña conditions on wave direction.[107] Compared to the long-term average, the most significant coastal changes have occurred within the mainland Townsville–Whitsunday management area (Figure 2.3).[99]



Understanding of coastline movements has advanced considerably since 2019



Shoreline status (% of coastline)	1988–2022				2019–2022			
	Australia	Great Barrier Reef			Australia	Great Barrier Reef		
		Mainland	Offshore	Combined		Mainland	Offshore	Combined
Stable (<0.31 m/year)	77.5	67.7	81.4	73.2	64.3	60.3	71.7	64.9
Dynamic (≥0.31 m/year)	22.5	32.3	18.6	26.8	35.7	39.7	28.3	35.1
Eroding	12.7	17.0	6.2	12.7	27.9	24.7	19.0	22.4
Prograding	9.8	15.3	12.4	14.1	7.8	15.0	9.3	12.7

Figure 2.3 **Rates of coastline change relative to 2022**

Top: Annual rates of coastal change (metres per year) relative to 2022 for all Digital Earth Australia (DEA) coastline positions within the Region for the period 1988 to 2022, mapped separately for mainland and offshore coastlines. The combined summary plot shows the mean annual rate of change at 30-metre intervals of latitude. Middle: The same analysis, for 2019 to 2022. Bottom: This table shows a greater proportion of coastlines were dynamic (predominantly due to erosion) from 2019 to 2022 compared to the full time series (1988 to 2022). Source: Analysis by Geoscience Australia [99] using Version 2.1 DEA Coastlines product and following methods described in Bishop-Taylor *et al.* (2021)[108]



Beach at Etty Bay. © Nick O'Carroll 2020

While most beaches remain resilient at present, sea level rise is slowly intruding on estuaries and low-gradient shores and is expected to begin affecting beaches in the coming decades.[103] This effect is not expected to occur uniformly across the Region. Local changes are likely to be further complicated by coastal development and associated changes in freshwater and coarse sediment dynamics.[109]

Non-rocky coastlines remain dynamic. Observed changes over recent years are likely to predominantly reflect natural variation in climatic and oceanic influences, but sea-level rise is expected to increase rates of erosion, recession and inundation in coming decades.

2.3.3 Mangrove forests

Mangrove forests are specialised plant communities with canopies of trees or shrubs, adapted to cope with the salty, oxygen-limited soils of the upper intertidal zone. These forests cover an area of approximately 2387 square kilometres in the Region.[110] The Region's mangrove forests are diverse on a world scale and support a high biodiversity of associated species, dominated by invertebrates (crustaceans, worms, molluscs, and other benthic animals) and fishes.[111] They are important to the cultural heritage of First Nations peoples, who have made use of these abundant natural resources for thousands of years.[112] Mangrove forests are an integral component of a mosaic of coastal ecosystems, including estuaries, seagrass beds, and saltmarshes (Section 3.5.1), that provide ecologically and economically important linkages between terrestrial and marine environments.[113] While the connections between mangrove forests and fisheries are complex, these habitats are known to play a crucial role in providing food, shelter, and breeding grounds for species of commercial and recreational fishing value, such as bream, mullet, mangrove jack, barramundi, and prawns.[114]

Mangrove forests also provide a range of ecosystem services, including coastal stabilisation storm buffering, filtration of land-based runoff, nutrient cycling and export to marine ecosystems, primary production, and carbon sequestration.[36,115,116] As 'blue carbon' ecosystems, their capacity to accumulate and store organic sediments makes them important carbon sinks, contributing to the net removal of carbon dioxide from the atmosphere.[117,118] It has been estimated that every hectare of mangrove wetland stores about 550 tonnes of carbon.[36]

Mangrove forests provide vital ecosystem services including carbon sequestration

Mangrove forests continue to occupy most of their historical extent,[110] although coastal development and natural processes have led to both losses and gains through time.[119,120] Coastal developments including berms, ponded pasture, dams, seawalls, and roads on coastal plains, can lead to loss or degradation of mangroves and associated wetlands[121] (Section 6.4). Historical removal is a common legacy issue on degraded agricultural land, presenting opportunities for carbon capture through restoration in these areas.[122] Although overall extent has changed little since 2015,[110] expansion of mangroves has been observed in low wooded islands of the Howick Group in the northern Great Barrier Reef. This expansion equates to 10,233 tonnes of new mangrove biomass since the 1970s and is thought to be a consequence of changing environmental controls including relative sea-level rise over the past century.[123] The ability of mangrove forests to keep pace with rising sea levels is limited.[124]

Climate change is an increasing threat for mangrove forests, with sea level rise and coastal squeeze expected to impact mangrove forests in future decades (Section 6.3.2). Cyclone impacts generally remained low since 2019, though the impacts of cyclones in late 2023 and early 2024 have not yet been quantified. Evidence that greater damage after severe cyclones proportionately impedes recovery processes [125] suggests that future return intervals for severe cyclones will be a key determinant of future trends.
Since 2019, important advancements in reporting on condition of mangrove forests include incorporation of a satellite-derived canopy-cover index [126] into the National Ocean Ecosystem Account.[127] Mangrove condition indexes have also been incorporated into the Reef 2050 Regional Report Cards.[128,129] The condition of mangrove forests across the Region is considered good, with an overall stable trend between 2005 and 2021.[130]

Little change has occurred to the overall extent of mangrove forests. Gains and losses are occurring due to natural and anthropogenic processes. Evidence regarding the Reef-wide distribution and individual causes of these changes is currently limited. Acute cyclone impacts were relatively low from 2019 to 2023, but the impacts of successive cyclones during the 2023–24 wet season have not yet been assessed. Mangrove forests have expanded on some islands in the northern Great Barrier Reef.

2.3.4 Seagrass meadows

Seagrass meadows are among the most extensive and important habitats in the Region, providing stability to the seafloor,[131] cycling nutrients,[132] and sequestering and storing carbon.[133,134] They are considered key ‘blue carbon’ ecosystems.[117,127] Approximately 3464 square kilometres of inshore seagrass meadows have been mapped in the World Heritage Area, and approximately 32,000 square kilometres occur in deeper waters.[130] The total estimated area represents nearly half of Australia’s, and between 13 and 22 per cent of the world’s, seagrass meadows — making the Region’s seagrass resources globally significant.[133,135]

Seagrass meadows provide shelter and anchoring structures for small fish, prawns, and various other invertebrates.[136,137] These provide food for both resident and migratory fish species, thereby facilitating connectivity and productivity of fisheries.[138,139] Deep-water meadows tend to support larger-bodied fish and invertebrates but are not as productive as inshore meadows for fisheries resources.[140] Seagrasses are also a food source for dugongs and green turtles, which are important to First Nations communities.[141] These larger grazers play critical roles in structuring and connecting seagrass meadows.[142,143]

The Region’s seagrass ecosystems are a complex mosaic of different meadow types with multiple species.[144] They are found in estuaries, sheltered intertidal and subtidal coastal areas, in deep water, and on coral reefs.[144,145] All are subject to frequent disturbance from wave and air exposure, for example, and naturally fluctuate in extent and condition.[42]

Deep-water meadows, which grow below 15 metres and down to 76 metres,[146] are poorly documented compared to shallower meadows, and their extent is largely inferred from models of habitat suitability.[147] They are usually sparse and have a high capacity for recovery as long as seed reserves remain intact.[148]



Picasso triggerfish swimming over seagrass meadow at Green Island. © Dieter Tracey 2020

The primary threat to seagrass meadows is poor inshore water quality caused by land-based runoff or wind-driven resuspension of sediments (Section 6.5.2). Poor water quality reduces the amount of light available to seagrasses for photosynthesis, either directly (suspended sediments absorb and reflect light) or indirectly (excess nutrients promote the growth of algae in the water, on the sea floor, and on the seagrass itself) (Section 3.2.7).[145] Pesticides from land-based run-off, thermal stress from rising sea temperatures,[42] anchor damage, and acute disturbance events, such as cyclones, can also damage these habitats. In turn, seagrass habitat depletion affects dependent species, such as dugongs (Section 2.4.16) and marine turtles (Section 2.4.10).

Long-term seagrass condition is measured through seagrass abundance and resilience, which are summarised as a seagrass condition index.[149] Reef-wide seagrass abundance reached a low point in 2019–2020 due to cumulative pressures and legacy impacts of cyclones, floods and heat stress, but condition has since improved. Increase in seagrass abundance is one of the factors underlying the recovery in seagrass condition. In approximately 60 per cent of the monitoring sites, abundance either improved or remained stable over the past 3 monitoring years (2020–21, 2021–22 and 2022–23). Since 2019, seagrass losses in the northern regions have subsided. The greatest improvement was seen in the Burdekin Natural Resource Management (NRM) region as it recovered from the effects of heavy rainfall and above-average discharge in early 2019. However, declines in abundances were detected in all 3 southern regions during 2020–21 and although these declines have abated in the Mackay Whitsunday and Fitzroy NRM regions, they have continued in the Burnett Mary NRM region (Figure 2.4).[149] Data from monitoring programs will assist in determining the effects of the high temperatures, cyclones and associated flooding that occurred during summer 2023–24.

Condition of seagrass habitat has improved in northern regions

A new resilience metric has been developed and included as part of the seagrass condition index since the 2020–21 reporting period[150] (Section 8.3.2). In the past 5 years, resilience has generally improved. However, in the southernmost regions, measured resilience continued to decline over the past 3 monitoring years (2020–21, 2021–22 and 2022–23), and these meadows remain vulnerable to further disturbances. Across the Region, the recent impact of marine heatwaves is likely impairing recovery in exposed areas, even when meadows exhibit a substantial level of resilient traits.[149]

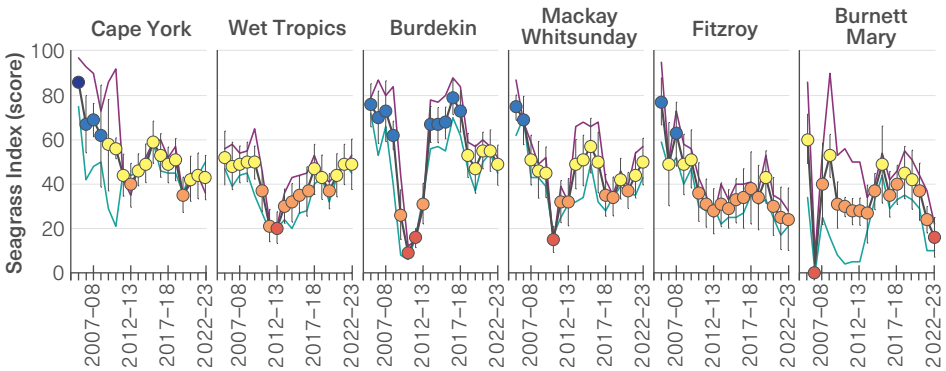


Figure 2.4 **Condition of inshore seagrass meadows in each region between 2005–06 and 2022–23**
Black line with circles represents the seagrass condition index score. Values are scaled from 0 to 100 (no unit) and colours indicate grade. Dark blue = very good (81–100). Blue = good (61–80), Yellow = moderate (41–60), Orange = poor (21–40), Red = very poor (0–20). The seagrass condition index combines indicators for seagrass abundance (teal line) and resilience (purple line). The condition (and trend in condition) of seagrass meadows varies at a regional scale. Over the past 5 years, condition has stabilised or improved in northern regions, but continued to deteriorate in southern regions.
Source: McKenzie *et al.* (2024) [149]

Seagrasses are affected by increasing temperatures and localised poor water quality. Recent shifts away from colonising species in northern regions are indicative of post-disturbance recovery. Due to impacts from flooding, seagrasses in the southern Fitzroy and Burnett Mary regions have not shown the same recovery. Information on condition of deep-water seagrass meadows is limited. Acknowledging regional variation, overall condition across the Region is assessed as good (borderline poor). In some parts of the Region, summer 2023–24 brought multiple stress events, the effects of which are not yet known.

2.3.5 Coral reefs

Coral reefs are the most iconic of the Great Barrier Reef's ecosystems and support the greatest diversity of marine species.[151,152] The Region's coral reefs have long provided sustenance, connection, and protection to First Nations peoples, and they provide vital ecosystem services to coastal communities, including productive fisheries, protection from damaging ocean swells and storm surges,[153] and a vibrant tourism industry. They are central to the Reef's outstanding universal value as a World Heritage Area.[154] This section assesses the condition (and trend in condition) of both emergent and shallow submerged reefs, and deeper coral communities. Since 2019, important advances have been made to improve baseline understanding of the distribution of coral reef habitat globally [155] and across the Region (Boxes 2.2 and 2.3).

A variety of calcifying organisms contribute to reef growth (most notably hard corals themselves). Complex habitat structure is also supported by older reef framework, associated coral rubble and sediments, and the physical and ecological processes which help to redistribute carbonate material within the reef system. In this section a focus has been placed on the coral components of coral reef habitats, even though other calcifying species are also important for reef building (Section 3.4.8).

Region overall

After a decade of cumulative impacts, the Reef experienced fewer major disturbances from 2018 to 2023 (prior to the 2023–24 summer). Only 3 cyclones tracked through the Region during this period (Section 3.2.2). Mass coral bleaching events occurred in 2020 and 2022. The 2022 event was the first recorded during a La Niña year. The 2020 event was the most widespread on record, with Reef-wide median temperature stress approaching levels associated with severe coral bleaching (Figure 8.3).[158,159] Despite the broad extent of bleaching, estimated coral mortality was low in both 2020 and 2022.[160,161,162] Observations of coral disease during this period[163] signal potential environmental stressors at affected reefs.[164]

A further two cyclones occurred early in summer 2023–24 (Jasper in December and Kirrily in January). Record global surface temperatures in 2023 and a transition to El Niño conditions[165,166] contributed to a widespread coral bleaching event in the Region in early 2024 (Box 2.3). At the end of summer 2023–24, the full extent and impacts of this latest coral bleaching event and the season's cyclones were yet to be determined.[167] These summer events are not considered in the assessment at Section 2.5.1.

The period 2018 to December 2023, which was relatively free of disturbances that cause widespread coral mortality, saw a substantial increase in coral cover, despite the 2020 and 2022 bleaching events. Increases were highly variable between reefs. Natural recovery followed a typical trajectory [174] of fast-growing corals (especially *Acropora* species) driving rapid increases in coral cover.[161,162] Despite their importance in leading ecosystem recovery, the susceptibility of these fast-growing corals to predation by crown-of-thorns starfish, thermally induced bleaching, breakage and removal during cyclones, and outbreaks of disease, is well documented.[175]

Natural recovery led by fast-growing corals drove rapid increases in cover

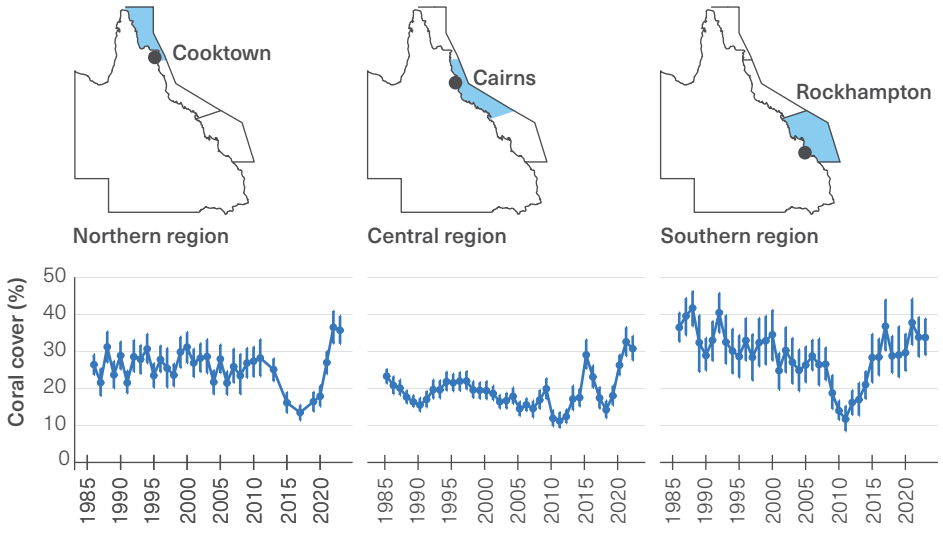


Figure 2.5 **Trends in mean hard coral cover since 1986 for the northern, central and southern Reef**

Mean hard coral cover (blue line) is shown for mid- and outer-shelf reefs. Blue shading represents 95 per cent credible intervals. Each graph shows trajectories of change over time (based on manta tow surveys). Levels of coral cover are mostly driven by the cumulative impacts of the main disturbances affecting surveyed reefs, including severe cyclones, outbreaks of crown-of-thorns starfish and coral bleaching. Source: Australian Institute of Marine Science (2023)[161]

Coral reefs within the shallow areas of the mid shelf and outer shelf have been systematically monitored for over 35 years.[176,177] Inshore coral reefs have also been monitored for nearly 2 decades to complement offshore monitoring. While a variety of metrics are assessed and reported following each survey cruise,[178] reef condition is primarily reported as changes in coral cover.[161] Coral cover is commonly used to quantify the state of coral reefs, as it is a simple metric easily obtainable across large scales. Although a widely used and very useful metric, coral cover on its own is unable to provide a reliable indication of diversity, ecological function, or the state of ecological processes (Section 8.3.1).

The condition of coral reefs across the Region is highly variable, both on a regional scale and at the scale of individual reefs. Overall, condition is assessed to have improved since 2019 due to increases in total cover of key reef-building coral species across many reefs. Understanding condition more broadly is complex and it is unclear whether the recovery in hard coral cover has resulted in shifts in the composition of species within coral assemblages or included recovery of reef-associated species. Coral reefs remain vulnerable to the cumulative pressures brought by climate change, crown-of-thorns starfish outbreaks, and poor water quality in inshore areas – factors that amplify impacts and inhibit recovery from acute disturbances such as cyclones and floods.[179] Little is known about the condition of deeper coral communities across the Reef due to the inaccessibility of these sites (Box 2.4), but they may provide critical refuge areas during periods of thermal stress.[180,181]



Measures of coral condition other than coral cover are poorly understood

Trends in coral cover on offshore reefs are reported for 3 regions: the northern, central and southern Great Barrier Reef (Figure 2.5). These coral cover results and condition more broadly are explored below.

Northern Great Barrier Reef — from Cape York to Cooktown | *Coral cover:* Reef-building coral cover in the northern region showed strong recovery after significant coral losses due to the cumulative effects of severe cyclones in 2014 and 2015, crown-of-thorns starfish outbreaks, and the 2016 mass bleaching event [163] (Figures 2.5 and 2.6). During summer 2022 hard coral cover reached record highs across the region; there was much variation between individual reefs.[182] Although this region experienced two cyclones that made landfall since 2019 (cyclones Trevor and Tiffany), impacts to coral reefs were generally local. Crown-of-thorns starfish density has been generally low, but recent evidence reported a buildup in numbers around Cape Grenville and Lizard Island.[183,184] The effects of exposure to moderate heat stress from the 2020 and 2022 bleaching events may have contributed to a flattening of recovery trajectories in 2023.[162,163]

Broader condition: As elsewhere, the impacts of moderate temperature stress on coral reef biodiversity and measures of coral condition other than coral cover are poorly understood. The northern region includes many remote and poorly studied reefs. Little is known about the condition of its inshore, fringing or deeper reefs, and remote reefs have potentially been under-sampled.

From 2019 to 2022, coral cover on offshore reefs recovered strongly from low levels of coral cover, although a pause in that trajectory occurred in 2023. Trends are highly variable among reefs and the condition of most coral reef habitat components is unknown.

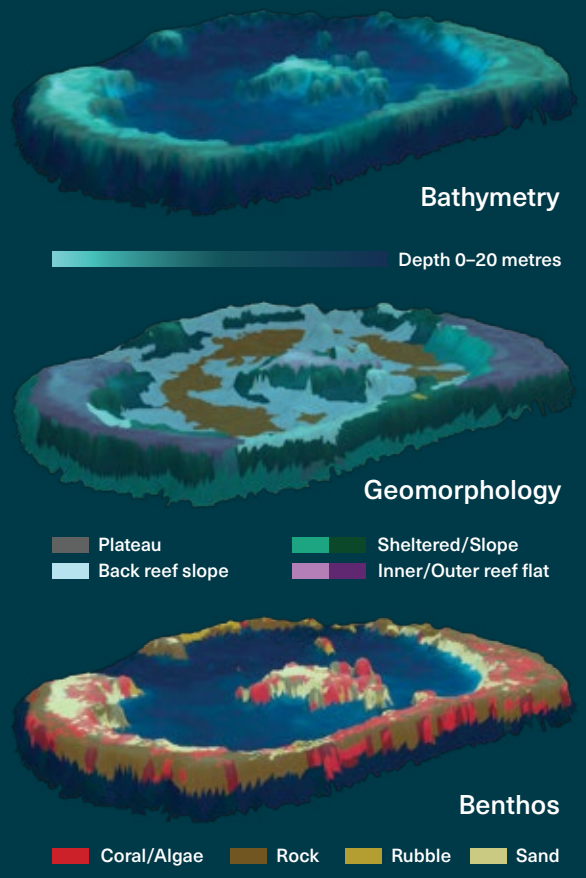
BOX 2.2

New habitat maps for the Great Barrier Reef

Detailed maps of benthic composition, geomorphic zonation, and bathymetry at high spatial resolution for every individual reef establish an improved baseline for monitoring, mitigation, management, permitting, and policy development across the Region.

The three-dimensional Great Barrier Reef habitat mapping project led by the University of Queensland is creating maps using a combination of field data, ecological knowledge, satellite imagery and machine learning. Offshore reef maps have been publicly available [156] since 2021, and maps of the Region's inshore reefs will be released in early 2025. The collective data may also be used to update the Reef Authority's indicative reef outline dataset displayed on zoning plan maps.[157]

Current applications of these maps include improved planning for the Crown-of-thorns Starfish Control Program, tracing coral larvae and finding their sources and sinks, hydrodynamic modelling to predict the movement of water and key environmental conditions over the Reef, and selecting intervention sites at reef and intra-reef scales.



Three-dimensional bathymetric, geomorphic and benthic habitat maps of Unnamed Reef 21-110, southern Great Barrier Reef. © The University of Queensland 2023

BOX 2.3

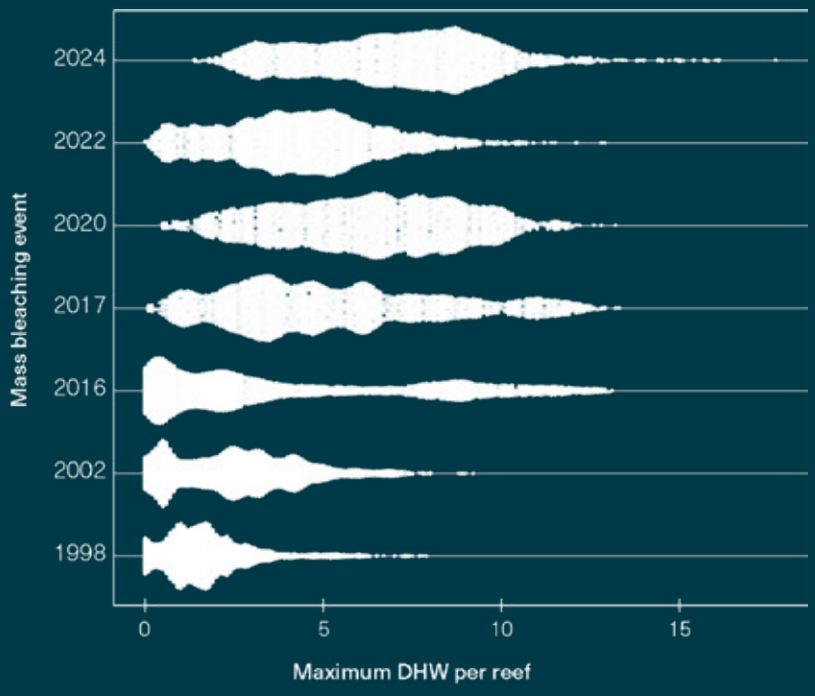
Another coral bleaching event affects the Great Barrier Reef

Heat stress accumulated in all 3 regions of the Reef over the 2023–24 summer.[167] Sea surface temperatures peaked at 2.5 degrees Celsius above historical summer maximums in the southern region, leading to accumulation of the highest levels of heat stress in the satellite record for the Reef.[168]

A mass coral bleaching event was confirmed in March 2024 following aerial surveys of over 1000 reefs.[168,169] This is the third mass bleaching event since 2019 and the seventh recorded for the Reef. In 2024, extreme levels of bleaching (where greater than 90 per cent of corals on a reef are affected) were, for the first time, recorded within all 3 regions.

The Reef Authority works with the Australian Institute of Marine Science, the Reef Joint Field Management Program, Crown-of-thorns Starfish Control Program, tourism operators, and researchers on gathering data from in-water surveys.[170] These complement the aerial survey results and provide detail on the severity of coral colony responses, the prevalence of bleaching in different habitats and depths, and levels of coral mortality.

At the end of summer, preliminary results indicated mortality had begun [167] in badly bleached areas. As it becomes available, further information on the severity of the 2024 mass bleaching event will be shared through the Reef Authority's Reef Health webpage [171] and the Australian Institute of Marine Science's Reef Monitoring webpage.[172]



Thermal stress during mass coral bleaching events,1998 to 2024
The graph shows thermal stress accumulated on individual reefs during each of the 7 mass bleaching events on the Great Barrier Reef. Thermal stress is measured in accumulated degree heating weeks (DHW), a measure of how long and by how much sea temperatures have exceeded a local temperature threshold. Source: Roff (2024)[173]

BOX 2.4

Deep coral communities

Shallow-water coral reefs, which are dominated by photosynthetic organisms, generally require high light conditions for the growth and calcification of reef-building corals and algae (Section 2.3.5). These reefs accumulate calcium carbonate faster than it is removed.[191] However, hard and soft corals also form abundant communities on deeper banks, which are fully submerged and not growing towards the surface. These banks are the remnants of earlier periods of reef growth and may be topped by drowned 'give-up' reefs that could not keep pace with rapidly rising sea levels following the most recent ice age.[192] Formed when sea levels were much lower, some shelf-edge banks and drowned reefs are found below 100 metres depth.[193] Numerous small drowned reefs have been mapped in the northern Reef since 2019.[194]

In combination with other physical processes, such as water movement, sedimentation, and temperature fluctuations, assemblages of deeper coral communities vary markedly with depth along gradients of light availability.[195] In deeper environments, such as the continental slope, communities are dominated by corals that can survive without light.[196] These depth-related changes in benthic community composition are associated with corresponding changes in the structure and function of fish and other faunal assemblages.[197,198] Fish assemblages in deeper habitats are dominated by mobile predatory species while shallower habitats support fish with a wide range of dietary preferences.[195]

Technological advances over the past two decades, including robotics and advanced diving technology, have seen an exponential increase in research interest on deeper coral communities.[198,199] Nevertheless, despite active research efforts and the importance of these habitats as potential refugia,[180] the logistical challenges of studying and monitoring deep-water habitats mean that knowledge of the ecological condition of the Region's deeper coral communities and how they have changed over time remains lacking.[198,200]

Central Great Barrier Reef — from Cooktown to Proserpine | The central region includes areas where mid- and outer-shelf reefs are relatively close to key population centres that provide access for research and visitation, as well as popular inshore fringing reefs, such as those in the Whitsunday islands. As a result, the central region has the best studied coral reefs at a region-wide scale. The region is also influenced by freshwater inflow from the Wet Tropics NRM region catchments, which receive average rainfall of more than 1500 millimetres per year. Reefs (inshore and mid-shelf) in the central region are affected by cumulative impacts, including coral bleaching, nutrients and sediments from land-based runoff, and pressure from fishing activities. Some inshore reefs are known to support a high diversity of coral species but they tend to have low coral cover [185] compared to their offshore counterparts. The outer continental shelf slopes more gently in this region than it does further north and is dominated by submerged reefs along the shelf edge [186] (Box 2.2).

Coral cover: The central region has seen large and rapid fluctuations in coral cover over the past decade. Record low coral cover in 2012 (11 per cent), primarily due to the impacts of cyclone Yasi, was followed by a period of recovery that peaked in 2016 (29 per cent).[160] This peak was followed by significant mortality resulting from mass coral bleaching in

2016 and 2017 and crown-of-thorns starfish outbreaks on many reefs. However, since 2019, the abatement of crown-of-thorns starfish outbreaks has been hastened by active culling of substantial numbers of starfish in the region.[187] Between 2019 and 2022, the period of low cyclone activity, low mortality following the 2020 and 2022 coral bleaching events and improved crown-of-thorns starfish control enabled coral cover to increase from 12 to 33 per cent (Figure 2.5), and it has remained stable since.[161] This recovery has been observed mainly on upper reef slopes and there is very limited information on the condition of deeper areas. In the Whitsundays, coral cover has gradually increased since the impacts of cyclone Debbie in 2017 on inshore reefs [185] (Figure 2.6).

Recovery since cyclone Debbie has been slow at some inshore reef sites

Early reports suggest cyclone Jasper in December 2023 led to minor and isolated bleaching on a few reefs, likely as a result of freshwater plumes, and minor damage to some exposed reef aspects.[188] Following cyclone Kirrily in January 2024, preliminary observations indicated some impacts to branching and plate corals in a limited number of inshore and mid-shelf reefs off Townsville.[189]

Broader condition: Improvements in inshore coral condition, measured through the coral index, a composite of 5 indicators (coral cover, proportion of macroalgae, juvenile coral density, rate of coral cover change and hard coral community composition), have been slow since cyclone Debbie, including for the Whitsundays reefs.[185] Recovery has been hindered primarily due to the persistence of macroalgal cover in some inshore reef sites.[185]

Since 2019, recovery of coral cover has been recorded in the central region; full community-level recovery may take much longer. Condition of individual reefs is highly variable, and recovery of some inshore reefs has been limited.

Southern Great Barrier Reef — from Proserpine to Baffle Creek | The southern region encompasses a huge area with a diversity of very different reef types. This region includes inshore reefs vital to tourism and has a greater coastal population with more industry than further north. It also includes many remote offshore reefs that are rarely visited and poorly studied. The continental shelf widens in this region, extending to the outer Pompey Reefs and the Swain Reefs.

Coral cover: The southern region has experienced the largest fluctuations in coral cover since systematic monitoring began.[161,185] Cyclone Hamish in 2009 decreased coral cover to a record low in 2011 in offshore reefs. A period of recovery brought coral cover to 37 per cent in 2017, but this was reduced again in 2018 by crown-of-thorns starfish outbreaks. Average coral cover in 2022 and 2023 was around 34 per cent (Figure 2.5).[161,178] The southern region was not as severely affected by the 2016 and 2017 mass bleaching events as the central and northern regions. Despite widespread bleaching of corals in 2020 and 2022, subsequent coral mortality on surveyed reefs was minimal. Since 2019, coral cover has been more variable between individual offshore reefs in the southern region than in the northern and central regions [161] (Figure 2.5). More reefs were recorded with high coral cover than with low or moderate. Outbreaks of crown-of-thorns starfish were ongoing in the Swain Reefs in early 2024,[167] but culling on these reefs has likely mitigated some of the coral losses. In the inshore reefs of the Keppel Islands group, coral cover has steadily increased since 2014, but variability exists between reefs.[190]



Figure 2.6 **Changes to coral communities since 2018**

Time-series photographs showing recovery in coral cover at monitoring sites within the Region.
First row: Changes in coral cover at North Reef, Lizard Island in the northern region.
Left to right: images taken in 2018, 2021 and 2023 showing recovery of coral cover over this period.
Images © Coral Sea Foundation 2018, 2021 and 2023.
Second row: Coral recruitment in Manta Ray Bay within the central inshore region. In 2017, waves generated by cyclone Debbie displaced a number of massive *Porites* corals (or bommies) in Manta Ray Bay. Three months after impact, bommies were manually repositioned back to subtidal areas of the reef flat. Since being moved back into place, natural recruitment of *Acropora* corals has been observed on the bommies, although no noticeable increase in *Porites* coral tissue has occurred. Left to right: images taken in December 2019, March 2022, and May 2023 showing an increase in the number and size of Acropora recruits with each survey. Images © Maya Srinivasan 2019, 2022 and 2023.

Crown-of-thorns starfish control has mitigated some coral losses

Broader condition: In the inshore region, the condition of coral reefs as measured by the coral index has been stable since 2019. However, macroalgal cover has steadily increased since 2020, which is hindering recovery of coral condition in some areas.[190] In mid-shelf and offshore reefs, macroalgal cover, after a decline between 2020 and 2022, macroalgae increased in 2023, though cover is still one-tenth that of inshore reefs.[178]



Teeming fish on a coral reef. © Matt Curnock 2021

Overall, coral cover improved, or at least stabilised, since 2019 at most reefs in the southern Great Barrier Reef. Coral cover is highly variable among reefs. In the inshore area, coral condition has stabilised since 2019, but remained poor for most reefs. Persistence of high macroalgal cover above local thresholds is a likely driver influencing overall coral condition in the inshore region. Crown-of-thorns starfish continue to affect reefs but are generally below outbreak levels, except in the Swain Reefs.

2.3.6 Lagoon floor

The lagoon floor encompasses the non-emergent seafloor of the continental shelf and represents approximately 61 per cent of the Region.[5] This huge area supports thousands of species, many of which were unknown before baseline surveys in the early 2000s.[201] A variety of lagoon floor ecosystems can be identified according to their unique biophysical attributes including substrate type, water clarity, and presence of characteristic flora and fauna.[33,202] Lagoon floor habitats vary from muddy, silty, and sandy sediments of terrestrial origin in inshore areas to carbonate sands and gravels of biological origin further offshore.[203] Where conditions are suitable (such as hardened areas of ancient shorelines[204,205]), more species-rich and structurally complex conglomerations of algae, sponges, bivalves, soft corals, and other sessile organisms are found.[203,206] Palaeochannels (ancient riverbeds) cross the lagoon floor in several areas. These geological features provide insight into past river flows and climate conditions[207] and some remnant palaeochannels are important conduits for water movement between continental slope and lagoon floor habitats.[208] The lagoon floor houses a wealth of historic shipwrecks and associated artefacts (Section 4.4.3) and likely evidence of early occupation of the Region by First Nations peoples.[15] Lagoon floor habits are economically important, supporting fisheries for prawns, scallops and sea cucumbers.[5]



Monitoring the lagoon floor presents an enormous logistical challenge

Knowledge of the condition (and trend in condition) of lagoon floor habitats is limited. Despite its importance, monitoring the lagoon floor presents an enormous logistical challenge for researchers.[209] Survey technologies, such as remotely operated underwater vehicles, advanced video analytics, and environmental DNA (Section 6.2.3) are poised to enhance understanding of lagoon floor habitats in coming years.[24,210]

Lagoon floor habitats can be affected by poor water quality, especially the presence of suspended sediments and nutrients that promote the growth of phytoplankton in the overlying water column. Sediments can smother benthic organisms and reduce light penetration, affecting photosynthetic organisms, such as benthic algae, seagrasses, and symbiotic zooxanthellae. Human activities, such as trawling,[211] dredging, and anchoring can cause physical damage to seafloor habitats and resuspend sediment, which affects water quality. Fishing, pollutants in land-based runoff and storms can also affect the integrity of lagoon floor ecosystems. Rising water temperatures are a threat, especially to sessile benthic organisms that cannot readily migrate as adults to avoid heat stress.[212]

The lagoon floor encompasses a wide diversity of habitats and species with varying sensitivity and exposure to anthropogenic impacts. Although not systematically monitored, much of the lagoon floor is exposed to increasing sea temperatures, with potential impacts to heat-sensitive species. Some areas also continue to be affected by fishing, anchoring and changes in water quality. Trend in condition has been assessed as stable since 2019 but the threats posed by climate change have not abated.

2.3.7 Other banks and shoals

In addition to coral reefs (Section 2.3.5) and *Halimeda* bioherms (Section 2.3.8), a range of other features rise from the seafloor and provide important habitat in the Region. These features have varying geological origins and different degrees of consolidation and structural complexity.[33] They can be categorised according to their unique set of biophysical characteristics [33,202] but, broadly, if they do not present a hazard to surface navigation, they are referred to as subtidal banks.[213] Otherwise, they are known as reefs (consolidated substrate) or shoals (unconsolidated substrate).[214] Many of these are relict coastal features created and modified as rising seas flooded the continental shelf following the most recent ice age.[215] These banks and shoals provide important habitat for a diversity of sessile and mobile species and are important sites connecting nearshore and offshore habitats.[216]

The degree to which seafloor features have consolidated into solid structures is important to their functioning as habitat.[33,202,215] Hard-bottom banks can support long-lived communities of benthic organisms.[217] They tend to be more physically complex structures than adjacent unconsolidated or flat seabed, providing a greater variety of microhabitats.[217] Most hard-bottom banks are relict coral reefs, many of which provide suitable habitat for coral communities (Section 2.3.5).[213,218] Other banks support rich benthic communities including gorgonians, sponge beds, seagrasses, and macroalgae assemblages,[193] which harbour a diverse and abundant fauna of fish, sharks, rays, sea snakes, and marine turtles.[206,219]

Banks and shoals support rich benthic communities and abundant mobile fauna

Unconsolidated shoals and deeper banks are important and widespread in the Region. These habitats are composed of mobile fragments unsuitable for many benthic organisms to colonise.[202] They include a range of active and relict features, such as drowned river deltas and tidal banks on the seafloor.[215,218,220,221] Submerged, dynamic landscapes of dune ridges and troughs, in places such as the far northern and southern Great Barrier Reef, likely represent an important habitat for mobile fauna.[222,223] Many unconsolidated banks occur in areas that are difficult to access and often highly turbid, resulting in only limited information being available on their ecological importance in the Region.[220]

The extent and condition of other banks and shoals are not well documented due to their unique locations and often inaccessible nature. Although not systematically monitored, condition is inferred to be good, and trend stable, based on a relative lack of intense disturbances (for example, from cyclones) since 2019 and unchanged anthropogenic pressures.

2.3.8 *Halimeda* bioherms and meadows

Halimeda bioherms are massive underwater structures consisting mainly of the accumulated remains of calcareous green algae (genus *Halimeda*).[224] They form ring-shaped mounds, up to 20 metres thick and 300 metres across, that are linked in honeycomb-like networks of decreasing complexity from west to east across the continental shelf.[225] The most extensive are found inside the northern Ribbon Reefs, where cold, nutrient-rich water from the deep ocean is pushed between the outer reefs by tidal jets (Figure 2.7), [201,226] but similar formations are found elsewhere, for example, in the Swain Reefs.[206,224] The northern bioherms are the most extensive actively accumulating *Halimeda* deposits in the world, contributing to outstanding universal value from a geological and geomorphological perspective [227] (Section 4.2). They cover an area of

approximately 6000 square kilometres of seabed, about 26 per cent of the narrower northern shelf, which equates to an area roughly equivalent to that of the shallow coral reefs in this region.[198,218]

The bioherms are overlain with meadows of living vegetation, dominated by *Halimeda*, but includes other algae and seagrasses.[225] Thirteen species of *Halimeda* are found in the Region, and the meadows are dominated by the same species that grow on nearby coral reefs.[228] Some species can grow in very low light, occurring down to at least 150 metres deep where they occasionally form cascading vertical 'draperies'.[193,229] *Halimeda* also grows in extensive meadows behind the Ribbon Reefs and in the central Reef, particularly in deeper waters (60 to 100 metres) in areas where bathymetry favours upwelling.[224,227] *Halimeda* bioherms have become a subject of research interest because of their significant impact on the carbon cycle and potential importance in cross-shelf nutrient cycling.[231] *Halimeda* grows very fast, producing a new segment every few days, and has physical and chemical defences against herbivory,[232,233] making it a highly productive source of calcium carbonate.[227] Unlike coral reefs, the bioherms have formed entirely since the peak of the most recent ice age, accumulating up to 4 times more carbonate sediment than nearby coral reefs during this time.[234] The relative lack of knowledge on the ecological condition (and trend in condition) of these features represents a key knowledge gap.

Knowledge of the extent and structure of *Halimeda* bioherms has improved

Little is known about the fundamental processes that control bioherm distribution and development, or about the biodiversity and ecology of *Halimeda* meadows.[235,230] However, important advances have been made in understanding the baseline condition and ecological importance of the northern Reef bioherms since 2019.[235] Seafloor mapping has provided systematic three-dimensional images that reveal the intricacy of bioherm topography at sub-metre resolution, and insights into their geologic foundations (Figure 2.7).[236]

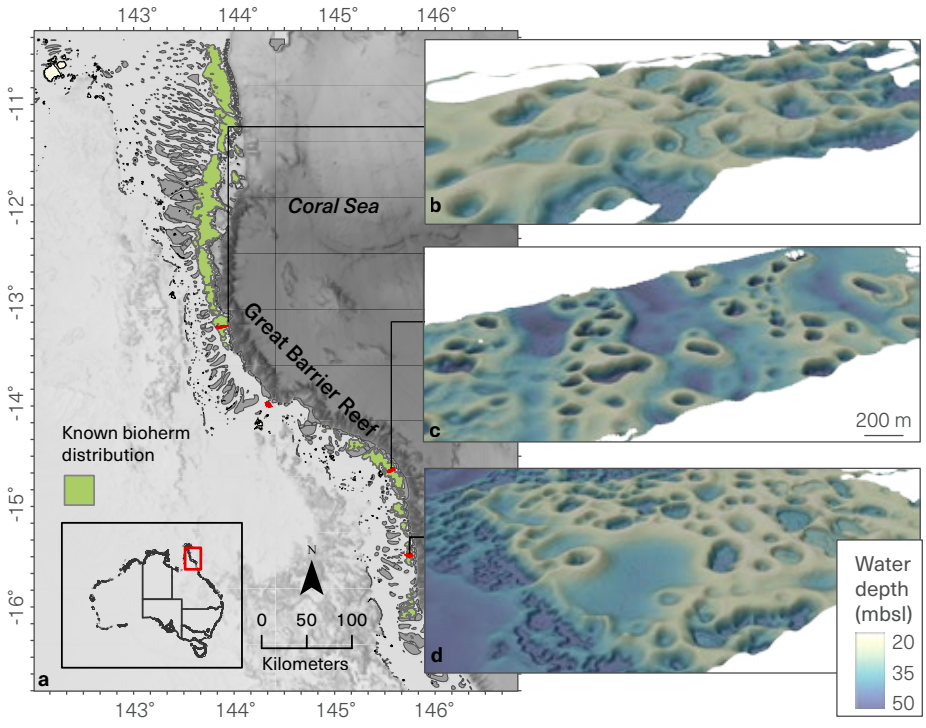


Figure 2.7 **Distribution and structure of *Halimeda* bioherms in the northern Great Barrier Reef**
The distribution of *Halimeda* bioherms is indicated in green. Representative three-dimensional images based on newly collected bathymetry data display the complex bioherm morphologies at 3 sites (b–d).
Source: Project HALO team/EOS [230]

Advances in understanding of meadow biodiversity have resulted from recent taxonomic collections and their ongoing study.[236] Several potential new species have been collected but are yet to be formally described and named[230] as have organisms not previously known to occur in these habitats.[237]

Knowledge of the extent and structure of the northern *Halimeda* bioherms has improved since 2019, alongside advances in understanding their functions and biodiversity. However, information on the condition (and trend in condition) of this habitat remains lacking. Since 2019, impacts from acute disturbances are inferred to be negligible due to the depth and isolation of these habitats.

2.3.9 Continental slope

The continental slope marks a relatively steep transition from the continental shelf to the deeper ocean basins. Covering about 15 per cent of the Region, the continental slope is a major part of the underwater landscape within the Marine Park. Slope habitats provide important connections within the Region and with the adjacent Coral Sea Marine Park.[238]

Within the slope, deep incisions have been carved out, creating steep-sided valleys called submarine canyons. The Region has more than 100 of Australia's 750 submarine canyons, found from the central to the far northern Reef.[239] Some of these canyons follow the paths of ancient river courses, while others have formed where sections of the slope have slipped away in undersea landslides.[194,240] Some are complex, interconnected systems incorporating channels, internal sand waves, landslides, and plunge pools.[241] These canyons play a crucial role in supporting and regulating the Reef's ecosystems, acting as conduits for cold, nutrient-rich waters to well up from the ocean depths to the slope and shelf.[239]



Slope habitats connect the Reef with the adjacent Coral Sea Marine Park

Remotely operated underwater surveys and collections provide evidence that the unique oceanographic conditions and high productivity of these areas support high biodiversity, including vulnerable species and habitats, such as cold-water corals and sponge gardens.[242] The canyons provide nursery and refuge sites, as well as navigation pathways, for many species; for example, they play a vital role in the ecology and life history of deep-water whales and dolphins[243] — about which little is known in the Region.

Recent research has focused on detailed mapping of the structure of shelf-edge canyons and associated features, such as extensive submarine landslides seaward of the Swain Reefs, and plunge pools found near the Detached Reefs off Cape York (Figure 2.8).[194,241] These latter features, of uncertain origin, [244,245] are found on deeper parts of the slope and resemble the plunge pools found at waterfalls. Detailed surveys have highlighted two main types of canyons: shelf-connected canyons and reef-blocked canyons.[241] Shelf-connected canyons transport continental (silica) sediments into the deeper ocean, whereas reef-blocked canyons have shallow reefs at the canyon rim that block the movement of this sediment. The ecological characteristics of these canyon types remain largely unexplored.[241]

As climate change continues to affect marine ecosystems, improved understanding of the hydrological and ecological roles of continental slope habitats is critical. For example, upwelling through submarine canyons can reduce thermal stress on offshore reefs during bleaching events.[246] These habitats are increasingly a subject of study as potential refuge areas from marine heatwaves, though the extent of biological connectivity between the slope and other habitats remains poorly documented.[247]

While knowledge of the detailed topography of the continental slope is advancing, and isolated biological surveys have occurred since 2019, confidence in the condition (and trend in condition) of this habitat remains low. Much of this habitat is thought to remain relatively undisturbed.

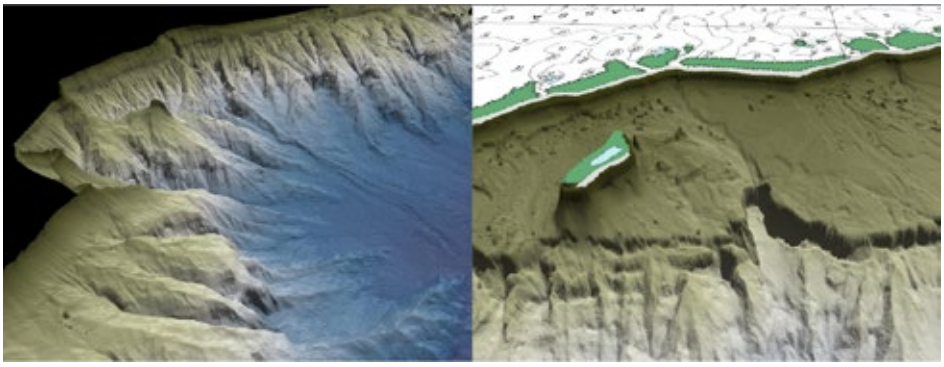


Figure 2.8 **Three-dimensional views of continental slope features**
Left: The canyons offshore from Princess Charlotte Bay, Cape York. Right: The plunge pools at around 1000 metres depth near the Small Detached Reefs, Cape York. Images © Schmidt Ocean Institute.

2.3.10 Water column

In this section, the term 'water column' refers to the pelagic zone, which encompasses the open ocean area between the coast and the outer boundary of the Marine Park. With a total volume of 7200 cubic kilometres, the water column serves as a crucial conduit linking all the habitats in the Region. It supports numerous species, including plankton and microbes, invertebrates, pelagic fish, sharks and rays, and cetaceans (whales and dolphins). The water column is an important medium for energy and nutrient cycling and facilitates the dispersal of numerous larval organisms via ocean currents. Condition of the water column as a habitat considers various physical, chemical, and biological factors (Chapter 3) that interact in complex ways. The assessment of condition (and trend in condition) of the Reef's pelagic habitats relies on expert knowledge from experimental, observational, and modelling science.[248]

Climate change is causing changes to various aspects of the water column habitat, including both physical oceanographic phenomena and environmental conditions [249] (Section 6.3.1). Plankton and microbes (Section 2.4.6) are crucial component of the water column and play a role in maintaining Reef function.[250] They are sensitive indicators of environmental change, and reorganisation of these communities is occurring consistent with expectations under climate change [251] (Box 2.5). Changes in ocean currents and circulation patterns can alter nutrient availability and the transport of larvae [249], thereby affecting the distribution of fish and other marine species.[252] One key driver of change is increasing ocean temperatures, which can affect the distribution and behaviour of marine species, including fish and plankton.[109] Warming waters also restrict the mixing of ocean layers, affecting nutrient and oxygen transfer through the water column.[253] These combined changes influence primary productivity, the abundance and species composition of plankton and microbes, and the timing and extent of phytoplankton blooms.[251] Although understanding of climate change impacts on water column assemblages is improving, key knowledge gaps remain, and systematic monitoring remains limited across the Region.[251]

Climate change is affecting water column conditions on large and small scales

In many inshore areas, water column condition is affected by delivery, resuspension, and recycling of excess nutrients and fine sediments from current and historical land-based runoff, which affects plankton and microbial communities (Sections 2.4.6, 3.4 and 6.5).

Important knowledge gaps remain regarding the condition (and trend in condition) of the water column. Increasing temperatures and changing ocean chemistry are directly affecting this habitat. Understanding of complex climate change impacts on diverse water column assemblages is improving but remains limited across the Region. Excess nutrients and fine sediments from land-based run-off also affect water column condition in many inshore areas.



Water column at Konomie Island (formerly known as North Keppel Island). © Ryan Ramasamy 2023

2.4 Condition and trend — populations of species and groups of species

Sixteen species groups are graded in terms of condition of populations and changes over the past 5 years due to human activities or changing environmental conditions. Of these, mangroves have remained in very good condition and 7 other groups (seagrasses, benthic algae, plankton and microbes, bony fishes, estuarine crocodiles, whales, and dolphins) are assessed as good. Eight species groups (corals, invertebrates other than corals, sharks and rays, sea snakes, marine turtles, seabirds, shorebirds, and dugongs) are in poor condition.

The full assessment summary is in Section 2.5.2.

The Region is home to thousands of species and new species are still being identified.[5] It provides particularly important habitat for species of conservation concern, such as dugongs, whales, dolphins, seabirds, marine turtles, sharks, and rays. The Great Barrier Reef's inscription on the World Heritage List recognises the global significance of its species diversity. With increasing sea temperatures, the ranges of some species are changing,[254] resulting in new records in some areas.

2.4.1 Mangroves

The Region's mangrove forests are the most functionally and biologically diverse in Australia. Although plant diversity is low compared to other ecosystems, mangrove forests in the Region are diverse on a world scale.[109,111] The Region is home to 44 mangrove species and hybrids,[255] representing almost all the species found in Australia and around half of the global total.[116] The number of mangrove species is a small fraction of the plants present in the Region, but these highly specialised plants, with their diverse shapes and structures, are enormously important for the ecosystem services they provide.[255] The continued persistence of mangrove species is important for maintaining longstanding cultural connections for the Reef's Traditional Owners.

Around half the world's mangroves species are found in the Region

Large shifts in the extent of mangrove forests have not been observed over the past 5 years (Section 2.3.3), but less is known about their condition. Changes to mangrove forests driven by local climatic and geomorphological processes and by global climate change (Sections 2.3.3 and 6.3.2) can differentially affect individual mangrove species.[123,256] For example, expansion of mangrove forest in the Howick Islands has involved successional replacement of colonising species with the dominant *Rhizophora stylosa*.[123] As the climate changes, species with broader environmental tolerances may be at lower risk than those near the edge of their physiological limits, especially where farmland and built structures restrict their upslope migration.[109] Warming is likely to allow some, but not all, mangrove species to expand their ranges southward and into areas currently occupied by other habitats, such as saltmarsh.[109] There is currently no evidence of significant deterioration of populations of any of the Region's mangrove species.

Although continued warming and accelerating sea-level rise are expected to lead to future changes in the local distribution and condition of mangrove species, no substantial changes in the extent or diversity of mangroves have been observed over the past 5 years.



Mangrove forests at Hideaway Bay. © Johnny Gaskell 2021

2.4.2 Seagrasses

Seagrasses are the only flowering plants to grow submerged in the ocean.[257] The Region is home to 15 seagrass species, around 20 per cent of the world's total.[258] One deep-water species, *Halophila tricostata*, is endemic to the area;[147] and another rarer species, *Halophila capricorni*, was first identified in deep-water coral environments in 1995.[259] Most seagrass species in the Region are found in water shallower than 15 metres. A range of disturbances, both natural and human-caused, can affect seagrass growth and survival (Section 2.3.4).

The species composition of seagrass meadows is important in determining the ecosystem services they provide, and their susceptibility to disturbances.[133,140] Seagrasses are the primary food source for dugongs and a major source for green turtles and several herbivorous fishes.[260] Dugongs prefer colonising seagrasses, such as species of *Halophila*, *Halodule* and *Cymodocea*,[260] though they will eat parts of virtually all seagrass species encountered.[141] The types of seagrasses present in a meadow affect both the quantity and nutritional quality of available food resources.[261] Dugongs and green turtles are both able to expand their diet opportunistically when meadows are seriously depleted. However, reliance on less preferred foods or more ephemeral colonising species can affect animal health [262,263] and leave these herbivores at greater risk from disturbances that affect short- and long-term seagrass availability (Sections 2.3.4 and 6.3.2).[141,260]



Recovery from disturbances occurs at different rates in different seagrass species

Recovery from disturbances occurs at different rates in different seagrass species.[145] Seagrasses are broadly categorised as having either persistent or colonising traits based on their ability to resist or rapidly recolonise following disturbances.[145] Persistent species are generally slower growing and invest more in biomass, enabling them to compete effectively for resources, whereas colonising species tend to have low biomass and high turnover rates. Species with a mixture of those traits are characterised as opportunistic. On a global scale, the seagrasses of the Great Barrier Reef would be mostly categorised as colonising (*Halophila* and *Halodule*) or opportunistic (*Syringodium* and *Cymodocea*). More robust and persistent types (such as *Thalassia* and *Enhalus*) are found in sheltered reef-top areas and in bays.



Colonising seagrasses such as *Halophila* can rapidly recolonise areas after disturbances.
© Dieter Tracey 2010

Monitored sites across the Region shifted towards a greater proportion of colonising species, reflecting declining meadow condition, between 2016 and 2020.[145] Since 2019, there has been recovery of species that are foundational to the meadows, resulting in a decreasing trend in the proportion of colonising species in the northern regions. This trend has not been evident in the southern Fitzroy and Burnett Mary regions, where meadow condition remains poor and a higher proportion of colonising species remains.

Seagrasses continue to be affected by increasing sea temperatures and localised decreases in water quality. Recent changes in the proportion of colonising and successional seagrass species in northern regions are indicative of seagrass recovery following past impacts from flooding. Seagrasses in the southern regions of Fitzroy and Burnett Mary are in poor condition, primarily due to the impacts of recent floods, and are vulnerable to future disturbances.

2.4.3 Benthic algae

Marine benthic algae are a diverse group of photosynthetic organisms incorporating several evolutionary lineages that diverged deep in Earth's history. Benthic algae include multicellular macroalgae and single-celled microalgae. The macroalgae are highly diverse and occupy most of the Region's habitats. There are 3 main types, green, brown and red, and a range of forms, from encrusting species to those making up algal turfs, to large fleshy species (seaweeds).[264] More than 600 species of macroalgae have been found on the Reef, based on limited collections; that figure represents around 30 per cent of the species in Australia.[264] Genetic studies have revealed this number may be considerably higher.[265]

Benthic algae perform a range of ecological roles, including contributing a large proportion of the primary production on reefs and in other habitats (Section 3.4.3).[264] Algal turfs stabilise sediment, produce oxygen, cycle nutrients, and provide food to grazing herbivores. Filamentous cyanobacteria (blue-green algae) living in intensely grazed algal turf communities fix atmospheric nitrogen, contributing to the supply of this key nutrient (Section 3.3.1).[266] Crustose calcareous algae contribute to framework cementation, accumulating calcium carbonate and helping bind substrate together into durable surfaces suitable for juvenile corals to settle on.[267,268] The green calcareous alga *Halimeda* and other upright calcareous algae are important producers of carbonate sediment on reef flats and elsewhere (Section 2.3.8).[100] Canopy-forming macroalgae contribute structural complexity and other key functions across the seascape, roles that may become increasingly important in a changing climate (Section 6.3.2).[269] Nevertheless, how different algal groups will respond to a changing climate remain major knowledge gaps.[270]

Excessive growth of turf and fleshy macroalgae can occur when there is a shift in the balance of processes affecting algal biomass — for example, a reduction in herbivory or increased availability of limiting nutrients (Section 6.5.2). Once established, some macroalgal species, especially those that grow densely across a range of habitats and depths, can inhibit the recovery of corals following disturbance by suppressing recruitment.[271,272] Palaeoecological records show long-term fluctuations in dominance between macroalgae and hard coral of the genus *Acropora* in the inshore Reef.[273]



Some macroalgal species can inhibit the recovery of corals following disturbance

Variation in cover of macroalgae along natural spatial gradients, as well as their functional diversity, seasonality, and variable responses to physical and chemical drivers, precludes any simple interpretation of macroalgal cover as a metric of human disturbance,[274] and links to availability of land-sourced nutrients are not straightforward.[275] The risks of nutrient enrichment promoting macroalgal overgrowth of corals are greatest in areas where herbivores are naturally scarce, such as inshore reefs.[276] Dominance of macroalgae is primarily limited to wave-exposed shallow inshore reef flats, crests and upper slopes where hard coral cover is often low.[275] Reef-wide monitoring from 1995 to 2021 shows that cover of upright fleshy and calcareous macroalgae increases steeply towards the coast, with increasing latitude and towards shallow depths (less than 3 metres). [42,275] However, no clear trends in macroalgal percentage cover were detected over that time, particularly for mid- and outer-shelf reefs.[275]

There is no dedicated monitoring of benthic algal species on the Reef, and most observations are limited to percentage cover of major algal groups in shallow water as part of coral monitoring programs. On inshore reefs overall, the relative proportion of large **fleshy macroalgae** has increased or remained stable over the past 5 years in most regions, although variation exists between individual reefs.[190] This increase was likely in response to major events, such as cyclone Debbie in the Mackay Whitsunday region. However, local variability is high in the Wet Tropics and Fitzroy regions, where average percentage of macroalgae can reach up to 35 per cent in some locations.[185] In offshore areas, macroalgal cover is generally low (less than 5 per cent) but with fluctuations of around 2 to 3 per cent in the Fitzroy region.[277] Potential changes in macroalgal cover in response to recent 2023–24 cyclones have not been assessed.



Different types of algae growing over coral. © Chris Roelfsema 2021

Turf algae is a consortium of microalgae and macroalgae, including cyanobacteria, which dominates benthic communities on many reefs worldwide.[278] In the Region, turf algae are one of the most common benthic algae in assemblages in shallow (less than 5 metres) areas of the Reef, and this has been relatively stable over the past 5 years.[277] Turf algae cover ranges from around 50 to 65 per cent in the inshore and mid-shelf reefs of Cape York, but drops to around 25 per cent in outer-shelf reefs.[277] In other regions, the distribution pattern is similar between inshore and offshore reefs at around 25 to 50 per cent, except at some sites where turf algae reach average cover of up to 70 per cent.[277]

Crustose coralline algae (CCA) are calcifying red macroalgae important for reef building[279] (Section 3.4.8). Certain species induce metamorphosis and settlement of corals, while others can inhibit coral settlement.[280] Some species support recruitment of crown-of-thorns starfish.[281] Cover of CCA has remained stable over the past 5 years across the Region, usually ranging from one to 40 per cent.[277] Highest cover (up to 50 per cent of total benthic algae) occurs in some of the offshore Ribbon Reefs in Cape York.[277] Recently, 3 new species of CCA belonging to the genus *Porolithon* have been described in the Region.[282] The increasing prominence of a group of rapidly spreading encrusting algae known as peyssonnelid algal crusts is an emerging issue reported from the Caribbean and wider Indo-Pacific.[283] It is unclear if this is occurring in the Region.

Among the **benthic microalgae**, Symbiodiniaceae is the most common group to establish symbiotic relationships with corals (as zooxanthellae) and other organisms like benthic foraminifera, giant clams and sea anemones.[284,285,286] Macroalgal surfaces support high abundances of these organisms, suggesting a key role for macroalgae in ensuring the ecological success of corals, particularly after bleaching.[287] While no monitoring program currently exists to assess diversity of benthic microalgae, several studies suggest that benthic populations of free-living coral symbionts have shifted to more thermally tolerant variants following the 2016 mass coral bleaching.[288]

Benthic algal cover in shallow reef areas has been relatively stable over the past 5 years. Significant variation exists across this diverse group. Future ocean warming and acidification may adversely affect coralline algae while providing increased opportunities for turf algae and fleshy macroalgae. Populations of microalgae important for coral symbioses may be shifting to more thermally tolerant variants.

2.4.4 Corals

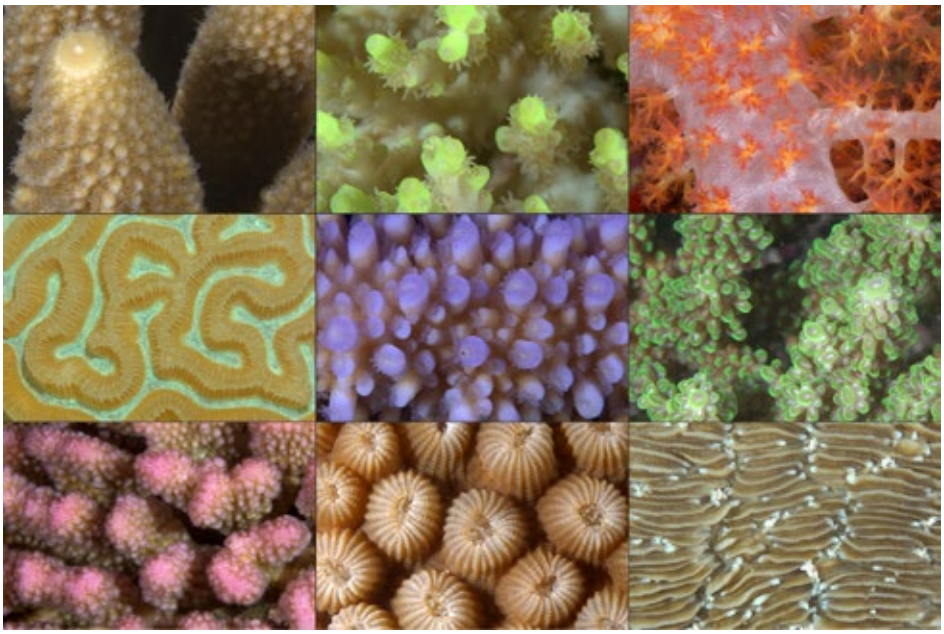
The Region is home to highly diverse coral assemblages, which incorporate all forms of corals belonging to the two subclasses Hexacorallia and Octocorallia (octocorals). Hexacorallia includes reef-building corals, sea anemones and black corals, and Octocorallia encompasses soft corals, gorgonians and sea pens.[289,290]

Reef-building corals build hard skeletons by depositing calcium carbonate [290] and often have symbioses with dinoflagellate algae called zooxanthellae.[291] These zooxanthellate corals are major habitat-forming organisms on the Reef, [290] and they exhibit a high degree of morphological, functional and genetic diversity.[21,292] Morphological diversity is evidence in the variety of growth forms, such as massive, encrusting, plating, branching, and solitary free-living corals.[290] Branching corals, including tabular forms,[293,294] are often represented by fast-growing species that are key for the function of the Reef.[295] These corals are sensitive to disturbances, such as thermal stress [296], cyclones and outbreaks of crown-of-thorns starfish,[297] but they are also first and fastest to recover and provide essential habitat for other species.[293] Diversity assessments in the Region often group corals into genera or families (rather than looking at the species level).[185,277] This approach underestimates the diversity of corals, particularly if grouping species belonging to the genus *Acropora*, which is the most species-rich and numerically abundant coral genus in the Indo-Pacific region.[292]

Black corals, sea anemones and octocorals are diverse groups of reef organisms, and they occupy diverse habitats and microhabitats across the Region.[289,298] These groups are critical for providing habitat complexity.[298] However, comprehensive taxonomic inventories are limited (and genetic analyses of sea anemones and octocorals are lacking), which leaves major knowledge gaps with respect to their diversity and distribution. Black corals are ecologically important because of their extensive distributional range. They provide habitat to diverse invertebrate communities from just below the surface to a depth of more

than 8000 metres, [299] but their diversity and distribution are poorly understood.[300] However, limited genomic analysis has seen the Region's known black coral species increase from 7 to 24.[299,301]

Sea anemones are a prominent member of coral reef communities and can establish symbiosis with zooxanthellae.[302] Overall, it is estimated that 40 morpho-species of anemones occur in the Region.[289] A total of 37 species of sea anemones have been described in submerged reefs at depths between 50 and 65 metres.[303]



The Reef's corals exhibit a vibrant diversity of colours and forms. © Chris Roelfsema and Johnny Gaskell

The octocorals include species that have no solid calcium carbonate skeleton.[298] This group includes soft corals, gorgonians and sea pens. Octocorals are a common feature of benthic habitats in shallow areas of the Reef and become increasingly prevalent as depth increases.[304] An estimated 289 species of soft corals have been identified in the Region using traditional taxonomic methods.[298] Soft corals provide structural complexity in the benthos across reef habitats, and essential habitat, shelter and food for many reef species.[305] Monitoring of soft corals in the Region occurs as part of broader monitoring programs focusing on reef-building corals but summary soft coral-specific analyses are limited.[190,277]

Community composition in corals is strongly influenced by cross-shelf, latitudinal and depth gradients.[306] Shallower areas (less than 30 metres) of the Reef are often dominated by zooxanthellate corals. As light availability diminishes towards deeper areas, communities become increasingly dominated by corals without these symbiotic partners.[307] Such corals tend to be solitary and to live in low light areas of shallow reefs; they are common on deeper banks down to the deepest waters of the continental slope (Section 2.3.9).[308] However, a few zooxanthellate corals can also live in low-light environments of the mesophotic zone (at depths between 30 and 150 metres), showing that some corals can adapt to marginal and extreme environments.[309] The study of corals in these and other extreme environments, such as mangrove lagoons, is becoming increasingly important for understanding how coral species might respond to changing environmental conditions linked to climate change.[310]

Corals continue to be extremely vulnerable to climate change, crown-of-thorns starfish outbreaks and reduced water quality in inshore areas. One of the major threats to zooxanthellate corals is heat stress associated with ocean warming and extreme

temperatures, [311] which can cause bleaching and mortality of corals (Section 3.4.6). Mass bleaching occurred in 2020 and 2022, although widespread coral mortality was not observed following either event. Different coral species have varying susceptibility to bleaching; fast-growing, branching species are often more vulnerable than massive species.[296,312] Following the 2020 and 2022 mass bleaching events (Section 2.3.5), most reef-building corals recovered, and widespread loss of diversity was not recorded.[161,182,313] The extent of impacts on other lesser-known species of octocorals, sea anemones and black corals is unknown.



The full extent of impacts on coral assemblages is not known

Early reports indicate impacts to branching and plate coral species occurred in localised areas following cyclone Kirrily in January 2024, [189] although a full assessment has not yet been made. Similarly, analyses over time will shed light on the extent of mortality and other impacts from high temperatures and subsequent extensive bleaching in summer 2023–24.[167,314] Systemic monitoring and accurately identifying and distinguishing coral species can enable the assessment of coral condition, particularly in relation to the functional traits that support resilience. The effects of cumulative pressures on species diversity are currently a knowledge gap.

Relatively few acute disturbances have occurred since 2019, facilitating recovery of some fast-growing coral species. Increases in cover of these species contribute to some improvement in condition of corals overall. Nevertheless, recovery across other species is less certain, and overall coral diversity likely remains affected. Crown-of-thorns starfish and reduced water quality have also affected corals in some locations. While widespread mortality or loss of diversity after the 2020 and 2022 mass coral bleaching events was not recorded, corals remain extremely vulnerable to rising ocean temperatures.

2.4.5 Other invertebrates

The Region supports a huge diversity of other (non-coral) invertebrates, including small symbiotic anemones,[315] giant clams,[316] sponges,[317] lace-like bryozoans and sediment-dwelling worms. More than 12,000 different invertebrate species have been described,[313,318] and these 'other invertebrates' account for the greatest overall animal diversity and biomass across the Region.[319]

Invertebrates occupy the full range of habitats across the Region. They play important roles in ecosystem processes that support functional integrity of coral reefs,[320] including primary production,[316] nutrient cycling,[317] calcification,[316] bioerosion,[321] symbioses,[315,322,323] ecosystem engineering [324,325] and recruitment facilitation.[321] Several invertebrates also have cultural and economic importance, for example, as traditional food, in Reef tourism, as part of school educational programs, or as targets for recreational and commercial fisheries.[326,327,328,329]

Invertebrates are affected by a range of different pressures and stressors, in particular climate change. Ocean warming directly affects survival in many invertebrates, and tropical marine species are often particularly vulnerable as they tend to live closer to their thermal limits.[330,331,332] Sessile benthic invertebrates are directly exposed to repeated thermal stress events, such as those in 2020, 2022, and 2024, and a lack of local thermal refugia in many areas means that only highly mobile species can actively avoid exposure.[333] The physiological and reproductive [334] effects of exposure to elevated temperatures, and the limits of physiological adjustment, are documented for very few species.[109,333] Still less is known about the ecosystem-level consequences of repeated exposure to thermal stress

and compounding impacts, but range shifts and altered community assemblages are already occurring.[109,335,336]

Many coral reef invertebrates have obligate associations with live corals, or rely on particular coral species for food and shelter, [319,337] so are sensitive to coral declines. Calcifying invertebrates, which build carbonate shells or skeletons, such as snails, crabs and sea urchins, are highly sensitive to ocean acidification, which can affect shell growth rates and composition.[338] Elevated carbon dioxide concentrations in sea water also affect foraging and predatory behaviours [339,340] and reproduction [341] in molluscs, potentially via mechanisms that disrupt the nervous system.[342] Cross-generational studies suggest some species, including crown-of-thorns starfish (Section 3.6.2), may have the capacity to acclimatise to increasing sea temperatures [343,344] and elevated carbon dioxide.[345] Reductions in water quality affects coastal and inshore areas and associated invertebrate fauna.[346]



Cuttlefish swimming over coral. © Matt Curnock 2021

Exploitation of target species can also affect invertebrate populations. The black teatfish fishery reopened in 2019 with stocks at around 40 per cent of their historical unfished biomass following 2 decades of closure,[347] while the saucer scallop stock is currently assessed as depleted [329] (Section 5.4).

Current knowledge of the condition (and trend in condition) of invertebrates in the Region is limited, partly due to the sheer number of species and the variations in life history and habitat requirements across this broad taxonomic grouping. The condition of invertebrates associated with coral reef habitats is affected by the cover, extent and condition of corals. Coral-dependent species are likely to be directly impacted by disturbances that affect corals.[204,348] In contrast, increasing production of fresh coral rubble is likely to benefit the highly diverse invertebrate fauna that occupy its reticulated surfaces and interstitial spaces.[34,204,349,350] As rubble beds erode, however, their three-dimensional structure becomes less complex, providing habitat for fewer species.[34] For non-reef invertebrates, it may be possible to draw broad inferences from the condition and status of other habitats within the Region, such as *Halimeda* bioherms,[225] seagrass beds, lagoons and mangrove forests. There is limited knowledge on how wider pressures are affecting the condition of non-coral marine invertebrates.

Significant variation exists in condition (and trend in condition) of different species within this diverse group. Pressures associated with climate change, habitat loss, fishing and poor water quality are likely to have affected invertebrates across a range of habitats within the Region.

2.4.6 Plankton and microbes

Plankton and microbes are incredibly diverse and abundant. This group includes microorganisms, from viruses and bacteria to single-celled plants and animals, and larger animals and animal larvae that drift in the water. Bacteria, archaea (another group of simple, single-celled microbes), phytoplankton and zooplankton account for nearly 78 per cent of all marine biomass, and phytoplankton are responsible for 40 per cent of global photosynthesis.[251,351] Plankton and microbes play vital roles in nutrient cycling (Section 3.3.1) and in influencing water quality, along with a multitude of ecosystem processes and symbioses (Section 3.4.6). Through their symbiotic relationships with key habitat-forming species, such as corals, sponges and algae, microbes are at the foundation of coral reefs. Plankton are the direct food source for many small fish, and invertebrates, such as mussels, clams and corals, as well as large planktivores, such as manta rays, whale sharks and baleen whales. Therefore, plankton and microbes act as key intermediaries between the physical environment and the rest of the marine food web. Some species produce toxins (for example, harmful algal blooms and box jellyfish).



Plankton and microbes are sensitive indicators of environmental change

Their global importance, short life, and sensitivity to change, make plankton and microbes indicators of ecosystem health and ecological change.[352,353,354,355] Many plankton and microbial communities exhibit cyclical fluctuations in abundance, diversity and community structure on various timescales, from diurnal to seasonal, inter-annual and decadal.[109,356] These fluctuations can be strongly affected by short-term environmental perturbations, such as marine heatwaves and floods.[357] The timing of seasonal cycles is important for the survival of larvae of higher trophic levels, including fish. Temperature regulates plankton physiology (for example, metabolism, reproduction, ingestion) and influences species interactions, such as competition, predation and disease. Warmer temperatures alter species' ranges (generally poleward), timing of blooms (generally earlier), diversity (higher), composition (more gelatinous and omnivorous) and individual size (smaller) [109,251] (Section 6.3.2).

One measure of the impact of temperature changes on marine life is the community temperature index (CTI), the relative abundance of species with different temperature preferences in a community.[251,356] Data from the Yongala National Reference Station suggest CTI increases (indicating increasing representation of species preferring warmer waters) have occurred since 2016 for most plankton groups [251] and that this has occurred in response to continued ocean warming in the Region (Section 3.2.6). Additional data collected since 2010 at the same site indicates no change in phytoplankton CTI, but increasing community representation of zooplankton species that prefer warmer waters.[250,357] Microbial abundance estimates are highly uncertain, but these groups (bacteria and archaea) have also undergone recent changes.[251] In archaea communities, a stable CTI but increased species diversity suggests they might contain new species with similar temperature preferences.[251] By contrast, bacterial communities have shown an increase in CTI but no increase in diversity, which suggests they do not contain new species and existing species preferring warm water are increasing in abundance.[251] Longer time series are needed to confirm these trends. Additionally, the East Australian Current is bringing warm-water picoplankton (plankton less than 2 micrometres (0.002 millimetres) in size) further south, including the dinoflagellates responsible for algal blooms, which can affect food availability and toxicity for higher trophic levels.[357]

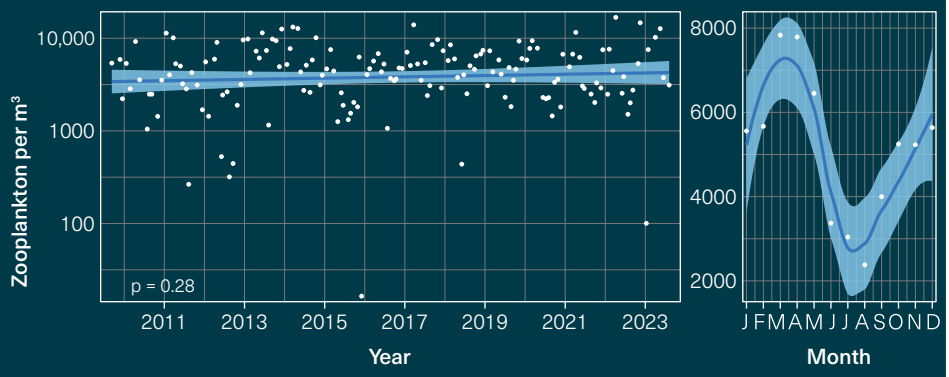
BOX 2.5

Plankton as essential ocean variables: indicators of ecosystem health and ecological change

Plankton are excellent indicators of climate change and ecosystem health because they have short lifecycles, are ectotherms (commonly called 'cold blooded'), and are sensitive to changes in temperature, acidity and nutrients. Phytoplankton and zooplankton biomass and diversity have been recognised as two essential ocean variables (EOVs) by the Global Ocean Observing System.[362] EOVs are components critical to the functioning of marine systems and are crucial for monitoring the current state of ecosystems and how they change.

Plankton EOVs are monitored under 3 programs in the Region: the Integrated Marine Observing System (IMOS) Australian Continuous Plankton Recorder (AusCPR) survey; the IMOS Yongala National Reference Station; and the Great Barrier Reef Marine Monitoring Program (Australian Institute of Marine Science Cairns transect [363]). Time-series analysis of plankton communities provides information on long-term effects of climate variability, including at higher trophic levels, for example, changes to productivity and food security, causes and frequency of harmful algal blooms, biogeographical shifts, regime shifts, and carbon sequestration. Plankton EOVs are considered scalable, in that regional timeseries can inform understanding of the long-term effects of climate change at global scales.

Currently, sufficient sampling in time and space is a primary limitation in plankton monitoring due to the high cost of sample collection and analysis (both genomics and microscopy). Remote sensing technology, though able to estimate total phytoplankton biomass and production does not provide information on species diversity or abundance, including that of archaea, bacteria and zooplankton. Remote sensing also has limited utility in shallow coastal areas. More broadly, little is known of many plankton groups and their dynamics, as they are so diverse. Longer time-series data and data from multiple locations are required to elucidate patterns in plankton communities over time.



Zooplankton biomass at Yongala monitoring station, 2010–2023
Long-term trend (left) and seasonal cycle (right) in zooplankton abundance at the Yongala National Reference Station, measured in number per cubic metre. Trend data are plotted without the seasonal signal removed. Since 2010, there has been a long-term increase in zooplankton biomass. Source: Richardson *et al.* (2023) [251]

Phytoplankton abundance is predicted to decline globally under climate change because ocean stratification will reduce the availability of surface nitrate, while warmer temperatures will promote higher phytoplankton diversity.[251] At the Yongala National Reference Station, no change in biomass was observed since 2010, but there was a significant increase in diversity.[251] Across the Region, continuous plankton recorders measured an increase in phytoplankton biomass and an increase in diversity as might be expected from warming. Nitrogen-fixing plankton, such as *Trichodesmium*, exhibited a long-term increase in abundance at the Yongala station since 2010, consistent with expected patterns under climate change (Section 3.3.1).[356,358] No trend was observed for the small nitrogen fixers *Prochlorococcus* and *Synechococcus*.[251]

Increases in zooplankton biomass have been detected in data collected at the Yongala station since 2010 and more broadly across the Region in data collected since 2014[251] (Box 2.5). This is consistent with the observed increase in phytoplankton and could improve feeding opportunities for invertebrates and vertebrates across the Great Barrier Reef. There was no significant change in copepod diversity, but copepod CTI has increased at the Yongala station. Zooplankton with calcareous shells, such as certain gastropods, bivalves and echinoderms, are affected by changes to ocean chemistry. A decrease in saturation of aragonite, a form of calcium carbonate (Section 6.3.2), can partially dissolve the calcium structures of these organisms, increasing maintenance costs and reducing growth rates.[359] Since 2010, there has been a weakly significant decline in calcareous zooplankton abundance observed at the Yongala station. More broadly across the Region, continuous plankton recorders have revealed no significant trend, emphasising the need for longer time series data and more sampling locations.

Plankton and microbes play important roles in mitigating or exacerbating effects of climate changes on the Reef's ecosystems.[109,360] Like coral reefs (Section 3.3.1), plankton are important producers of dimethylsulphide, which aids cloud formation, thereby reflecting solar radiation back to space. Plankton also shunt carbon from the surface to the deep ocean in a process known as the biological pump, which can lock up carbon for millennia.[361] Beyond the carbon cycle, plankton are important in oceanic nitrogen, phosphorus, sulfur, and iron cycles, and in remineralisation of organic matter (Section 3.3.1).

Changes in water temperature and availability of inorganic nitrogen likely affect abundance and diversity of phytoplankton within the Region, which has trophic implications for zooplankton and beyond. Calcifying zooplankton may be affected by increasing acidification, though there is no consistent declining trend in calcifier abundance in the Region. From the limited available data, increases in diversity and abundance of warm-water species are evident across many plankton and microbe groups consistent with expectations under climate change.

2.4.7 Bony fishes

Bony fishes (class Osteichthyes) are characterised by having skeletons made from bone instead of cartilage. Found in many habitats, from intertidal areas to the open ocean, bony fishes have a major role in both the ecological and economic values of the Reef (Sections 5.4.2 and 5.4.3). Approximately 1625 species are found in the Region, and the majority (1468) are classed as coral reef species.[318]

As with other species and groups, bony fish have strong associations with their habitat and the surrounding environmental conditions.[364] As a result, current trends of habitat degradation are having flow-on effects, such as a trend towards species that are ecological generalists.[365] Understanding the strength of habitat associations is essential for anticipating how the functional roles of fish may be affected by current and future

environmental change.[366,367] Since 2019, understanding of how species composition of fish assemblages varies with changing habitat and environmental conditions has advanced considerably.[252,366,368] This information is vital for understanding the functional make up and subsequent ecological role(s) of fish assemblages.[140,369] Moreover, there are subsequent and reciprocal effects on ecological processes, such as food availability, recruitment and predation (Chapter 3).

Effects are not consistent between species; while some highly specialised species will decline, others may persist (for example, the lemon damselfish, which can use different habitats, such as dead substrata), [370] though this can result in functional loss.[365] Indeed, over time summary metrics, such as abundance and species richness, may recover or even appear quite stable but can mask changes to species composition.[371,372] Under future climate scenarios, fishes that already live close to the upper limit of their thermal tolerance (for example, some estuarine species) may be exposed to greater thermal stress.[373] Models predict the range of suitable habitat for some important fishery species (such as juvenile red throat emperor, dusky flathead and blue threadfin salmon) will substantially reduce. Conversely, some species (for example, the flowery rockcod and barred javelin) may increase their distribution, benefiting from increased prey availability.[368]



Improved understanding of habitat connections to fish assemblages is vital

Understanding of the effects of ocean warming on the condition of individual bony fishes has increased since the previous report. Development during elevated temperatures can lead to larvae depleting yolk reserves faster [374] and significant reductions in size of juveniles.[374,375] This is of particular concern because peak recruitment periods for juvenile fishes occur during the warmer months in the Region, a time of year when periods of elevated sea surface temperature (including marine heatwaves) are more likely. Transgenerational acclimatisation (that is, conditions experienced by both current and previous generations) can influence future offspring in some bony fish. For example, in the spiny chromis exposure of both parents and grandparents to elevated temperatures improved the aerobic capacity of offspring.[376]

Current extraction rates for some bony fish species in the Region are considered sustainable, though there are concerns for others (Section 5.4). Importantly, recent research into archival data has provided quantitative historical catch-rate estimates for two species, giant grouper (a protected species in recent times) and barramundi.[51,377] Investigations like this assist with recognition and avoidance of shifting baseline syndromes.

Microplastic contamination may harm bony fish resulting in cellular stress, [378] hormonal imbalances [379] and behavioural traits that may reduce survival.[380] Microplastics enter bony fish mainly through ingestion (planktivorous species [381]) and other pathways (such as passive uptake through the gills [382] or trophic transfer [383]). In general, microplastic loads across the Region are low compared to more densely populated areas of the country.[384] Since 2019, spikes in microplastic loads have been associated with seasonal and localised weather events. This issue has the potential to increase in the Region over time as coastal populations grow.

Long-term monitoring of 3 key fish groups (butterflyfish, parrotfish and surgeonfish) across the Region has identified some changes in mean abundance across reefs surveyed since 2009 (Figure 2.9). Butterflyfish, which rely heavily on coral and other invertebrates for food, have shown possible increases since 2018–19 at the Cooktown–Lizard Island, Cairns and Townsville reefs, the Swain Reefs and offshore Whitsundays reefs. The increase seen in

2016–17 for Capricorn Bunker group reefs has persisted. Abundances of surgeonfish and parrotfish, which feed on a combination of microorganisms that live on or within calcareous substrata,[385] have been more variable over time. A trend of slowly increasing parrotfish abundance may be emerging in the Capricorn Bunker group over the long term, while reefs in the Pompeys and around Townsville (mid-shelf and offshore) have shown an overall increase in numbers since 2019–20. Since 2019, patterns in surgeonfish abundance have been variable across surveyed reefs. For instance, surgeonfish abundance has generally decreased in the offshore Whitsundays reefs since 2016–17 (apart from in 2022, when an increase was recorded) and are now below the 2008–09 level. In contrast, numbers of surgeonfish at Swain Reefs and in the Capricorn Bunker group have increased since 2019.



Sweetlip swimming over the reef. © Chris Roelfsema 2021

Changes in the mean abundance of some bony fishes have been observed since 2019 and over the longer term. Trends vary between species groups and regions, and both increases and declines have been observed. In some cases, the observed changes may reflect natural fluctuations in populations. Climate change, habitat degradation and targeted extraction are exerting pressure on bony fishes, and having varying effects in different species and functional groups.

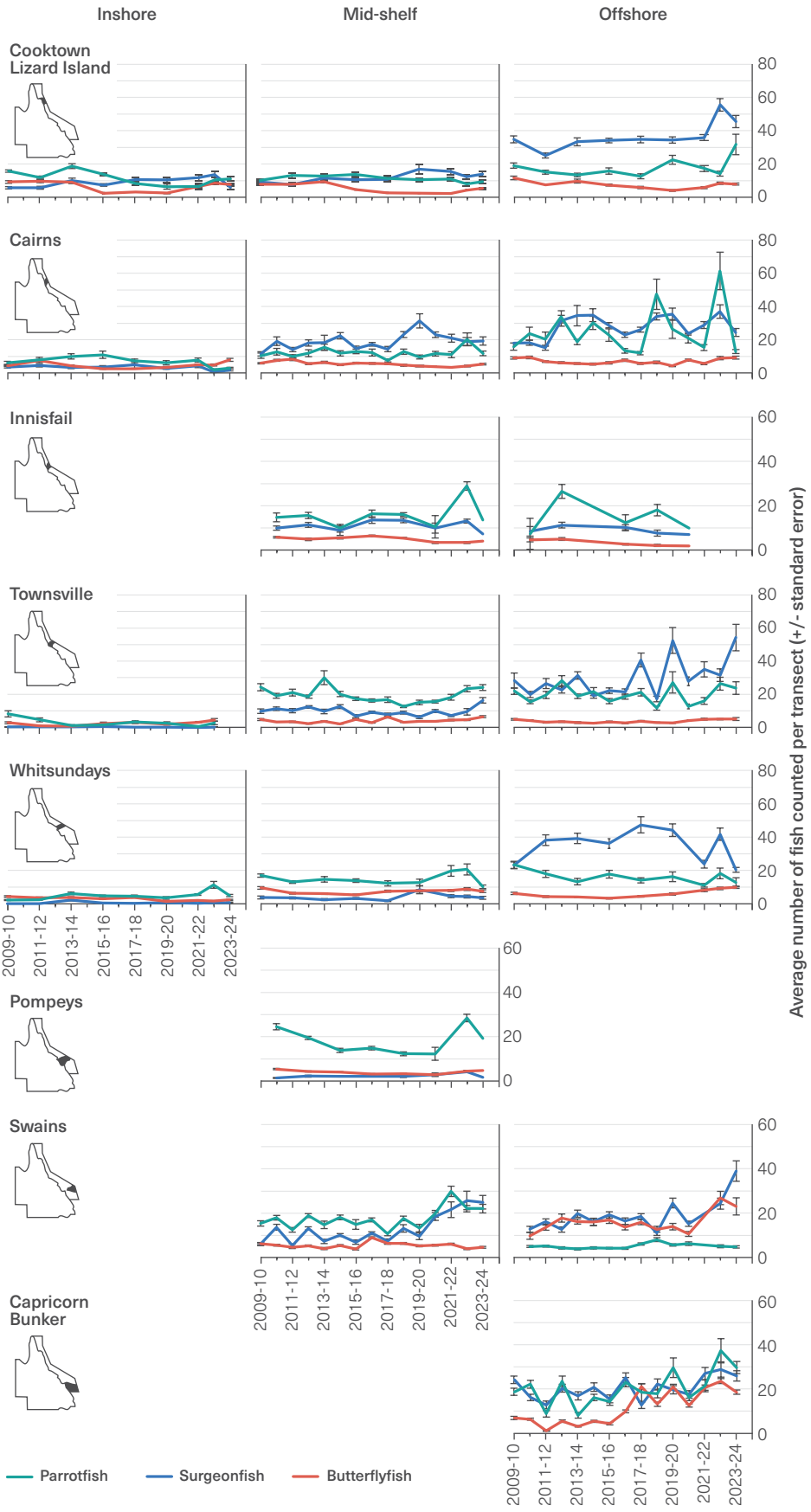


Figure 2.9 **Abundance of some coral reef fishes, 2008 to 2023**

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 5 metre transects at each reef. Where possible, 3 or more reefs were surveyed at inshore, mid-shelf and offshore positions across the continental shelf. The average number of reefs visited in a year was 54. The maximum visited was 69, in 2021–22. Note the differences in scale between some y-axes. Source: Australian Institute of Marine Science Long-term Monitoring Program [386]

2.4.8 Sharks and rays

Sharks and rays (class Chondrichthyes) are fish that have a cartilaginous skeleton, rather than bone. Approximately 140 species of sharks and rays are found in the Region.[387] These range from species that remain on a single reef for their entire life (such as epaulette sharks) to transient species that pass through reef habitats (such as cownose rays and tiger sharks).[388]

Since 2019, knowledge of the fine-scale movements, behaviour and habitat use of juvenile sharks and rays in shallow waters and coastal nursery areas has improved.[389,390] For example, in the north of the Great Barrier Reef the waters around Milman Island have been identified as a possible nursery area for both blacktip reef sharks and giant shovel-nose rays, based on observations of social grouping behaviour in juveniles.[391,392] In the south, a repeat observation of an individual ornate eagle ray suggests that Lady Elliot Island may be an important location for this species.[393]

Sharks and rays play a range of important roles in the ecosystem.[388] Some are apex predators that provide top-down control over prey populations, while others are mid-level predators [394] (mesopredators), benthic invertivores and filter feeders.[395] Most reef sharks are mesopredators.[394,396] Larger predatory sharks modify behaviours of herbivores such as turtles and dugongs,[397,398] and of mesopredator fish species, such as groupers, snappers and emperors. These fish species spend less time undertaking risk-prone behaviours when they live on a reef with sharks.[397,399,400] Recent research indicates that great hammerhead sharks play an apex predator role in shallow, inshore habitats, potentially shaping space-use and foraging behaviours of rays.[401] Rays may assist ecosystem processes, such as bioturbation,[402] and indirectly affect behaviour of species in their habitat.[402,403] Generally, declines in shark numbers on coral reefs have been associated with an increased dominance by rays, indicating a community-wide shift that may be associated with reduced ecological functioning.[404]



Whitetip reef shark at Challenger Bay. © Pablo Cogollos 2023

Globally, populations of oceanic sharks and rays have declined by 71 per cent over the past half century due to an increase in fishing pressure.[405] Within Queensland, long-term declines may have occurred in coastal populations of several shark species over the period 1962 to 2017, with corresponding declines in body size also observed.[49] Several sharks found in the Region are assessed as critically endangered, vulnerable or conservation dependent under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act), while many other species are listed as threatened at a global scale by the International Union for Conservation of Nature.[258] Nevertheless, a recent global assessment of sharks and rays highlighted Australia as among the nations with greatest shark presence and potential for conserving sharks (based on sites including the Great Barrier Reef).[406]

Many sharks and rays are long lived, mature late and produce relatively few young, characteristics that can make them vulnerable to anthropogenic impact. Species such as great hammerhead sharks that have specialised foraging behaviour and limited demographic connectivity may be particularly vulnerable.[401] Overfishing is the main threat to sharks and rays worldwide, including through unintentional catch by recreational fishers [407] and in small- and large-scale fisheries.[406,408,409,410] Other threats include climate change and habitat loss and degradation.[388,411] Understanding of the effects of climate change on sharks and rays has expanded since 2019, with fast swimming species expected to be disproportionately affected by increasing temperatures.[412] Impacts on embryos and juveniles of some species as a result of warming [413,414] and acidification [415] are also likely.

Protected area management offers the greatest protection for sharks and rays,[416,417,418] particularly when complemented with other management tools (such as bycatch reduction devices).[406,419] These tools are implemented within the Region and are likely to reduce pressures on sharks and rays. Sustainable fisheries are currently being advanced in the Region to help protected threatened species and reduce bycatch incidents (Box 5.2). In 2023, all species of hammerhead sharks, guitar fish and requiem sharks were listed on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Section 5.4.1). Since January 2024, taking of hammerhead sharks from the Region is no longer permitted.[376]



Protected area management offers the greatest protection for sharks and rays

Fisheries-related 2020 stock status assessments for east coast stocks of the Australian blacktip shark and common blacktip shark classified them as sustainable.[420,421] The same was true for the northern Australia stock of the spot-tail shark.[422] However, in general, robust population data is lacking for many shark and ray species in the Region. For example, historical declines are recognised for multiple sawfishes across their broader Australian range but contemporary estimates of population size or change in the Region are not available.[423,424,425,426]

Overfishing (including unintentional catch) and climate change-related ocean warming and acidification affect many species of sharks and rays worldwide. In the Region, multiple species are in a reduced state compared to historical population levels. Current management tools may be helping to reduce further impacts. More work is needed to understand the condition (and trend in condition) of individual species.

2.4.9 Sea snakes

Sea snakes, although the most diverse group of marine reptiles, have received relatively little scientific attention.[427] There are two groups of sea snakes: the amphibious sea kraits and the marine 'true' sea snakes.[427] True sea snakes produce live young and are entirely marine, never venturing onto land. Offshore marine species retain traits from their terrestrial ancestors, such as needing to drink fresh water obtained from lenses that form on the surface of the ocean after rainfall.[428,429] Sea snakes are important ecologically as predators and have been used as bio-indicators for cryptic species of fish.[427]

The Region forms part of a global hotspot of sea snake diversity that encompasses northern Australia and the Indonesian–Malaysian archipelago. Sixteen species of true sea snakes have been recorded in the Region, and 14 maintain permanent breeding populations.[430] Most are benthic foraging species, but different species are associated with different habitats.[431] The highest density and diversity of sea snakes are found in the central and southern Reef, and species like the olive sea snake and spine-bellied sea snake are commonly recorded in inshore bays and fringing reefs along the Queensland coast.[427]

Low reproductive output and limited dispersal capability limit recovery potential

Sea snakes have a low reproductive output and limited dispersal capability limiting their potential for population recovery and recolonisation when populations are affected.[432,433] Studies on sea snake movements on the Reef have shown that some species are highly attached to specific reefs, for example, olive sea snakes[427] and turtle-headed sea snakes[434] do not venture far from their home reef. During the mating season, males increase their movements to find females on the same reef, and seasonal aggregations of sea snakes are often observed in areas with large populations.[427] The limited capability of sea snakes to disperse between reefs can result in highly fragmented populations[435] such as found in the Swain Reefs and Pompey Reef complex in the southern region.[427]



Sea snake at the Yongala shipwreck. © Pablo Cogollos 2023

Long-term population trend data are severely limited. Densities of sea snakes at Marion Reef, east of Airlie Beach, declined by more than 80 per cent between 2012 and 2017,[436] whereas populations in other areas (for example, Cleveland Bay) are considered stable.[427] The extent and underlying causes of population declines remain uncertain. Most species of sea snakes are considered to be at medium risk from interactions with trawl fisheries in Queensland, and bycatch mitigation strategies to quantify and reduce mortalities are being advanced in collaboration with industry.[437]

Despite reported declines in some locations, the lack of systematic population monitoring means the status of sea snakes in the Region remains uncertain. Based on the limited available evidence, the condition of sea snakes in the Region is inferred to be stable.

2.4.10 Marine turtles

The Region is home to 6 species of marine turtle, all of which are listed as either vulnerable or endangered under Commonwealth and Queensland legislation and recognised internationally as species of conservation concern. Marine turtles have significant cultural importance for Traditional Owners. For example, the green sea turtle is a totem species for the Mandubarra people [76] and turtle nesting is one of the key indicators in the Woppaburra seasonal calendar.[78] Marine turtles also have economic importance for the tourism industry as an iconic Reef animal.

Globally important nesting and foraging areas exist in the Region for green, flatback, hawksbill and loggerhead turtles. Olive ridley and leatherback turtles forage in the Region but are generally not known to nest. However, in December 2023 an olive ridley turtle nested on a beach near Mackay.[438] Marine turtles are ecologically important to reef ecosystems, both as herbivores and predators, and they contribute to the cycling of nutrients and sediment creation.[439] Green turtle herbivory significantly influences the condition and structure of seagrass meadows,[142,440] and enhances seed dispersal and germination [441] (Sections 2.3.4 and 2.4.2). Some Traditional Owner groups report that the numbers of turtle have declined on their Sea Country and are having less successful nesting seasons.[76,442]

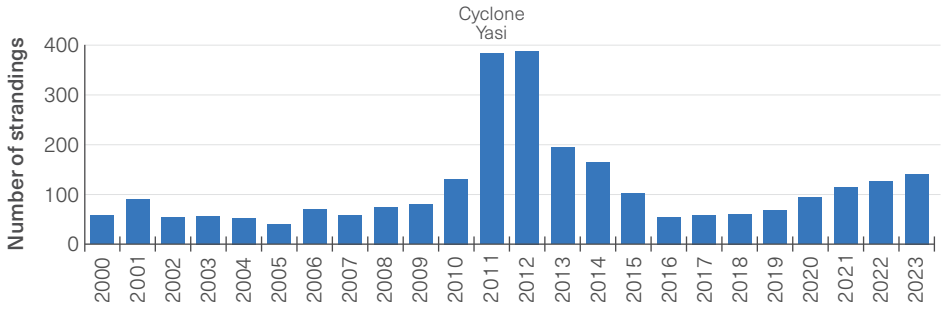


Figure 2.10 **Green turtle strandings in the Region, 2000 to 2023**

Green turtle strandings (dead and alive) in the Region from 2000 to 2023. Stranded marine turtles that were not identified to species level are not included in the graphed data, so the total is potentially higher than shown. Source: Queensland Department of Environment, Science and Innovation (2024) [461]

A range of factors influence the health and condition of marine turtles. Although the risks vary between species and genetic populations, the key threats to marine turtles include climate change, marine debris, domestic and international take, terrestrial predation, entanglement, fisheries bycatch and light pollution.[443] Significantly, climate change is leading to unsustainably high female to male ratios in sea turtle populations across the Region (and globally),[444,445,446] as hatchling sex is determined by sand temperature at nesting beaches.[447] Rising sand temperatures lead to decreased egg survival.[448] Nest temperatures remain cooler in areas that are shaded or experience rainfall during

the nesting period,[449] and manual application of fresh water or sea water to nests has been trialled as a cooling management measure in some locations.[450] Other impacts of climate change, such as rising sea levels [451] and increased storm events, are changing the availability (for example, sand depth) of turtle nesting habitat in some areas [452] and affecting important food resources, such as seagrasses and corals [444] (Sections 2.3.4 and 2.3.5).



Instances of declining population trends are reported for most marine turtles

Northern and southern green turtle populations on the Reef are genetically distinct. The southern population mainly nests at North West, Wreck, Hoskyn, Tryon, Heron, Lady Musgrave and Masthead islands. This population is considered to be moderately recovering from historical lows after the cessation of commercial harvest in 1950 and implementation of large-scale habitat protection.[443] The population increase has continued since 2019, although the increase in numbers observed during the most recent nesting season was smaller than in previous seasons.[438] In addition to key threats outlined for marine turtles generally, contemporary pressures on southern green turtles include exposure to reduced water quality.[263,453,454,455]

The northern green turtle population (for which 90 per cent of nesting occurs on Raine Island and Moulter Cay) [456] is considered to be in significant decline.[443] Low nesting and hatchling success has been reported from Raine Island since the mid-1990s.[452,457] Since 2019, declines in hatchling production have continued despite some successes from management interventions implemented on the island across the past decade.[452,458,459] The decline is attributed to a number of potential factors, including reduced suitability of nesting habitat, [452] early embryo death, [460] and adult mortality outside the breeding season from unquantified hunting pressure [12,443]. Very few male green turtles have been recruited to the northern green turtle population in recent years, reflecting effects of high sand temperatures on hatchling sex.[446]

Since 2019, green turtle strandings, which can occur as a result of both human and natural causes, have increased slightly (Figure 2.10).

Hawksbill turtles nest on islands in the far north of the Region, including a significant rookery at Milman Island.[462] Key foraging areas in the Region include reefs north of Princess Charlotte Bay and the Capricorn-Bunker reefs. Individuals foraging in the Region migrate to nesting sites within the Region, other parts of northern Queensland, and the wider Coral Sea region.[463,464,465] Historically, this species was commercially harvested for tortoiseshell. Ongoing legal and illegal harvest in the wider Coral Sea region may still affect the species, [443] and survival to breeding may be low for turtles outside the Region.[466] The numbers of clutches at the Milman rookery has steadily declined since monitoring began in 1990.[462] The population is currently considered to be in significant decline and modelling suggests a risk of complete loss of nesting locally (and potentially for the north Queensland stock) within the next 10 to 15 years.[443,462]

Loggerhead turtles in the south-west Pacific population nest exclusively along the east coast of Australia and New Caledonia. Important nesting beaches are found on the mainland coast between the Woongarra coast (Mon Repos beach) and Wreck Rock, as well as on Tryon, Heron and Erskine islands. Key foraging areas and migration routes occur throughout the wider Region.[467] Hatchlings disperse as far as South America in ocean currents before returning to Australian foraging and nesting grounds as young adults approximately 16 years). Significant declines in the number of turtles returning to Australian nesting beaches have been attributed to bycatch mortality and ingestion

of marine plastic, either in Australian waters or throughout the oceanic journey.[468] Moderate population recovery was observed for mainland nesters after the introduction of mandatory turtle exclusion devices in prawn trawl fisheries in 2001.[469] More recently, an overall decline in the number of nesting loggerhead turtles was recorded on the Woongarra coast over the 5 years since 2016[470] and on the Wreck Rock coast over the past 6 summers.[471] The annual recruitment of young female loggerheads into the Woongarra coast breeding population has declined over the past 2 decades.[470] Island nesters have not demonstrated strong recovery post 2001. Mainland and island nesters have recently been shown to use different foraging grounds.[467] Coastal development and predation continue to affect mainland nesting sites, while in-water life stages are affected by overseas fisheries, boat strikes, marine debris and changes to foraging habitat. Initial beach cooling studies suggest that measures such as artificial rain and beach shades can improve hatchling emergence success.[470] Overall, the species is endangered, and the population is considered to be severely depleted.[443]

Flatback turtles are endemic to the Australian continental shelf. Several genetically distinct populations have been identified. The eastern Queensland stock are known to forage throughout the Region, nesting on southern mainland and island beaches (including Peak, Curtis, Wild Duck and Avoid islands).[472] The nesting population at Peak Island declined by 50 per cent from 1980 until 2001 but is now increasing.[443,473] Nesting populations at Curtis Island have also increased since about 2010,[473] while Wild Duck Island continues to be the largest rookery on the east coast.[474] Nevertheless, the species remains vulnerable [443] due to the relatively low population size overall and reductions in the number of young females recruiting into the nesting population.

Leatherback turtles from the north-west Pacific population forage and migrate through the Region. Historically, a small population used to nest in eastern Queensland. It is unknown whether these animals were part of the wider north-west Pacific population or a genetically separate population. Although a mating pair was sighted off Bundaberg in 2021,[475] no nesting has been reported from the east coast of Australia since 1996.[443] The species is endangered following significant decline regionally.[443,476]

Olive ridley turtles are sighted rarely on the Great Barrier Reef. Individuals foraging in the Region likely originate from the significantly depleted western Cape York Peninsula nesting population, where they are affected by sandmining.[443]



Green sea turtles migrate to Heron Island to breed. © Matt Curnock 2022

Declining population trends are reported for most species and distinct genetic populations of marine turtles in the Region. Since 2019, the southern green turtle population and eastern Queensland flatback turtles have shown moderate recovery. The nesting population of hawksbill turtles is in significant decline and could be at risk of loss within the next 10 to 15 years. Key threats include climate change, marine debris, national and international take, terrestrial predation, fisheries bycatch and light pollution.

2.4.11 Estuarine crocodiles

Estuarine crocodiles are iconic apex predators and an important keystone species in the coastal ecosystem. They are also of exceptional cultural significance to many First Nations groups across northern Australia.[477] Estuarine crocodiles commonly inhabit tidal reaches of rivers, beaches and islands across the Region, but most are riverine.[478] Nonetheless, they are capable of long-distance movements extending over hundreds of kilometres.[479] Since 2019, the data gap for crocodile populations has been filled. The most comprehensive crocodile population monitoring in more than a decade was carried out between 2016 and 2019.[478] The study, published in 2022, confirmed the population has had only a modest increase through time, and it is not projected to significantly increase in the future.[478] The population started from a very low base due to previous hunting, and recovery has been relatively slow and highly variable across Queensland.[478]

Crocodile populations have continued to recover following historical reductions

Since the 1980s, the subpopulation between Cooktown and Ingham has been increasing at a rate of 2 to 3 per cent per year.[478] The spatial distribution of estuarine crocodiles in Queensland has not changed since the 1980s, and there is no evidence of a southern expansion of their range.[478] The size of the estuarine crocodile population in Queensland is currently estimated at 20,000–30,000 non-hatchlings at an average of 1.7 crocodiles per kilometre of river surveyed.[478] This is considerably lower than crocodile abundance and distribution in the Northern Territory.[478] The density of crocodiles is highest in northern Cape York Peninsula (3.0 per kilometre) and declines southward, with 1.2 per kilometre in the Cairns region, down to 0.2 per kilometre in the Fitzroy River, Rockhampton.[478] This southerly reduction is a likely consequence of lower temperatures and less suitable habitat.[478]



Saltwater crocodile basking in the sun. © Queensland Government 2017

The crocodile population south from Cooktown represents around 20 per cent of the Queensland total.[478] While the crocodile population has continued to increase relatively slowly along the east coast between Cooktown and Ayr, the average size of crocodiles has reduced in this area. This is likely to be a consequence of the regular removal of 'problem crocodiles' under the Queensland Crocodile Management Plan.[478] Since 2019, population genetic studies have improved understanding of migrations between subpopulations, and the sources and sinks of such movements, vital information for the management of this large predator.[479,480] Most crocodiles in eastern Queensland appear to remain close to their place of birth with 90 per cent of crocodiles dispersing less than 50 kilometres. The Proserpine and Fitzroy River populations are the most genetically isolated in the Region.[479,480]

Estuarine crocodile populations have continued to recover following historical reduction to very low numbers. Since 2019, although statewide surveys and genetic studies have highlighted some vulnerabilities, the overall condition of crocodile populations is thought to have improved, and confidence in this assessment has increased.

2.4.12 Seabirds

Seabirds are key indicators of changing oceanographic and trophic conditions.[481] They occupy upper-trophic levels of marine food webs and play a key role in the cycling of nutrients between marine and island ecosystems.[481,482,483]

The Region supports breeding populations of 21 seabird species. All are protected under the EPBC Act.[484] There are 55 key locations for nesting and roosting seabirds that are regionally and globally important. Most support multiple species of seabirds, and many (65 per cent) are in the Reef's southern section.[101] Overall, 39 of the 55 sites (71 per cent) are globally significant as they meet, individually or as a group, specific criteria, such as supporting greater than one per cent of the global population size of a species, over a season, and during one or more life history stages. The remaining 16 sites (29 per cent), which do not meet global significance criteria, are regionally significant as they support, for example, seabird species that are geographically restricted in their nesting area and/or one of the 5 largest nesting or roosting populations of seabird species in the Reef.[101] Ten highly diverse seabird rookeries occur within the Reef, where populations of 7 or more species nest on islands and cays, including the most diverse, Raine Island (13 to 17 species).[70,101] Notably, some seabird species, such as the Herald petrel, only nest in large numbers on a few of these key locations or exclusively on one.[101]



Mixed species of seabirds on a coral island. © Queensland Government. Photographer: Matt Wright 2023

Some species inhabit the Region year-round, while others migrate to distant foraging grounds where they remain for large parts of the year. As seabirds depend on resources both at sea and on land, they are exposed to impacts in both environments.[485] Threats at sea include the depletion of prey resources driven by, for example, natural fluctuations in sea surface temperature, as well as environmental changes associated with climate change.[481,486] Coastal and tourism development, the introduction of invasive animals and weeds and legacy impacts from land-based guano-mining continue to adversely affect seabirds on land.[486] Erosion and overwashing of key habitats for nesting and roosting seabirds can be exacerbated by extreme weather events, sea-level rise and the destruction of vegetation.[486]

Improved demographic information is essential to understanding seabird condition

Although seabird populations are an area of active investigation, current monitoring programs do not yet generate sufficiently robust demographic information, such as nesting success, that is essential to understanding the condition of seabird populations.[70] High-quality baseline data for assessing longer-term condition and population trends remains limited to a few sites and species. Despite recent advances, knowledge about the distribution of pelagic foraging grounds also remains limited, mostly due to the small sample sizes of tracked birds from different colonies and species.[487]

Published in 2021, long-term trend analysis of populations of 9 seabird species from 32 of the Reef's islands and cays found that trends varied markedly among species and sites from 1979 to 2018.[486] Most species (including, for example, lesser and greater crested terns) showed increases and decreases at different sites. Overall, population declines were detected in 39 out of 86 assessed species and site combinations (45 per cent), followed by 'no change' in 31 (41 per cent) and increases in 12 combinations (14 per cent). Probable Reef-wide population declines occurred for 3 out of 5 assessed species, and no long-term changes were detected in the two most widely distributed species, including the brown booby. Declines of brown booby were offset by increases at a single large colony on East Fairfax Island, pointing to the likely success of habitat restoration on the island.

Overall, confidence in the condition (and trend in condition) of seabirds has improved since 2019 but remains limited. Although available information on population trends is highly site-specific, probable declines are occurring in some species, while other species' populations appear static or have probable increases. Key pressures in the Region include climate-related environmental changes and impacts on availability of prey species.

2.4.13 Shorebirds

Queensland's wetlands provide a key habitat for 61 species of resident and migratory shorebirds [102] — at least 41 (67 per cent) of these inhabit the Region's coastal wetlands.[488] Millions of shorebirds return each year along the East Asian–Australasian Flyway from breeding grounds in the Arctic and Subarctic to the Region's wetlands.[489,490,491] Migratory shorebirds and associated wetlands are protected under the EPBC Act.[484] However, critical foraging and breeding habitats outside the Region continue to be degraded, if not lost altogether, due to human activities.[492,493,494] Local threats include non-native plants and animals and disturbance through tourism and recreation.[488]

Migratory shorebirds are vulnerable to habitat loss outside the Region

The Shoalwater and Corio Bays Area, one of Queensland's 4 coastal wetlands listed under the Convention of Wetlands of International Importance especially as Waterfowl Habitat (the Ramsar Convention), falls within the Region. It supports thousands of resident and at least 26 species of migratory shorebirds, including large populations of 6 species in the East Asian–Australasian Flyway.[495] Bowling Green Bay, another Ramsar-listed site, is adjacent to the Region and similarly supports internationally significant numbers of migratory shorebirds.[496]

Existing trend analysis of shorebird populations highlight ongoing nation-wide population declines, over the past 50 years, for many of the Region's species.[489,497] Seven out of 14 modelled species have experienced nation-wide declines of 30 to 80 per cent over 28 years (seasons) from 1993 to 2021.[489] In 5 of these 7 species a deceleration in the rate of decline has been observed over the final 9 years of the period, although the change was only significant for one species (eastern curlew). Population declines of less than 30 per cent were reported for a further 5 species, while increases were observed in only 2 of the 14 modelled species, but these trends were not statistically significant.



Terek sandpipers. © Queensland Government. Photographer: Andrew McDougall 2023

Several key knowledge gaps limit understanding of condition (and trend in condition) of the Region's shorebirds. These include a lack of structured survey and monitoring approaches that sample the full range of important wetlands at a frequency sufficient to detect trends.[498] Demographic information is scarce, and much of the existing data are spatially and temporally limited, making it challenging to identify causes of population changes beyond a few locations and species.[498,499] However, 206 locations have recently been identified as potential shorebird monitoring sites for the Region as part of a wider strategy to increase survey effort and associated data quality.[499]

The available data are nationwide, and shorebird population trends must be inferred for the Region. The condition (and trend in condition) of shorebirds in the Region have been assessed as unchanged since 2019. Migratory and resident shorebird species are subject to local pressures, such as disturbance and habitat decline, while migratory shorebirds are vulnerable to habitat loss outside the Region during their migration.

2.4.14 Whales

Approximately 15 species of whales are known to occur within the Region. The two most commonly encountered species are the humpback and the dwarf minke whale.[500,501] Sightings of killer whales, false killer whales, short-finned pilot whales and various beaked whales have been recorded in the Region. Habitat use and the extent to which these species are resident within the Region remain important knowledge gaps. All species of whales within the Region are protected by legislation.[502]

Several Traditional Owner groups along the coast, such as the Woppaburra people of the Keppel Islands, regard whales (*Mugga Mugga*) as totemic species.[78] Humpback and dwarf minke whales are economically important to the Region, as reliable and extremely popular tourist attractions. The only known predictable aggregation of dwarf minke whales in the world can be found in the northern Great Barrier Reef each winter.[503] Due to their small size and cryptic behaviour, dwarf minke whales are difficult to study, and the size of their population is unknown.



Minke whales are a tourist attraction as they travel through the Reef each winter. © Matt Curnock 2022

Since the most recent surveys in 2015, the humpback whale population may have increased to a projected 40,000 animals, making the east Australian humpback population one of the largest humpback whale populations globally.[504] This exceptional recovery of the population was one of the reasons humpback whales were removed from Australia's threatened species list in 2022.[505]

Humpback whale populations have recovered strongly

Threats to individual whales include entanglement in fishing and shark-control nets, ship strikes and underwater noise.[506] The risk for humpback whales of getting entangled in nets or struck by ships is projected to increase three- to five-fold over the next 10 years due to their increase in numbers.[506] On a population level, the biggest threat to whales is changes in food availability in the Southern Ocean due to climate change.[507] Information on disease or parasites is generally unavailable, but disease incidence in humpback whales is likely to increase as the population approaches carrying capacity.[508] The extent of interactions between populations is an important knowledge gap with implications for understanding drivers and risks to the condition of whale populations in the Region.[509]

Populations of whale species within the Region are inferred to be stable. Humpback whales have recovered strongly. Climate change is the greatest threat to whale populations and their food sources outside the Region.

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. Dolphins can concentrate contaminants in their tissues; high levels of contaminants can be an indication of ecosystem stress. Economically, dolphins are important to tourism and recreational users as iconic marine megafauna. Dolphins are also deeply significant to the culture of many Traditional Owners communities with cooperative fishing having been geographically widespread in eastern Australia[510] and rock paintings of dolphins found across northern Australia.[511] Two species of dolphin are culturally significant for the Mandubarra Traditional Owners as indicators for assessing Sea Country health.[76]

Four dolphin species are known to reside in the Region year-round. The spinner dolphin is found from the coast to the eastern boundary of the Region. The other 3 species, the Australian snubfin dolphin, Australian humpback dolphin, and the Indo-Pacific bottlenose dolphin, inhabit inshore waters. Another 14 species are occasionally sighted in the outer waters of the Reef. Data for these species and the extent to which they are resident within the Region are limited. All dolphin species within the Region are protected by legislation.

There are no Region-wide abundance assessments for Australian humpback and snubfin dolphins, and estimates for discrete populations show they occur in generally low numbers (less than 150 individuals) at low densities.[512] Population sizes of bottlenose and spinner dolphins in Great Barrier Reef waters are unknown and no trend data exist for any of the 4 coastal dolphin species.



Demographic characteristics make individual populations particularly vulnerable to threats

All 4 resident dolphin species are long lived (multiple decades). They have low reproductive rates (single calf and long intervals between births) and are late to reach sexual maturity (approximately a decade).[512,513] These characteristics make individual populations particularly vulnerable to threats causing mortality, such as drowning due to entanglement.[514] All shark control nets have been removed from the Marine Park, while[131] drumlines are allowed under permit. Gillnet fishing will be phased out by 2027. Eight strandings of dolphins have been reported in the past 5 years, the majority found washed up on beaches.[461]

Anthropogenic activities vary widely across the Queensland coastline, resulting in a broad range of potential stressors for coastal species. The main stressors include habitat loss and degradation through disturbances from boating activities, underwater noise and an increase in the severity of extreme weather events (for example, cyclones and floods) caused by climate change. As port development and floods are expected to increase along the Queensland coastline over the coming decades, concerns about the vulnerability of inshore dolphins are increasing.[515] 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 some dolphin species within the Region are inferred to have continued deteriorating since 2019.

2.4.16 Dugongs

The Region is home to a globally significant population of dugongs recognised as contributing to the Reef's outstanding universal value. Dugongs are also culturally significant to many coastal First Nations people in Australia [141] and are a cultural keystone species.

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. As large herbivores, dugongs consume a considerable amount of seagrass (approximately 7 per cent of their body weight per day). They are also highly selective eaters.[516] This consumption strongly influences the productivity of seagrass ecosystems, which in turn provides other ecosystem services, such as carbon sequestration and storage.[133] Individual dugongs have been recorded to move up to 560 kilometres within the Reef region [517] in a few days, potentially supporting large-scale seagrass dispersal and thereby contributing to connectivity between seagrass meadows and aiding seagrass resilience and recovery.



Researchers conducting aerial surveys of dugong populations. © Christophe Cleguer 2023

Australian dugongs are genetically diverse with an abrupt genetic break in the Whitsunday Island region (20.3 degrees south), [518] suggesting that there are distinct breeding units north and south of the Whitsundays.[447] Although individual dugongs can be highly mobile,[517] movements across the genetic break in the Whitsundays have not been confirmed. However, such movements are inferred from aerial surveys, which recorded differences in population sizes between surveys that were too large to be explained solely by dugong births and deaths.[519]

Standardised aerial surveys of dugong distribution and population size along the Queensland coast have been conducted since the 1980s.[520] Since dugongs are highly mobile, immigration and emigration between survey areas between years can confound any population estimates. Differences in total number of animals between years should, therefore, be regarded with caution. Trend analyses that consider long-term datasets provide more reliable indication of the status of a population.

Aerial surveys conducted in late 2023 indicate that the Great Barrier Reef region north of Cape Bedford (between 15.2 degrees south and 10.8 degrees south) continues to support globally significant populations of dugongs, with densities remaining stable, if not increasing, since 2006.[521] As of the 2023 surveys, the dugong population density in this region was estimated to be 0.250 dugongs per square kilometre, very similar to the 2018–19 dugong density of 0.249 dugongs per square kilometre (Figure 2.11). Since 2006, the dugong densities in the northern Great Barrier Reef show an upward trajectory with an annual increase of 1.8 per cent per year (95 per cent confidence interval -0.012 to 0.047) and a probability of increase of 88 per cent.

Dugong populations in the region south from Mission Beach to Bundaberg show evidence of a long-term decline between 2005 and 2022 of –2.3 per cent per year[522] (Figure 2.11). Poor condition of seagrass beds within the Fitzroy and Burnett Mary areas[149] may affect southern dugong populations.

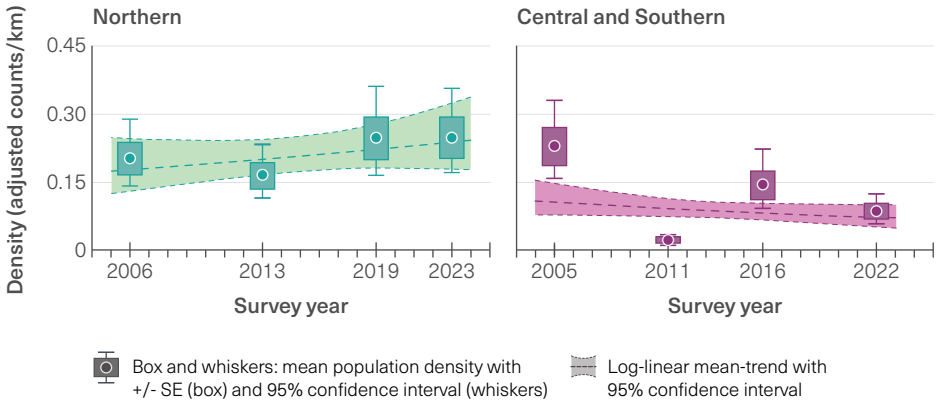


Figure 2.11 **Estimated dugong densities in the Great Barrier Reef since 2005**

Estimated trend and per-survey densities of dugongs in northern areas of the Great Barrier Reef between 2006 and 2023 (left), and in central and southern areas of the Great Barrier Reef between 2005 and 2022 (right). The 2023 density and trend analyses for the northern area were performed on survey blocks between Cape York and Cape Bedford. The central and southern surveys occur from Mission Beach south to Bundaberg. Average population densities (circles) are shown ± 1 standard error (box), with 95 per cent confidence intervals (whiskers). Estimated trends (thick dashed lines) are shown with a 95 per cent confidence interval (fine dashed lines). Source: Cleguer *et al.* (2024) [521] and Cleguer *et al.* (2023) [522]

There is evidence of a long-term decline in dugong populations in the south

Key impacts on dugongs include direct pressures causing mortality, such as incidental catch, vessel strikes, marine debris, traditional hunting and illegal fishing. Indirect pressures, such as loss or degradation of seagrass habitats (Section 2.3.4), 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. Climate change is a threat to dugong populations since it affects coastal environmental conditions, flood events and severity and frequency of cyclones, all of which affect dugongs and the seagrass habitats they rely upon. There is potential for pollutants to accumulate in dugongs due to their longevity, slow metabolism and high fat deposits, [523] but this risk is considered low.[524]

Dugong populations from the Great Barrier Reef region north of Cape Bedford are considered stable, if not increasing. However, between 2005 and 2022 there is evidence of a long-term decline in dugong populations in the south.

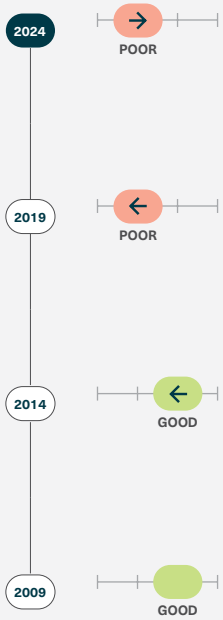
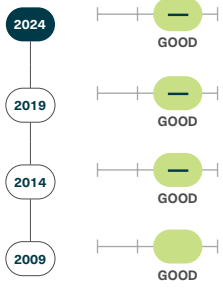
2.5 Assessment summary — Biodiversity

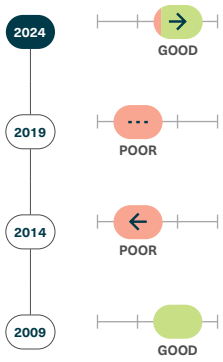
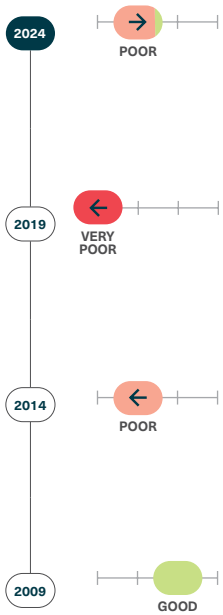
Paragraph 54(3)(b) of the *Great Barrier Reef Marine Park Act 1975* (Cth) requires '... an assessment of the current biodiversity ...' within the Great Barrier Reef Region.
This assessment is based on two assessment criteria:

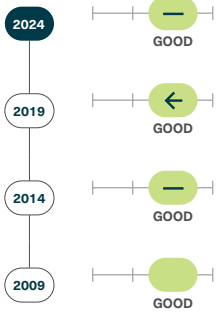
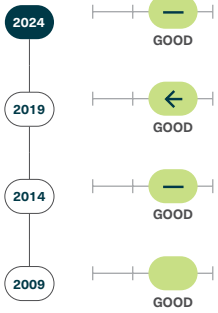
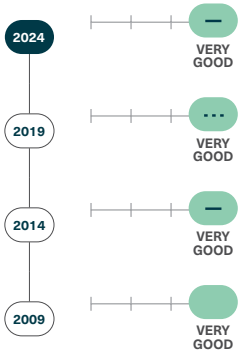
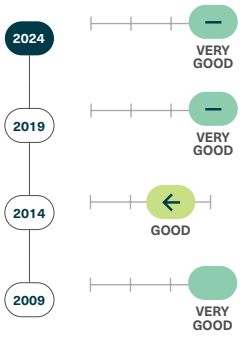
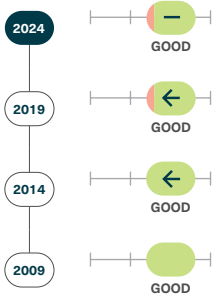
- habitats to support species
- populations of species and groups of species

2.5.1 Habitats to support species

Grading statements — Habitats to support species		Trend since previous report	Confidence
	**Very Good:** All major habitats are essentially structurally and functionally intact and able to support all dependent species.	Improved Stable Deteriorated No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
	**Good:** 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.		
	**Poor:** Habitat loss, degradation or alteration has occurred in a number of areas leading to persistent, substantial effects on populations of some dependent species.		
	**Very Poor:** Widespread habitat loss, degration or alteration has occured in a number of areas leading to persistent, substantial effects on many populations of dependent species.		
	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

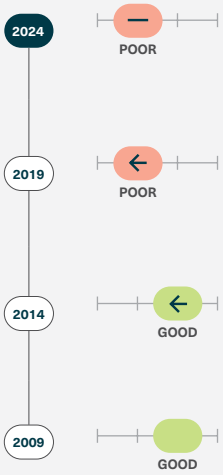
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Habitats to support species: Overall, the condition of habitats is poor on a Region-wide scale, as habitat loss, degradation or alteration in a number of areas continues to have significant effects on populations of some dependent species. There is substantial variation in the assessed condition (and trend in condition) of different habitats, as well as in the amount of data available to inform each assessment. Coral reef condition varies between reefs and regions, and between inshore and offshore reefs. Recovery of key reef-building corals, particularly in the northern region, has contributed to an improved trend since 2019, and coral reefs are now assessed to be in poor (borderline good) condition overall. The condition of seagrass meadows has also improved somewhat since 2019, reflecting the recovery from past flooding impacts in some areas and is now considered in good (borderline poor) condition. Other habitats remain in good or very good condition. Although fewer intense disturbances (temperature extremes, cyclones) have affected habitats since 2019 up until the 2023–24 summer, the threats posed by climate change have not reduced, and most habitats remain extremely vulnerable.			
Islands: The condition of islands varies considerably across the Region and between island types. Some islands have experienced localised damage from severe weather and the accumulation of plastic pollution. Improvements have occurred on others due, for example, to pest eradication. Monitoring of island condition is increasing, and work is underway to assess the response of coral cays to sea-level rise.			
Mainland beaches and coastlines: Non-rocky coastlines remain dynamic. Observed changes over recent years are likely to predominantly reflect natural variation in climatic and oceanic influences, but sea-level rise is expected to increase rates of erosion, recession and inundation in coming decades.			
Mangrove forests: Little change has occurred to the overall extent of mangrove forests. Gains and losses are occurring due to natural and anthropogenic processes. Evidence regarding the Reef-wide distribution and individual causes of these changes is currently limited. Acute cyclone impacts were relatively low from 2019 to 2023, but the impacts of successive cyclones during the 2023–24 wet season have not yet been assessed. Mangrove forests have expanded on some islands in the northern Great Barrier Reef.			

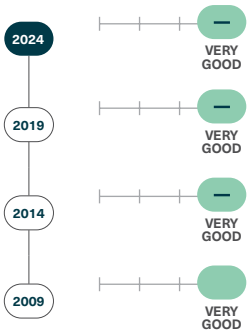
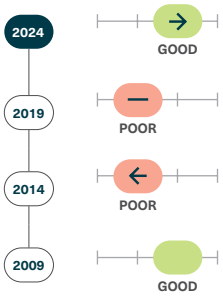
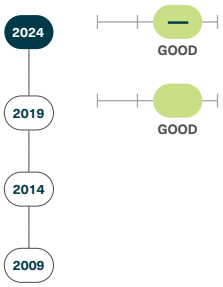
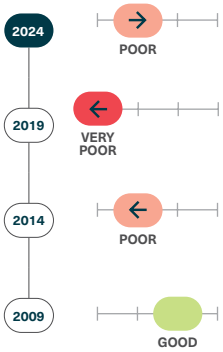
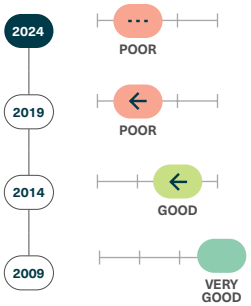
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Seagrass meadows: Seagrasses are affected by increasing temperatures and localised poor water quality. Recent shifts away from colonising species in northern regions are indicative of post-disturbance recovery. Due to impacts from flooding, seagrasses in the southern Fitzroy and Burnett Mary regions have not shown the same recovery. Information on condition of deep-water seagrass meadows is limited. Acknowledging regional variation, overall condition across the Region is assessed as good (borderline poor). In some parts of the Region, summer 2023–24 brought multiple stress events, the effects of which are not yet known.		ADEQUATE	ADEQUATE
Coral reefs — Region: The condition of coral reefs across the Region is highly variable, both on a regional scale and at the scale of individual reefs. Overall, condition is assessed to have improved since 2019 due to increases in total cover of key reef-building coral species across many reefs. The culling of crown-of-thorns starfish has facilitated recovery at many locations. Understanding condition more broadly is complex, and it is unclear whether the recovery in hard coral cover has resulted in shifts in the composition of species within coral assemblages or included recovery of reef-associated species. Coral reefs remain vulnerable to the cumulative pressures brought by climate change, crown-of-thorns starfish outbreaks, and poor water quality in inshore areas — factors that amplify impacts and inhibit recovery from acute disturbances such as cyclones and floods. Little is known about the condition of deeper coral communities across the Reef due to the inaccessibility of these areas, but they may provide critical refuges during periods of thermal stress. (The full extent and impact of the 2023–24 summer cyclones and mass bleaching event is not known at time of writing and is not considered in this assessment).		ADEQUATE	ADEQUATE
Coral reefs — northern: From 2019 to 2022, coral cover on offshore reefs recovered strongly from low levels of coral cover, although a pause in that trajectory occurred in 2023. Trends are highly variable among reefs and the condition of most coral reef habitat components is unknown.		LIMITED	
Coral reefs — central: Since 2019, recovery of coral cover has been recorded in the central region; full community-level recovery may take much longer. Condition of individual reefs is highly variable, and recovery of some inshore reefs has been limited.		ADEQUATE	
Coral reefs — southern: Overall, coral cover improved, or at least stabilised, since 2019 at most reefs in the southern Great Barrier Reef. Coral cover is highly variable among reefs. In the inshore area, coral condition has stabilised since 2019, but remained poor for most reefs. Persistence of high macroalgal cover above local thresholds is a likely driver influencing overall coral condition in the inshore region. Crown-of-thorns starfish continue to affect reefs but are generally below outbreak levels, except in the Swain Reefs.		ADEQUATE	

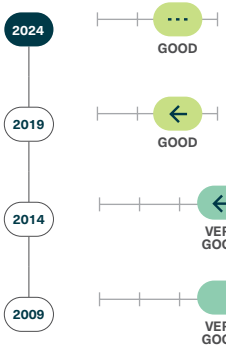
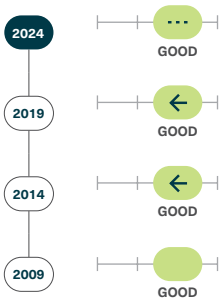
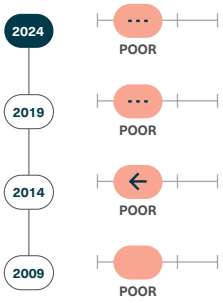
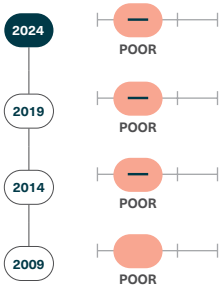
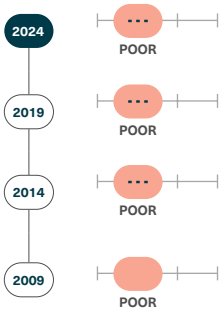
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Lagoon floor: The lagoon floor encompasses a wide diversity of habitats and species with varying sensitivity and exposure to anthropogenic impacts. Although not systematically monitored, much of the lagoon floor is exposed to increasing sea temperatures, with potential impacts to heat-sensitive species. Some areas also continue to be affected by fishing, anchoring and changes in water quality. Trend in condition has been assessed as stable since 2019 but the threats posed by climate change have not abated.		INFERRED	INFERRED
Other banks and shoals: The extent and condition of other banks and shoals is not well documented due to their unique locations and often inaccessible nature. Although not systematically monitored, condition is inferred to be good and trend stable based on a relative lack of intense disturbances (for example, from cyclones) since 2019 and unchanged anthropogenic pressures.		INFERRED	INFERRED
***Halimeda* bioherms and meadows:** Knowledge of the extent and structure of the northern *Halimeda* bioherms has improved since 2019, alongside advances in understanding their functions and biodiversity. However, information on the condition (and trend in condition) of this habitat remains lacking. Since 2019, impacts from acute disturbances are inferred to be negligible due to the depth and isolation of these habitats.		INFERRED	INFERRED
Continental slope: While knowledge of the detailed topography of the continental slope is advancing, and isolated biological surveys have occurred since 2019, confidence in the condition (and trend in condition) of this habitat remains low. Much of this habitat is thought to remain relatively undisturbed.		INFERRED	INFERRED
Water column: Important knowledge gaps remain regarding the condition (and trend in condition) of the water column. Increasing temperatures and changing ocean chemistry are directly affecting this habitat. Understanding of complex climate change impacts on diverse water column assemblages is improving but remains limited across the Region. Excess nutrients and fine sediments from land-based run-off also affect water column condition in many inshore areas.		LIMITED	LIMITED

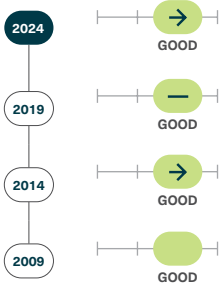
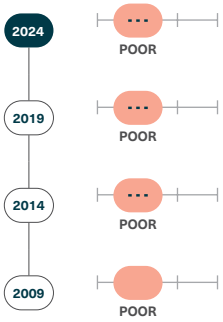
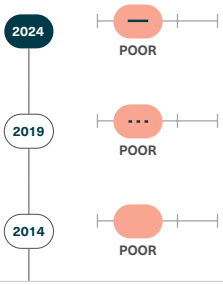
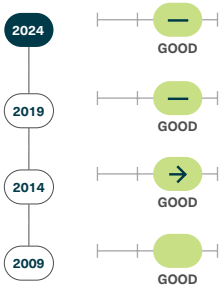
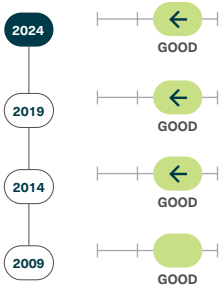
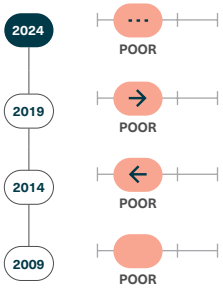
2.5.2 Populations of species and groups of species

Grading statements — Populations of species and groups of species		Trend since previous report	Confidence
	**Very Good:** Only a few, if any, species populations have deteriorated as a result of human activities or declining environmental conditions.	Improved Stable Deteriorated No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
	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.		

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Populations of species and groups of species: Overall, the condition of species and groups of species remains poor on a Region-wide scale, mainly due to the impacts from ongoing climate change and localised reductions in water quality, and there is potential for compounding pressures. There is significant variation between different species and species groups and, in many cases, data are limited. Most populations of marine turtles and seabirds within the Region have declined, as have dugongs in the southern area of the Region, while humpback whales continue to show strong recovery. Increases in cover of some fast-growing corals have occurred, although species diversity and other aspects of coral condition likely remain affected. The condition of seagrasses has improved across many northern regions, but remains poor in the south.			

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Mangroves: Although continued warming and accelerating sea-level rise are expected to lead to future changes in the local distribution and condition of mangrove species, no substantial changes in the extent or diversity of mangroves have been observed over the past 5 years.			
Seagrasses: Seagrasses continue to be affected by increasing sea temperatures and localised decreases in water quality. Recent changes in the proportion of colonising and successional seagrass species in northern regions are indicative of seagrass recovery following past impacts from flooding. Seagrasses in the southern regions of Fitzroy and Burnett Mary are in poor condition, primarily due to the impacts of recent floods, and are vulnerable to future disturbances.			
Benthic algae: Benthic algal cover in shallow reef areas has been relatively stable over the past 5 years. Significant variation exists across this diverse group. Future ocean warming and acidification may adversely affect coralline algae while providing increased opportunities for turf algae and fleshy macroalgae. Populations of microalgae important for coral symbioses may be shifting to more thermally tolerant variants.			
Corals: Relatively few acute disturbances have occurred since 2019, facilitating recovery of some fast-growing species. Increases in cover of these species contribute to some improvement in condition of corals overall. Nevertheless, recovery across other species is less certain, and overall coral diversity likely remains affected. Crown-of-thorns starfish and reduced water quality have affected corals in some locations. While widespread mortality or loss of diversity after the 2020 and 2022 mass coral bleaching events was not recorded, corals remain extremely vulnerable to rising ocean temperatures.			
Other invertebrates: Significant variation exists in condition (and trend in condition) of different species within this diverse group. Pressures associated with climate change, habitat loss, fishing and poor water quality are likely to have affected invertebrates across a range of habitats within the Region.			

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Plankton and microbes: Changes in water temperature and availability of inorganic nitrogen likely impact abundance and diversity of phytoplankton within the Region, which has trophic implications for zooplankton and beyond. Calcifying zooplankton may be affected by increasing acidification, though there is no consistent declining trend in calcifier abundance in the Region. From the limited available data, increases in diversity and abundance of warm-water species are evident across many plankton and microbe groups consistent with expectations under climate change.		LIMITED	LIMITED
Bony fishes: Changes in the mean abundance of some bony fishes have been observed since 2019, and over the longer term. Trends vary between species groups and regions, and both increases and declines have been observed. In some cases, the observed changes may reflect natural fluctuations in populations. Climate change, habitat degradation, and targeted extraction are exerting pressure on bony fishes, and having varying effects in different species and functional groups.		LIMITED	LIMITED
Sharks and rays: Overfishing (including unintentional catch) and climate change-related ocean warming and acidification affect many species of sharks and rays worldwide. In the Region, multiple species are in a reduced state compared to historical population levels. Current management tools may be helping to reduce further impacts. More work is needed to understand the condition (and trend in condition) of individual species.		LIMITED	LIMITED
Sea snakes: Despite reported declines in some locations, the lack of systematic population monitoring means the status of sea snakes in the Region remains uncertain. Based on the limited available evidence, the condition of sea snakes in the Region is inferred to be stable.		INFERRED	INFERRED
Marine turtles: Declining population trends are reported for most species and distinct genetic populations of marine turtles in the Region. Since 2019, the southern green turtle population and eastern Queensland flatback turtles have shown moderate recovery. The nesting population of hawksbill turtles is in significant decline and could be at risk of loss within the next 10 to 15 years. Key threats include climate change, marine debris, national and international take, terrestrial predation, fisheries bycatch and light pollution.		ADEQUATE	LIMITED

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Estuarine crocodiles: Estuarine crocodile populations have continued to recover following historical reduction to very low numbers. Since 2019, although statewide surveys and genetic studies have highlighted some vulnerabilities, the overall condition of crocodile populations is thought to have improved, and confidence in this assessment has increased.		ADEQUATE	ADEQUATE
Seabirds: Overall, confidence in the condition and (trend in condition) of seabirds has improved since 2019 but remains limited. Although available information on population trends is highly site-specific, probable declines are occurring in some species, while other species' populations appear static or have probable increases. Key pressures in the Region include climate-related environmental changes and depletion of prey species, as well as nest predation by invasive species at some sites.		LIMITED	LIMITED
Shorebirds: The available data are nationwide, and shorebird populations must be inferred for the Region. The condition (and trend in condition) of shorebirds in the Region have been assessed as unchanged since 2019. Migratory and resident shorebird species are subject to local pressures, such as disturbance and habitat decline, while migratory shorebirds are vulnerable to habitat loss outside the Region during their migration.		INFERRED	INFERRED
Whales: Populations of whale species within the Region are inferred to be stable. Humpback whales have recovered strongly. Climate change is the greatest threat to whale populations and their food sources outside the Region.		LIMITED	LIMITED
Dolphins: Overall, due to multiple and cumulative threats, populations of some dolphin species within the Region are inferred to have continued deteriorating since 2019.		INFERRED	INFERRED
Dugongs: Dugong populations from the Great Barrier Reef region north of Cape Bedford are considered stable, if not increasing. However, between 2005 and 2022 there is evidence of a long-term decline in dugong populations in the south.		ADEQUATE	ADEQUATE

2.6 Overall summary of biodiversity

Biodiversity is a critical component of the Reef's outstanding universal and natural heritage value. The Region is host to one of the world's most diverse and remarkable ecosystems and contains the largest coral reef system in the world. Biodiversity was assessed in terms of habitats and populations of species, and while there are a range of positive or encouraging results, these are balanced by some serious ongoing issues. Turning declines around is often neither easy nor fast.

Across the entire Region, the condition of habitats (as a group) was rated poor, the same overall rating as 2019. This assessment reflects that habitat loss and degradation or alteration in a number of areas continue to have persistent and substantial effects on populations of some dependent species. Overall, populations of species within the Region also remain in poor condition, and over half of the assessed component species and species groups are graded as being in poor or very poor condition. Species assessments reflect both the long-lasting effects of significant past population declines (for example, from historical commercial harvesting) and the impact of deterioration of the habitats species depend on.

Some species assessments reflect past declines and the condition of key habitats

Coral reef habitats within the Region are assessed to be in poor (borderline good) condition, reflecting an improvement since 2019. Significant and large-scale impacts on coral reef habitats continue to be observed, primarily as a result of climate-related ocean warming. Coral reefs remain highly vulnerable to climate change, crown-of-thorns outbreaks and poor water quality in inshore areas. Mass bleaching of corals occurred in both 2020 and 2022 in response to extreme sea temperatures, however, these events did not result in the extensive mortalities seen during 2016 and 2017. From a populations of species perspective, corals improved overall, but remain in a poor condition. The 2019 to 2023 window of reduced acute disturbances has enabled recovery in cover of fast-growing coral species in some areas. However, it is likely that alterations to habitat and species diversity remain in a number of areas. This is the context in which the additional effects of the summer 2023–24 mass coral bleaching event will unfold.

Despite encouraging recovery in some areas, coral reefs remain highly vulnerable

Grades provided are for the entire Region for all habitats and species, yet the size of the Region is extensive and there is variability in condition. So for the first time in Outlook reporting, the condition of coral reef habitats is also assessed at a regional scale to provide some insight on variation between the northern, central and southern regions. Even at a regional level, considerable variability exists between inshore and offshore areas and within and between individual reefs. Reefs that have escaped impacts from bleaching, crown-of-thorns outbreaks and reduced water quality remain in good condition.

Condition varies across the Reef shelf and within and between individual reefs

The overall condition of seagrass meadows has improved to good (borderline poor), reflecting recovery in northern regions. However, in contrast to the overall trend, seagrass meadows in the south have continued to decline as a result of flooding impacts in recent

years, while little is known about the condition of deep-water seagrass meadows. Similarly, the condition of seagrasses as a group has improved from poor to good since 2019, which again reflects the recovery of seagrasses in northern regions, while seagrasses in the south remain in poor condition.

Coastal habitats, including mangroves, islands and mainland beaches and coastlines, remain in good condition across the Region. Observed changes in coastlines and coastal habitats in recent years may be the result of natural fluctuations in climatic and oceanic processes, although these habitats will be particularly vulnerable to projected future sea level rise. Other habitats remain in good or very good condition.

Marine turtles are in poor condition, and population declines are reported in most species other than southern green turtles and eastern Queensland flatbacks. Dugongs also remain in poor condition, showing no consistent trend at a Reef-wide scale. Northern dugong populations are considered stable, but there is a high probability that southern populations have deteriorated. Overall, sharks and rays, sea snakes, seabirds, shorebirds and other (non-coral) invertebrates are also all assessed or inferred to remain in poor condition, based on variable, and often limited, available data.



Condition remains positive for some species components and poorer for others

Other species components are assessed as being in good or very good condition. Benthic algae, bony fishes and whales are all graded as good condition and have a stable trend. The overall condition of whales partially reflects the strong recovery of the east coast humpback whale population; the conditions of other whale species are largely inferred. Notably, the condition of populations of estuarine crocodiles is considered to have improved and retains a good condition grade.

Key knowledge gaps remain for many species and habitats that are not comprehensively monitored. The lack of information on many groups of species means that declines may not be evident until critical thresholds are exceeded. For some of the deeper and less accessible habitats, such as *Halimeda* bioherms and meadows, the continental slope and lagoon floor, the condition is inferred. Although knowledge of these habitats has improved since 2019, they are not frequently or comprehensively monitored. Information is needed to inform assessment of condition and trends in these habitats.



Condition of deeper and less accessible habitats is poorly documented

The Region's biodiversity has undergone relatively few intense disturbances, such as temperature extremes or cyclones since 2019, although impacts from high temperatures and successive cyclones in late 2023 and early 2024 are not yet fully understood. However, the threats posed by climate change have not abated, and most habitats and a range of species remain extremely vulnerable. Future deterioration in their condition is likely if threats persist and windows for recovery are not adequate.



Heron Island reef flat © Chris Roelfsema 2021

Chapter 3

Ecosystem health



Ecosystem health

(an element of natural heritage)
'an assessment of the current health of the ecosystem within the Great Barrier Reef Region and of the ecosystem outside that region to the extent that it affects that region', s 54(3)(a) of the *Great Barrier Reef Marine Park Act 1975* (Cth)



Parrotfish scraping turf algae at Moore Reef. © Commonwealth of Australia (Reef Authority). Photographer: Ryan Ramasamy 2023

"Dugongs and seagrasses tell us that Sea Country is healthier and we can see the dugong tracks in the seagrass. It's looking so healthy. There's so much marine life. It's thriving. Our reef is very strong, even the science is showing us that our part of the Reef has special resilience in some species, like seagrass and sea meadows.

"Dugong are back, seagrass, fish life, the water quality, the whole reef restoration process. This year, I've noticed a brighter pink, and that indicates a stronger spawn. It's been different, and healthier all round. Our coral were able to become more heat tolerant by adapting to conditions and being resilient.

"It reminded me of us, of Woppaburra people. Looking at the coral and how it adapts, and relating that to our adaptation, made it easy for me (to relate to the science). The cycle of our life of how it spawns and then just floats along in its seabed environment, and the dangers it faced, and the things it had to tolerate to find its way home, build its home, and its stability. We're learning about ourselves as we learn about the coral and it makes it easier to talk about and share."

— Meaghan Cummins, Woppaburra Traditional Owner



The Traditional Owners of the Keppel Islands (16 out of the island group), lying off the Capricorn Coast in Central Queensland — are the sea-faring Woppaburra people. Coral rehabilitation is just one of many marine and cultural projects that has paved the way for the Woppa (island) 'burra' (people belonging to) to re-embrace custodianship of their Country and Sea Country.

Woppaburra Traditional Owner, Meaghan Cummins, reflects on an emotional journey of mob coming home to Woppa and the cultural and marine conservation work underway.

Caring for Country is paving the way for healing on Country. Meaghan says there has been a long-needed shift from 'science working on us, to science working with us.' This focus on science for good is also enabling a revitalisation of cultural heritage and knowledge with positive inter-generational impacts for Traditional Owners.

"In the beginning, scientists would take coral for the formalities of study, but now we work with the Australian Institute of Marine Science (AIMS) who then engaged with us and involved us. They respected the importance of generational processes of decision-making and understood that we had to go back to families. Some families take longer and they gave us the space to do that."

— Meaghan Cummins, Woppaburra Traditional Owner

Source: Caring for Sea Country — Traditional Owner Stories from the Great Barrier Reef [1]

3.1 Background

The Region's ecosystem includes all of its species interacting together within the physical and chemical environment. Ecosystem health encompasses these key interactions and processes that operate to keep an ecosystem functioning. For example, without the process of larval dispersal by currents, species and habitats would not replenish after disturbances. Broadscale impacts have more potential than smaller localised impacts to disrupt ecosystem processes.

Change in biodiversity can only be used as an approximate indicator of ecosystem status. An ecosystem is considered healthy if it is able to maintain its structure and function in the face of external pressures. A functioning ecosystem provides a range of services and benefits to humans, including supporting, provisioning, regulating and cultural services.

This systematic assessment of the health of the Reef ecosystem is based on 5 assessment criteria that encompass the Region's main underpinning processes and interactions (Figure 3.1):

- physical processes
- chemical processes
- ecological processes
- coastal ecosystems that support the Great Barrier Reef
- outbreaks of disease, introduced species and pest species.

The scope of the components assessed remains the same as the previous Outlook Report, with a few minor updates to titles (Appendix 2). It is important to note that these processes operate at a hierarchy of scales in both space and time and many are significantly interlinked.

Consideration has been given to the relevance of observed change over the past 5 years in the context of variability expected over widely varying timescales, from days to the many centuries over which the modern Reef has formed.

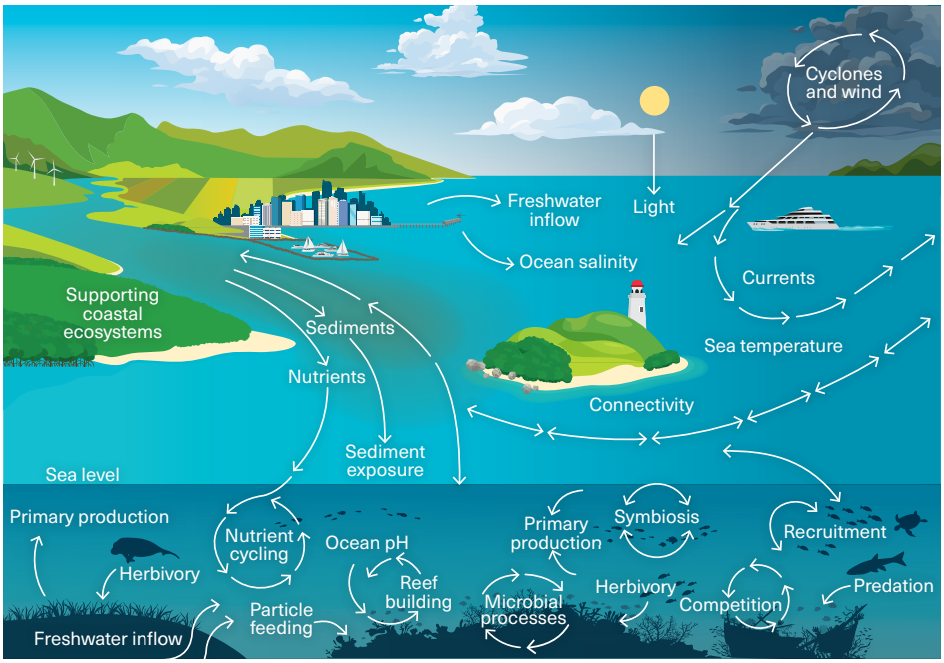


Figure 3.1 **Major physical, chemical and ecological processes**
The health of the Reef ecosystem is assessed by considering its physical, chemical and ecological processes as well as the condition of its supporting coastal ecosystems. Outbreaks of pests and diseases are also considered as a guide to overall health.

3.2 Condition and trends — physical processes

Seven physical processes are graded in terms of changes over the last 5 years due to human activities and consequential effects on ecosystem function. Of these, currents remain in very good condition and 4 other processes (cyclones and wind, freshwater inflow, sea level and light) in good condition, while sediment exposure and sea temperature remain in poor and very poor condition, respectively.

The full assessment summary is in Section 3.7.1.

3.2.1 Currents

Ocean currents can be driven by tides, winds and gradients in temperature, salinity and sea surface height. Currents on the Reef are influenced mostly by the westward-flowing South Equatorial Current and prevailing winds. Along the continental slope, the South Equatorial Current enters the Region and splits into the East Australian Current flowing south and the Gulf of Papua Current (made up of the North Queensland Current and the Hiri Gyre) flowing north [525,526] (Figure 3.2). The South Equatorial Current influences the Region at multiple locations [527] and controls the relative strength of the North Queensland Current and the East Australian Current.[525] South-easterly trade winds are the main driver of currents on the continental shelf and closer to the coast. Driven by wind and the Coriolis Effect, most river plumes in the Region are primarily dispersed northwards along the coast.[528]

The far northern Great Barrier Reef shows little connectivity with the rest of the Reef; it operates as a semi-enclosed sea that is poorly flushed.[530] The Gulf of Papua Current does not directly flow into the lagoon, and most of the northwards water movement within the lagoon is wind driven. The North Queensland Current can provide cooler waters and protection from marine heatwave events.[246] However, this current slows down when the prevailing winds stop and localised heating can contribute to bleaching in this region.[530,531] Some research suggests the North Queensland Current may have decelerated since 1980.[532]

Currents continue to connect and transport species and nutrients but are changing

Currents in the Region continue to connect and transport species and nutrients. However, some changes are occurring. The offshore East Australian Current has intensified since 1980, and both current strength and the frequency of its southward extensions have increased.[356,533,534] How climate change will affect long-shore and cross-shelf transport of seawater through potentially altered wind directions and current strengths is not well understood.[535] If the strength of the East Australian Current continues to increase as expected,[536] the Reef could be exposed to an increasing frequency of marine heatwaves.

Although changes are occurring, currents in the Region continue to connect species and habitats and transport nutrients. Longer-term changes to currents due to climate change are expected.



Suspended particles in the water make flow lines from tidal currents and eddies readily visible around islands east of Mackay. © Landsat 8 | NASA Ocean Color Image Gallery 2020

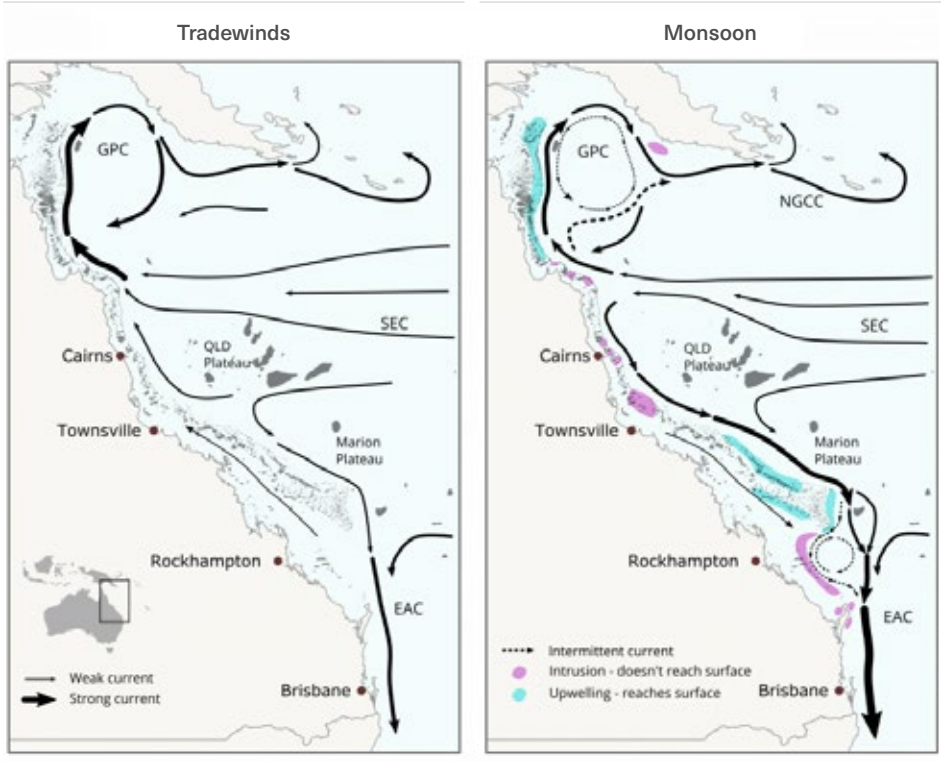


Figure 3.2 **Seasonal prevailing surface currents and oceanic upwelling within the Region**

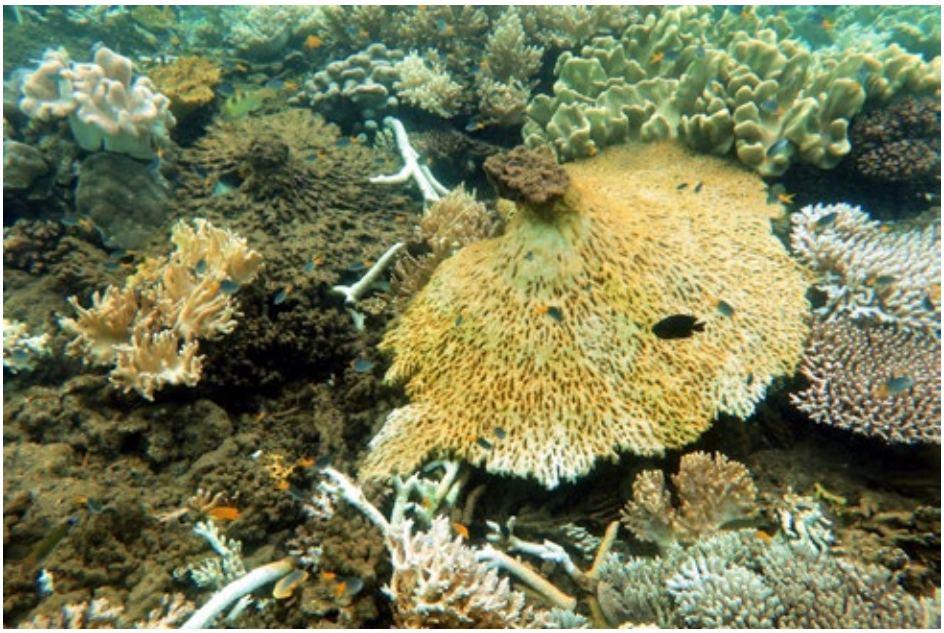
Prevailing surface currents are shown for both trade winds (left) and monsoon (right) seasons. Variations due to weather and eddies are not depicted. GPC = Gulf of Papua Current, NGCC = New Guinea Coastal Current, SEC = South Equatorial Current, EAC = East Australian Current. The Gulf of Papua Current includes the North Queensland Current and the Hiri Gyre. During the trade winds season (usually in winter), consistent south-easterly winds boost northward-flowing currents and slow southward-flowing currents. In the monsoon season (during summer), there is very little effect on currents from surface winds. Source: eAtlas[529] attribution: Craig Steinberg, Eric Lawrey, CC BY

3.2.2 Cyclones and wind

Cyclones are intense, large-scale, low-pressure weather systems that form over warm tropical waters and rotate, producing persistent destructive winds that can build extreme seas given sufficient time and fetch. The number of cyclones making landfall is not random over time.[537] Rather, the frequency of landfall is higher during La Niña years than El Niño years [538,539] (Box 6.1). The number of cyclones has decreased across northern Australia since at least 1982, and likely since 1900 [540] (Section 6.3.1). A continuing trend of decreasing cyclone numbers, but with an increasing average intensity, is expected along with typically large variations in cyclone numbers from year to year.[540,541]

Cyclones can disturb coastal and marine ecosystems through the high winds, waves, storm surge and heavy rain they generate, so they are important drivers of ecosystem change in the Region.[179] Coral reefs, seagrass meadows, mainland and island beaches, and ecosystems on the coastal fringe, such as mangrove forests, are especially vulnerable to such impacts. For instance, mangroves can be damaged by high winds and inundation with salt water, and mangroves at the outer fringe can be wave damaged.

Observed and projected global increases in the average severity of cyclones [542,543] (Section 6.3.1) have important implications for Reef ecosystems (Section 6.3.2). For example, coral reefs can experience damage of widely differing severity, from breakage or removal of individual coral colonies to damage to the reef structure itself, depending on the intensity and duration of wave exposure.[544] Cyclone-induced wave force and resulting damage varies at local scales due to factors like depth, the shape of the seafloor, the presence of physical barriers and reef orientation.[545] Some species are more fragile than others and are more likely to break or dislodge under the force of the waves.[544] In a healthy reef ecosystem, the patchiness of cyclone damage can promote diversity by creating a range of microhabitats and enabling the growth of corals with varying morphologies and rates of growth.[546,547] Reef recovery depends on factors such as the severity and duration of exposure, the pattern and frequency of future disturbances,[537] and the availability of suitable conditions for coral regrowth.[548] If consolidated reef matrix is badly damaged recovery can be very slow.[544]



Overturned plate coral after cyclone Jasper at Fitzroy Island. © Ryan Ramasamy 2024

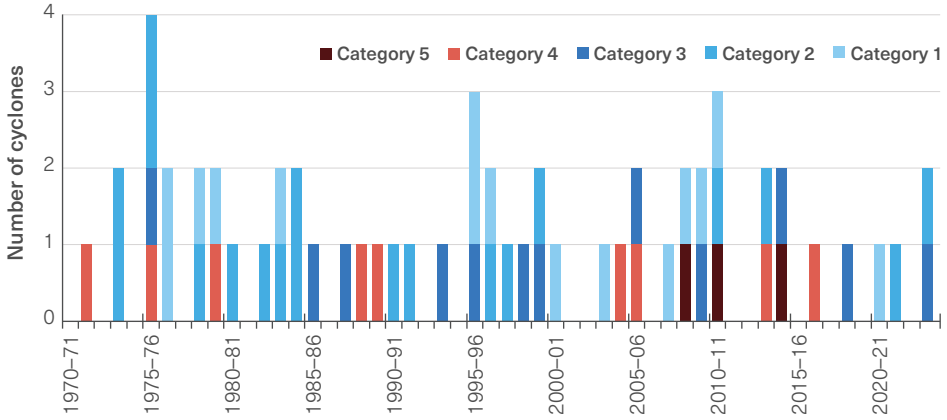


Figure 3.3 **Number and severity of cyclones, 1970–71 to 2023–24**

Showing the number and category of cyclones that entered the Region between 1970–71 and 2023–24 (1 July–30 June). The cyclone category shown is the maximum category reached within the Region for a particular system. Cyclone categories have been determined based on the mean maximum windspeed recorded in the Region in kilometres per hour (kmph). Category 1: 63–88 kmph, Category 2: 89–117 kmph, Category 3: 118–159 kmph, Category 4: 160–199 kmph, Category 5: >200 kmph. This analysis method may exclude some cyclones which remained outside the Region but caused wave damage within the Region (such as cyclone Iris in 2017–18). Source: Commonwealth of Australia Bureau of Meteorology [558,559,560]

The extent to which cyclone-induced waves damage coral reefs depends on a combination of the cyclone's intensity, size and the length of time spent tracking near coral reefs.[549] Although a trend of increasing intensity (but decreasing frequency) [540] appears to be emerging, future trends for the other determinants of damage to reefs (cyclone size and speed of travel) remain uncertain.[549] Likewise, there is considerable uncertainty surrounding potential future shifts in locations and patterns of areas exposed to cyclones.[549] While poleward shifts in the latitude of maximum intensity of cyclones have been observed in both northern and southern hemispheres,[550] and there is evidence showing potential expansion of regions suitable for cyclones,[551,552] it is unclear whether these trends are occurring in the Region.

Cyclones and other low-pressure systems can produce oceanic storm surges that cause serious damage to coastal infrastructure and ecosystems. One of the most certain future impacts from cyclones will be an increase in coastal flooding when storm surges are superimposed on higher sea levels (Section 3.2.5), increasing their destructive power.[540,553] The probability of heavy rain events has also increased in recent decades due to regional warming (as warmer air carries more moisture), and it is projected to increase further as air temperatures continue to rise.[540,554] Conversely, wave action associated with cyclones has been shown to upwell cooler water that can lower sea surface temperatures and reduce the impacts of coral bleaching at regional scales,[555] while the cooling influence of increased cloud cover can also reduce sea surface temperatures at local scales.[556]

Cyclones remain key drivers of ecosystem change in the Region

Over the past 5 years, cyclone activity has been relatively low (Figure 3.3). Cyclone Trevor crossed the Region before making landfall on 23 March 2019 near the town of Lockhart River in Cape York as a category 3 system, causing significant damage on land. Impacts to the Reef were found to be minimal at long-term coral reef survey sites in the vicinity, noting most were well south of the cyclone's track.[557] Cyclone Kimi tracked through the Region in January 2021 reaching category 1 but not making landfall. Cyclone Tiffany reached category 2 intensity within the Region, before making landfall near Cape Melville on Cape York Peninsula on 10 January 2022 at category 1. Cyclone Jasper crossed the Reef before

making landfall at Wujal Wujal, north of Cape Tribulation, on 13 December 2023 as a category 2 system. Cyclone Kirrily crossed through the Region in January 2024, making landfall at Townsville as a category 3 system. The period of relative quiescence before the successive cyclones in late 2023 and early 2024 saw a welcome recovery in coral cover (Sections 2.3.5, 2.4.4 and 8.3.1), highlighting that the Reef remains a resilient and dynamic ecosystem. Maintaining this resilience by addressing pressures amenable to management action is crucial for the long-term health of the Reef in the face of compounding impacts from climate change and ocean acidification.

Winds are an important influence on the Reef, affecting a range of processes, including the shaping of islands and coastlines, the movement and local characteristics of waves and currents, and distribution pathways of marine pollution.[561] Established wind patterns can affect the breeding success and life history traits of reef animals such as corals, fish,[562] and sea snakes.[435] Any changes in wind patterns may affect connectivity within the Region, via the distribution of windborne seeds [563] and larvae of coral, fish and invertebrates.[564] Climate change may affect wind speeds and patterns in the Region, but the specific changes are likely to be complex and are not yet well understood.[565,566,567]

In the past 5 years, cyclone activity has been relatively low. However, large variation in the numbers of cyclones is expected, and cyclones remain one of the most important drivers of ecosystem change in the Region. A longer-term trend may be emerging of decreasing cyclone numbers and increasing average intensity.

3.2.3 Freshwater inflow

The Reef receives freshwater inflow from a Catchment area of approximately 424,000 square kilometres, about a quarter the area of Queensland.[42] These flows are driven by rainfall patterns that are highly variable on seasonal, inter-annual and decadal timescales. Sixty to 80 per cent of rainfall occurs during the wet season (December to April), often associated with monsoon troughs and the passage of low-pressure systems and cyclones.[568] More extremes in flow are being experienced during wet and dry seasons. Variation from year to year is strongly linked to major climatic drivers, such as the El Niño–Southern Oscillation and the Madden–Julian Oscillation (Box 6.1). Monsoonal and cyclonic events can cause major flooding across the Region. These varied temporal patterns are superimposed on decadal rainfall trends occurring due to climate change.

Rainfall in northern Queensland has increased by around 10 per cent since 1750 and has become more variable, as rainy years became much wetter, while dry years remained dry.[569] Heavy rainfall events are predicted to become less frequent but more intense as a result of ongoing global warming.[540] Daily rainfall totals associated with thunderstorms have increased since 1979, particularly in northern Australia, but declined in other areas of the Great Barrier Reef Catchment. This trend is expected to continue in future.[540]

Following rainfall, major river systems transport vast amounts of freshwater runoff from the surrounding landscape, channelling it towards the coast and into the Reef. In many areas along the coast, fresh water is also channelled through extensive networks of wetlands and other coastal ecosystems.[36] These act as natural filters and buffers, trapping and removing nutrients (including via denitrification) and sediment before they reach the ocean. Large flood events cause rivers to break their banks and inundate floodplains and wetlands, which affects the dissolved and suspended constituents of water entering the Reef. Historical clearing and draining of coastal wetlands are important legacy impacts affecting the quantity and quality of freshwater inflow.[42]

The Catchment is made up of 35 major river basins, which vary considerably in their volumes and patterns of discharge. Rivers in the Wet Tropics Natural Resource Management region generally flow year-round; their discharge is driven by groundwater

base flow and higher, more consistent rainfall than in other regions. Average rainfall is also relatively high across parts of the Cape York and Mackay Whitsunday regions. Rivers in the Burdekin, Fitzroy and Burnett Mary regions exhibit highly variable discharge that is characterised by very large but infrequent flood events.

The most direct effect of freshwater inflow is a reduction in salinity, to which corals are sensitive.[570] Fresh water is less dense than sea water, and it forms surface plumes that extend long distances in calm conditions. Freshwater inflow can also bring with it a range of land-sourced substances, including dissolved and particulate nutrients, suspended fine sediments, pesticides, and plastic waste (Section 6.5). In excess, many of the constituents of land-based runoff act as pollutants and can negatively affect organisms in nearshore waters. For example, land-sourced nutrients drive productivity in the marine environment but excess nutrients can be damaging to ecosystems.[571] The combined effects of lower salinity, reduced light due to the suspended sediments, and high sedimentation can contribute to localised coral and seagrass mortality.[572] At a Region-wide scale, exposure to floodwaters has been shown to correlate with declines in the recovery rate of coral cover.[573]

More extremes in flow are being experienced during wet and dry seasons

Freshwater flow has become more variable since European settlement, and more extremes are being experienced during wet and dry seasons.[569,574] Substantial changes in freshwater flow into the marine environment also appear to be associated with changes in the El Niño–Southern Oscillation. Historical records show a marked shift in the frequency and size of river discharge from the 1850s and again in the 1950s.[574] Cores taken from long-lived corals indicate that the frequency of high freshwater flows into the Region has increased over the past 2 centuries, from every 20 years from 1748 to 1847 to every 6 years from 1948 to 2011.[575] Along with climate change, extensive land clearing and changes in land use (Section 6.4) have occurred over this period, altering hydrology in ways that have led to higher freshwater discharges and reduced coastal wetland processing of pollutants. These changes have resulted in water of poor quality entering the Reef lagoon.[36] Exposure to freshwater inflow and associated poor water quality over successive years of high-flow events can hinder recovery of nearshore habitats.[576,577] Projected increases in the frequency of such freshwater flow events[540] mean they are likely to continue to affect condition and recovery trend of these habitats.

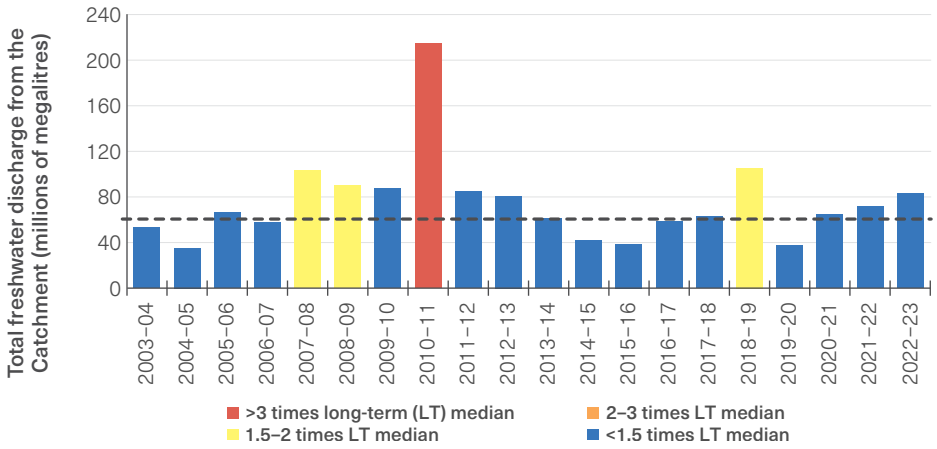


Figure 3.4 **Total annual freshwater discharge from major rivers in the Catchment, 2003–04 to 2022–23**

Discharge in millions of megalitres (water monitoring year: 1 October to 30 September) for the 35 main Reef river basins. Bar colours: red = >3 times long-term median flow, orange = 2–3 times, yellow = 1.5–2 times, blue = <1.5 times. Dashed grey line indicates long-term median for the total Reef discharge over the period 1990–91 to 2019–20. Source: Gruber *et al.* (2024).[579] Data: Department of Regional Development, Manufacturing and Water (2023).[583]

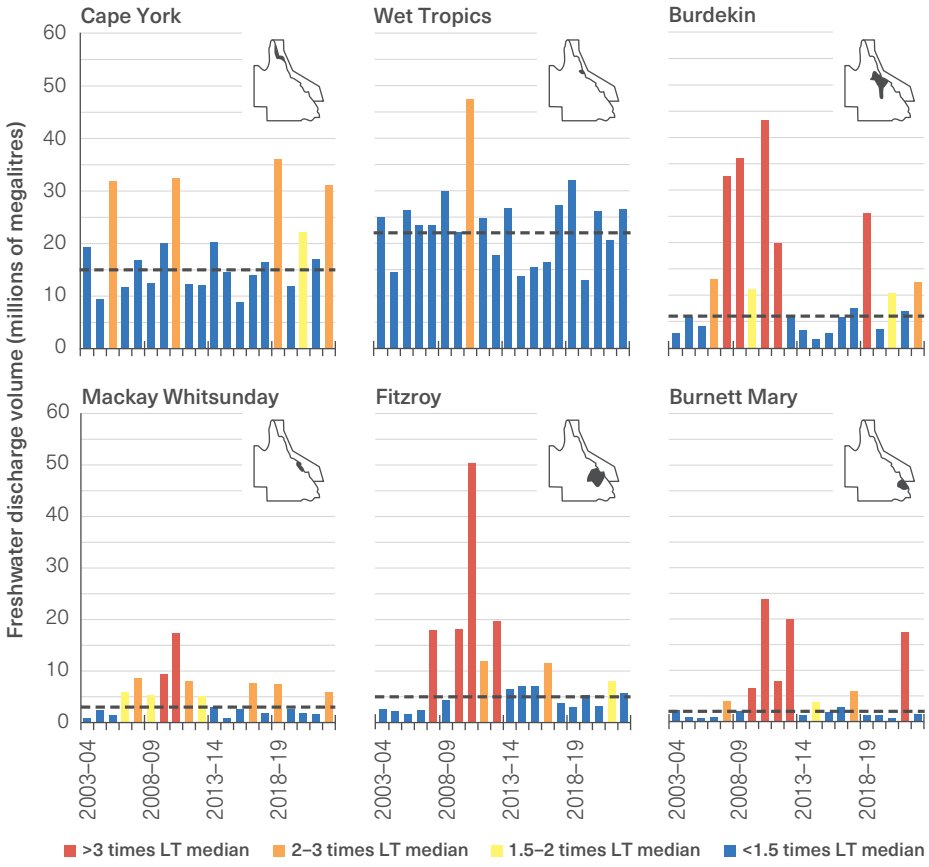


Figure 3.5 **Annual freshwater discharge from major rivers, by region, 2003–04 to 2022–23**

Discharge in millions of megalitres (water monitoring year: 1 October to 30 September) for the 35 main Reef river basins, aggregated into the 6 natural resource management regions. Bar colours: red = >3 times long-term median flow, orange = 2–3 times, yellow = 1.5–2 times, blue = <1.5 times. Dashed grey line indicates long-term median for each natural resource management region. Source: Gruber *et al.* (2024).[579] Data: Department of Regional Development, Manufacturing and Water (2023).[583]

The Catchment is large, and spatial and temporal variation in freshwater discharge are common. The 2018–19 water monitoring year (October to September) saw significant flooding of the Daintree River and flooding of rivers in the Burdekin region,[578] whereas 2019–20 was a dry year in which discharge across the Catchment was below the long-term (1990–91 to 2019–20) median (Figure 3.4). In 2020–21, discharge from the overall Catchment area was just above the long-term median. On a regional basis, the 3 northern natural resource management regions had above-median discharge in 2020–21: Cape York was 1.7 times higher than the long-term median, Wet Tropics 1.2 times higher, and Burdekin 1.7 times higher (Figure 3.5). In comparison, the 3 southern regions had well below median discharge, all recording less than 50 per cent of their long-term median values. In 2021–22, river discharge across the Catchment as a whole was again just above the median.[363] However, major floods in some locations led to high regional variation. River discharge in the Burnett Mary region was almost 9 times the long-term median, whereas discharge in the Mackay Whitsunday region was around half the long-term median.[363] In 2023, above-median discharge occurred in the Cape York, Burdekin, and Mackay Whitsunday regions.[579]

Overall, the average annual discharge across the Catchment over the past 5 years (2018–19 to 2022–23) was approximately 1.3 times the long-term median for total Reef discharge (Figure 3.4).[579] However, this may be an underestimate of the 5-year average, as data from the intense flooding [580] that followed cyclone Jasper in December 2023 [581] are not yet incorporated. The year 2023 marked the third consecutive year of La Niña conditions, a duration which has only occurred 3 times in the past 50 years.[582]

Reef health surveys documented bleaching on inshore reefs off Cairns following the extreme rainfall associated with cyclone Jasper,[581] likely caused by freshwater exposure, but the extent and severity of damage will take time to determine.

Interactions between freshwater inflow, coastal development (Section 6.4), land-based runoff (Section 6.5), sediment exposure (Section 3.2.4), light (Section 3.2.7), nutrient cycling (Section 3.3.1), and the condition of coastal ecosystems (Section 3.5) are complex and integral to the health of the Reef.

In summary, over the past 5 years, the average annual freshwater inflow across the Catchment has been just above the long-term average and shown regional variability. Documented and projected changes in rainfall are affecting this process over decades.

3.2.4 Sediment exposure

The process of sediment exposure includes the transport of sediment into and throughout the Region, primarily from land-based runoff, but also through resuspension and increased turbidity and sediment settling on bottom-dwelling organisms. The inflow from land to sea, and subsequent dispersion, resuspension and consolidation of sediments, are natural processes that have affected water quality, and modified and shaped lagoon floor habitats (Section 2.3.6) since modern sea levels were reached about 7500 years ago.[584] However, suspended sediments entering the Reef lagoon are estimated to have increased 1.4 to 5-fold since European settlement,[42] which can be largely attributed to changes in land use.[42] This increase is a result of soil erosion from rangeland grazing and cropping, urban development, deforestation, and mining. Some of the increase can also be attributed to climate change and associated changes in rainfall and land-based runoff.[42,585]

Most new sediment is delivered to the Region during flood events (Figure 3.6). Amounts delivered vary between the 6 natural resource management regions and individual catchments.[42] Modelling of land-derived total suspended solids indicates that the highest exposure levels from anthropogenic sediment loads are concentrated in inshore areas and the largest inputs come from the Burdekin River (Section 6.5.1).[579] Most sediments delivered from river catchments settle and are retained along the coast, within floodplains, estuaries, close to river mouths and within the eastern sections of north-facing embayments.[42,586,587] Nearshore and inshore fringing coral reefs also host considerable proportions of land-derived sediments within their internal structures.[42] Within the Reef lagoon, land-derived sediments are mostly contained within the inner shelf (from 0 to 20 metres depth).[586]

The composition of suspended sediment is an important factor influencing its distribution and effects. Most fine sediments tend to clump together in a process called flocculation and settle in areas where fresh water and saltwater mix.[588] However, some fine sediments can be carried long distances away from river mouths in suspension, and they occasionally reach mid-shelf and even outer-shelf areas of the northern and central Reef when very large riverine discharge events coincide with low wind speeds.[42,586]

Cross-shelf transport of land-derived sediments also occurs by a variety of other mechanisms.[586] Fine sediment can be resuspended by wind and tidal currents in shallow waters and may persist in the water column for at least 6 to 8 months following river input.[589] Delivery and resuspension of new sediments, and resuspension of legacy sediments can affect water quality year-round.[42] Multiple lines of evidence from turbidity loggers, remote sensing, and modelling show that river discharge and associated sediment loads are linked to elevated and prolonged turbidity levels, resulting in longer periods of reduced light available for photosynthesis in certain inner and mid-shelf areas of the Reef lagoon (Section 3.2.7).[42,586]



Figure 3.6 **Satellite image of the Normanby River flood plume, 22 December 2023**
Image captured by NASA's moderate resolution imaging spectroradiometer (MODIS) Aqua satellite. The Normanby River is in the far north of the Region. Source: NASA Goddard Space Flight Center.[590]

Excessive sediment exposure can result in the degradation of habitats

Sediment exposure has both positive and negative effects on ecosystems. For example, sufficient sediment supply is crucial for some habitats, such as low wooded islands, to keep pace with rising sea levels.[591] However, excessive sediment exposure can result in the degradation of coral reefs, soft-bottom habitats, seagrass meadows and freshwater wetlands, and can affect filter feeders and fish.[39,592,593,594] Sediment exposure influences ecosystems in several ways such as through increased in water turbidity, by settling on and even burying organisms, remineralising into bioavailable nutrients that can drive productivity,[595] and providing a vector for the spread of pathogens.[596] There is mounting evidence that sediment exposure can suppress recovery from other disturbance events, such as marine heatwaves and cyclones.[42,39] The effects of sediment and particulate nutrients on freshwater wetlands and estuarine wetlands, such as mangroves, marshes and supratidal forests, in the Region is a key knowledge gap.[42,39]

Inshore locations are frequently exposed to turbid waters that absorb light required for photosynthesis, affecting both quality and quantity of light reaching the seafloor.[597] Seagrasses are especially vulnerable to reduced light availability.[598,599] Seagrass canopies capture suspended sediment, and loss of seagrass causes feedback loops that can result in persistent impacts on seagrass habitats[600,601] and indirectly affect dependent species (such as dugongs).[602] Sedimentation and changes to the substrate are important for seagrass and reef organisms, especially for influencing settlement.[42]

Some coral species and reefs live in turbid conditions,[227,603] and a high abundance and diversity of coral species can be found in shallow water in some turbid inshore settings with favourable hydrodynamics.[42] However, excess loads of sediment and particulate nutrients can affect coral physiology and recruitment, and reef community composition (Section 6.5.2), and coral diversity is generally lower on inshore reefs than at offshore locations.[39] Coral assemblages on inshore reefs are dominated by turbidity-tolerant species and depend more on food capture by coral polyps. In contrast, offshore reefs have more turbidity-sensitive corals and a greater reliance on photosynthesis by symbiotic partners for food.[604] Turbidity reduces the growth of macroalgae but they tend to be less sensitive than corals, and reefs chronically affected by sediment exposure often have higher cover of fleshy macroalgae than reefs in clear waters.[42,39] Settled sediment is energetically costly to remove and affects the suitability of the substrate for coral recruitment and growth.[605] Settled sediment can also interfere with predation and directly or indirectly (through altering algal substrate) affect herbivorous grazing.[606]

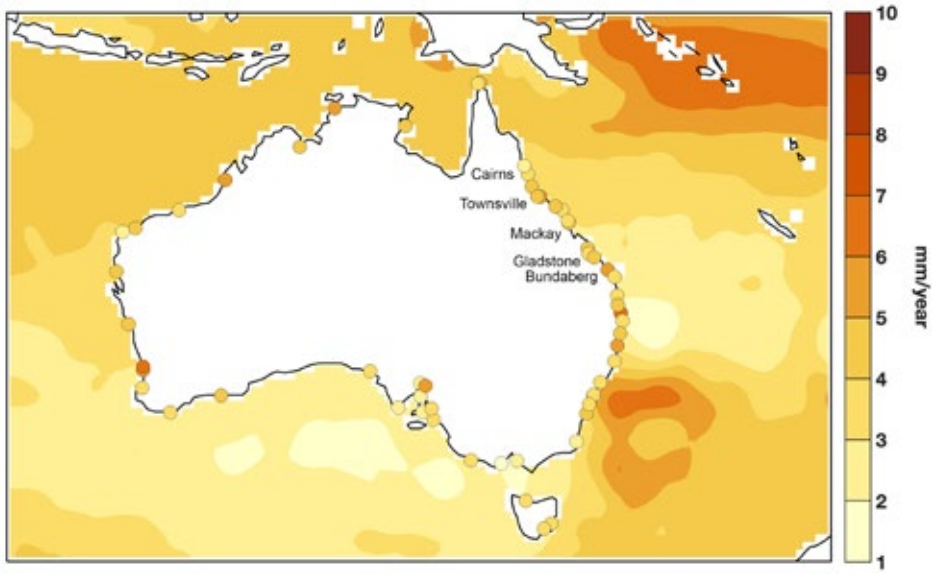
Many other key species groups, including sponges, crustose coralline algae and large benthic photosynthetic foraminifera, are also negatively affected by sediment exposure.[42] For fish communities, suspended sediments can affect the growth and time to metamorphosis of juvenile fish, juvenile gill morphology, foraging time, body condition and mortality. Suspended sediments can also interfere with the visual cues that juvenile fish use to settle into habitats, impairing their ability to: distinguish between live and dead coral; extend their settlement time; and alter feeding patterns.[39]

In the 2022–23 water monitoring year (October to September), measurements of total suspended solids met guideline values in most regions where data were collected. While concentrations of total suspended sediments exceeded guideline values in the Mackay Whitsunday region, they have shown a recent trend of improvement.[579] Additional information on sediment loads since 2019 is given in Section 6.5.1. Wet season river influence from 2018–19 to 2022–23 rarely extended seaward of inshore waters.[579] Therefore, impacts to mid-shelf and offshore ecosystems from land-derived sediment exposure during this period were low, and this period has seen the recovery of previously affected seagrass meadows in several locations (Section 2.3.4). However, sediment exposure over the past 5 years was still considerably higher than pre-European levels. Across the Region, the relative influence of sediments sourced from river discharge compared to resuspension of sediments already existing in the ecosystem remains poorly understood.

Sediment loads delivered during flood events, and resuspension of legacy sediments continue to contribute to the poor state of many inshore coastal and inshore marine ecosystems. Since 2019, some areas have seen improvements in sediment exposure, but other inshore areas continue to be affected by resuspended and catchment-derived sediments.

3.2.5 Sea level

Sea level varies throughout the world's oceans due to variations in the pull of gravity, the temperature and salinity of the water, the pressure of the atmosphere above the ocean surface and the movement of ocean currents.[607] These factors combine to create a surface with a natural slight topography of hills and valleys that vary in height by up to 2 metres. Climate phenomena, such as El Niño and La Niña can cause cyclical variations in sea level of 20 to 30 centimetres over years or decades.[608] Superimposed on this uneven surface are the normal, frequent fluctuations in sea level, such as those associated with tides, storm surges, and ocean waves (swell and wind waves), in the order of metres.



	Cairns	Townsville	Mackay	Gladstone	Bundaberg	GMSL
1966-2023	*	2.27	*	*	2.11	2.38
1993-2023	2.09	4.34	3.89	4.40	5.08	3.61

Figure 3.7 **Sea level trends around Australia**

Contours show offshore sea level trends measured by satellite altimeters from December 1992 to February 2024. Coloured dots show coastal sea-level rise from the Permanent Service for Mean Sea Level (PSMSL) multi-decadal tide gauge dataset over the same time period. The table provides relative sea level trend data in millimetres per year for 5 tide gauge stations within the Region for the periods 1966–2023 and 1993–2023 compared to global mean sea level (GMSL). * Asterisk indicates insufficient data are available to assess trends for this period. Source: CSIRO (2024)[616] using altimetry data provided by the NOAA Laboratory for Satellite Altimetry.[617] Tide gauge records are from PSMSL.[618,619] GMSL observation considers an ensemble of tide gauge reconstructions (1966–1993) and satellite observation (1993–2023).[620,621]

Sea levels have been monitored with near-global coverage using satellites for more than 25 years, while a network of tide gauges has provided more detailed local and regional records for more than a century.[609,610,611] Remote sensing data suggest that offshore sea levels within the Region rose at a rate of around 3 to 4 millimetres annually between 1993 and 2020[540] (Figure 3.7). Over a similar period, data from coastal tide gauges indicate that sea levels have risen around 2 millimetres per year near Cairns, Townsville and Gladstone, and by 3 to 4 millimetres per year at Mackay and Bundaberg.[612] In both Townsville and Bundaberg, where sufficient data are available to assess longer-term trends, a higher rate of sea-level rise is reported in more recent years (1993 to 2019) than over the longer time period (1966 to 2019).[612]

Globally, average sea levels are rising as a direct consequence of anthropogenic global warming.[613] Two main processes are driving this: thermal expansion (an increase in the volume of sea water as it warms) and increased melting of land-based ice.[540,614] Global average sea level rose faster during the twentieth century than in any prior century during the past 3000 years and this rise has accelerated since the late 1960s to around 4 millimetres per year [582,608,615] (Section 6.3.1). The rise is increasingly due to the loss of land ice, and recent increases in meltwater from Greenland and Antarctica have made this process the largest contributor to global sea level rise since 2006.[608]

Sea level rise is likely to continue to accelerate and will continue for centuries

The effect of sea level rise on coastlines depends on numerous factors, including vertical land movements and ocean circulation changes, in addition to the factors driving global sea-level rise.[622,623] Human communities and coastal ecosystems are affected by the local height of the ocean relative to the coastline,[624,625] referred to as relative sea level. Sea level rise, though incremental, is likely to continue to accelerate in coming decades and will continue for centuries even if strong global action is taken to reduce greenhouse gas emissions[608] (Section 6.3.1).

The natural fluctuations in sea level caused by weather, tides and ocean swell create occasional extremes of sea level such as king tides and storm surges, which can cause serious damage to coastal ecosystems, infrastructure and communities. As average sea levels rise, these extreme events will be superimposed on a higher baseline, increasing the environmental and economic impacts of coastal flooding and erosion.[540,553,626]

In Townsville, the frequency of occurrence of coastal inundation has been doubling every 34 years since 1959.[612] Species such as marine turtles and seabirds that rely on low-lying beaches and cays for nesting and breeding are also at high risk from sea-level rise.[627,628] If increases in the Region are similar to the global average, extreme sea level events that in the recent past occurred around once per century will occur about 20 to 30 times as often by 2050 and 160 to 530 times as often by 2100.[608,629]

Sea-level rise is also expected to interact with the complex bathymetry of the Reef to locally increase or decrease tidal ranges, so some coastal areas will be more affected than others.[630] A range of factors such as such as local sediment supply also affect how habitats respond on different timescales. For example, mangrove forests on low wooded islands have expanded over recent decades likely due to increased habitat availability linked to sea-level rise.[123]

Current impacts from sea-level rise are often difficult to disentangle from individual weather events and cyclical variations, such as those driven by El Niño. For example, beach erosion is influenced by a local combination of human activities, current-induced sediment transport and storm events.[109] Rising sea levels are an emerging and inevitable future threat to Reef ecosystems (Section 6.3.2) and coastal communities (Section 6.3.3). Early impacts of accelerating sea-level rise at sheltered or subsiding coasts are likely to include chronic flooding at high tides, wetland salinisation and ecosystem shifts, increased erosion, coastal flood damage and increased vulnerability of low-lying islands.[96,109] The disproportionate concentration of economic development in and around coastal settlements means that future risk to many of the Region's communities from the impacts of sea-level rise is high.[109,631]

Sea level has been rising over recent decades, leading to increases in the frequency of high-tide flooding events. Year-to-year changes remain small in the context of inter-annual natural variability. Impacts of sea-level rise will increase in coming decades.

3.2.6 Sea temperature

Sea temperatures within the Region are affected by global-, regional- and local-scale processes. Global anthropogenic warming is the main driver of increasing ocean temperatures [536] both at the sea surface and at depth. Large-scale climate drivers, such as the El Niño–Southern Oscillation (Box 6.1), influence sea temperatures on an annual basis: sea temperatures are warmer during the El Niño phase.[540,632,633] A positive Indian Ocean Dipole may also be associated with warmer-than-average sea temperatures in the Region.[634] Seasonal and regional patterns in solar energy, cloud cover, currents [252,635] and storm events [163,636] affect sea temperature and the circulation of ocean heat within the Region. Regional oceanographic processes, such as upwellings, river plumes and

seasonal current flows lead to variation in surface and subsurface temperatures within the Region.[635,637,638] During winter, dense shelf water cascades occur in some locations where cool water (which forms near the coast) flows offshore along the seabed.[639] At fine scales, tides, wind and waves affect the flow of water over shallow reef structures, leading to thermal microclimates within individual reefs.[635,640,641]

Oceans play a significant role in regulating global climate systems and in slowing the rate of warming on land and at the sea surface.[540] Since the 1970s, the world's oceans have absorbed 91 per cent of the extra heat stored by the planet due to increased greenhouse gas emissions.[536,540] This increasing ocean heat content has consequences for oceanic and atmospheric circulation patterns, sea levels (Section 3.2.5), decreasing solubility of oxygen [540,642,643] (Box 6.2) and the frequency and intensity of cyclones. Ocean warming gives rise to longer and more frequent marine heatwaves within the Region.[644] Marine heatwaves, defined as periods of at least 5 days where temperatures are in the upper range of historical conditions for that area,[645,646] have major impacts on reef ecosystems.[647]

Ocean warming and increasing marine heatwaves affect the health and resilience of marine ecosystems (Section 6.3.2).[246,333,647] Most marine animals are ectotherms, so changes in sea temperature can alter their distribution, survival, metabolism, respiration and behaviour.[330,648,649,650] Thermal stress, as a result of high temperatures, is a primary cause of bleaching in reef-building corals and can lead to mortality. While corals can recover from bleaching, their capacity to recover is reduced with increasing intensity, duration and frequency of thermal stress.[163] Thermal stress, particularly when associated with marine heatwaves, has significant impacts for many habitats and species, including corals,[163,651,652,653,654] seagrasses [185,655] and fishes.[252,366,656] Additionally, warmer sea temperatures reduce the solubility and mixing of oxygen within the ocean,[657] reducing the availability of oxygen for respiration by marine organisms.

Global sea temperatures are continuing to increase, leading to record monthly global sea surface temperatures during 2023 [166] and high daily means recorded so far in early 2024 (Figure 3.8). Since 1950, each decade has been warmer than the previous. Ocean heat content reached its highest level in 2023 the latest available full year on record,[166] superseding previous highs in 2022, 2021 and 2020.[540,658,659] Average sea surface temperatures around Australia have risen by 1.05 degrees Celsius since 1900,[540] higher than the global average.[536]



Coral colonies in varying stages of bleaching © Matt Curnock 2022

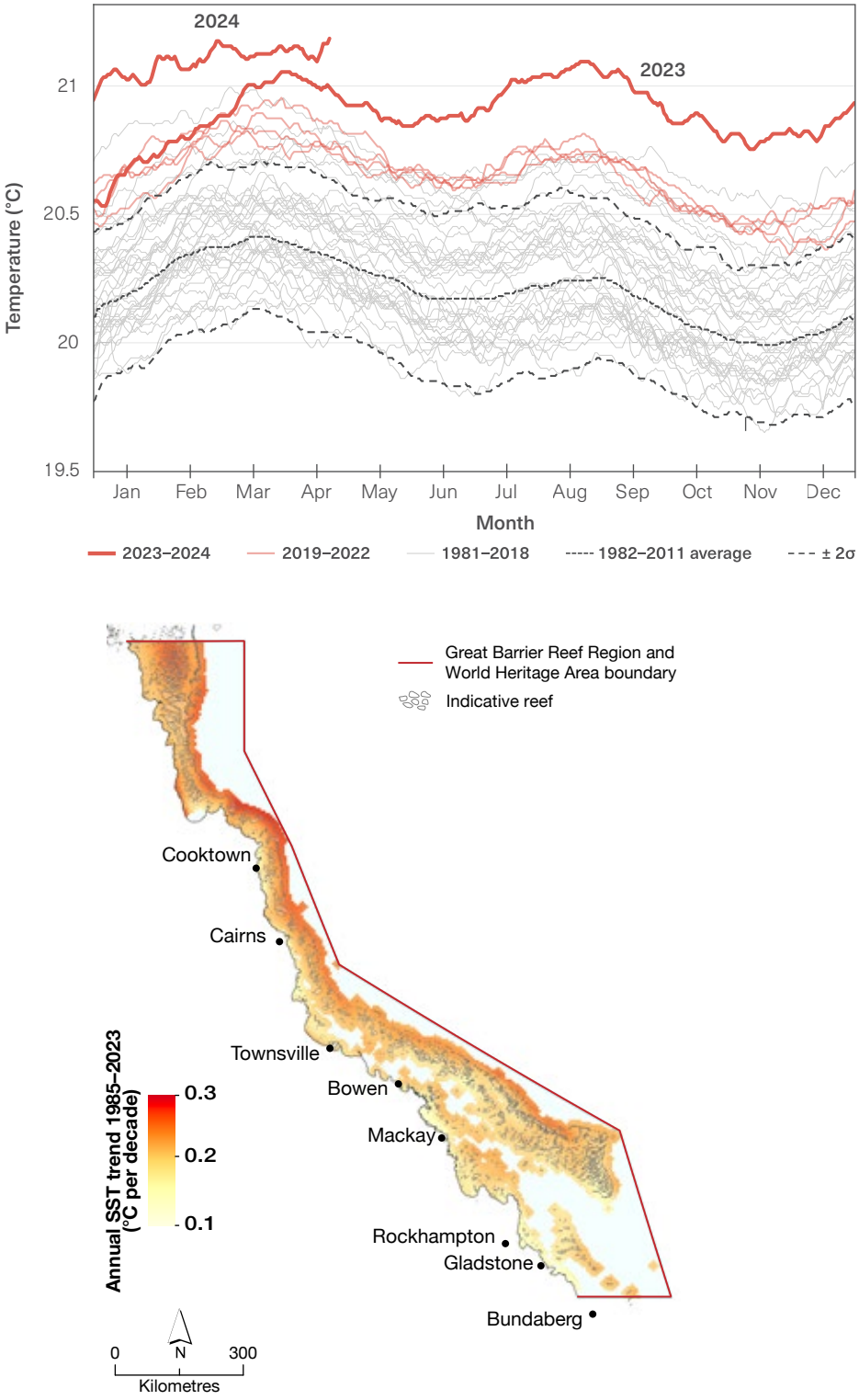


Figure 3.8 **Warming of sea surface temperature at global and Reef scales since the 1980s**

Graph (top) shows daily mean global (60°S to 60°N) sea surface temperatures between 1981 and early 2024. Sea surface temperatures from the past 5 years (since 2019) are highlighted in orange; 2023 and 2024 are shown in bold. The dark grey dotted line is the average daily sea surface temperature from 1982 to 2011, and the dark grey dashed lines above and below it show 2 standard deviations of the mean (±2σ) for the same period. Map (bottom) shows average warming of annual sea surface temperature between 1985 and 2023 for the Great Barrier Reef. Since 1985, average sea surface temperatures in the Region have increased by between 0.1 and 0.3 degrees Celsius per decade. Rates of increase are higher in northern and offshore areas. Graph source: ClimateReanalyzer.org, Climate Change Institute, University of Maine, using data from NOAA Optimum Interpolation SST (OISST) version 2.1.[668,669] Map source: NOAA Thermal history annual sea surface temperature trend product (1985 to 2023), Version 3.5, using CoralTemp daily 5 km satellite sea surface temperature dataset, Version 3.1.[670,671]

In the Great Barrier Reef Region, sea surface temperatures have risen by 0.94 degrees Celsius since 1900 [660] and warmed by 0.08 degrees Celsius on average per decade from 1950 to 2021.[540] Record high sea surface temperatures were recorded in February 2020.[635,661] Sea temperatures over the 2021–22 summer were again above the long-term average despite the occurrence of La Niña, a climatic phase usually associated with more cloud cover and cooler ocean temperatures [185,662] (Figure 3.9).

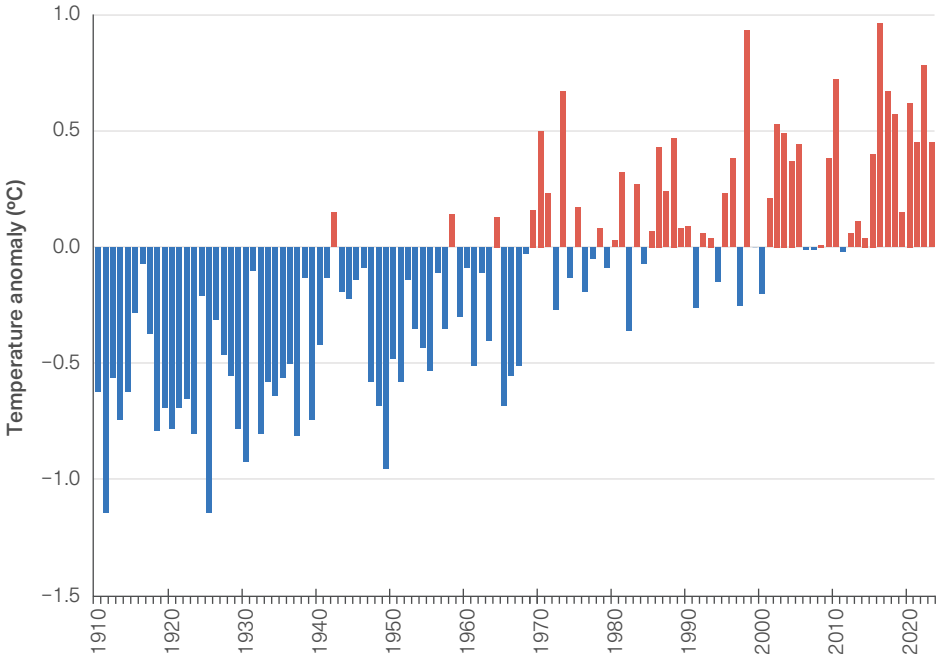


Figure 3.9 **Sea surface temperature anomalies for Great Barrier Reef waters, 1910 to 2023**
Anomalies are relative to a 30-year climatology (1961 to 1990). Source: Bureau of Meteorology.[660]

Thermal stress affects many habitats and species, especially reef-building corals

Rising temperatures and marine heatwaves are associated with mass coral bleaching events in the Region, most recently in 2016, 2017, 2020, and 2022 (and 2024, Section 2.3.5).[663] Bleaching in 2020 was associated with a strong marine heatwave,[636] while the event in early 2022 was the first mass bleaching event to occur under La Niña conditions.[163] Potential areas of thermal refugia for coral reefs exist where oceanographic features such as upwellings help to reduce the accumulation of heat.[158,180,664] With climate models predicting increasingly frequent and intense marine heatwaves,[665] the persistence of such refugia under future warming conditions is uncertain.[666,667]

Average sea surface temperatures within the Region have continued to increase over the past 5 years, and record high temperatures were recorded in February 2020. Marine heatwaves occurred in 2020 and 2022, triggering mass coral bleaching in both years, although relatively limited coral mortality. Another mass coral bleaching event unfolded in early 2024, after the end of the 2019 to 2023 assessment period.

3.2.7 Light

Light is an important environmental variable in shallow marine environments. It plays a critical role in determining the depth range, growth rate, physiology and distribution of photosynthetic species, such as seagrasses, algal symbionts of corals and phytoplankton.

Shallow inshore waters are generally more turbid (have more suspended particles which reflect and scatter light) than deeper offshore areas, which makes them subject to lower and more variable light conditions.[672] Increased sediment and nutrient loads contribute to higher turbidity and prolonged reductions in light availability along certain sections of the inner and middle shelves of the Reef lagoon.[586] Although larger sediments tend to settle in the vicinity of river mouths (Section 3.2.4), fine particles that remain in the water column can greatly attenuate light reaching the seafloor.[586] Artificial light is discussed in Section 6.4.

Patterns in the availability and intensity of benthic light affect the maximum depths that coral can grow,[673] which can be as shallow as 5 metres in inshore areas and exceed 50 metres in clear offshore waters.[674] Some photosymbiotic corals even occur at depths below 100 metres.[675,676] Although different corals survive under a wide range of light regimes across the Region, and inshore corals naturally experience periods of low light,[677] significant reductions in light can lead to coral bleaching, decreases in growth and lipid content,[677,678,679,680] and diminished recruitment success[681] and juvenile survival.[680] Although light is important for maintaining productivity in corals,[682] high levels of light can aggravate the effects of thermal stress, such as bleaching.[683] While reduced light (for example, due to cloudy skies) appears to reduce these impacts,[683] extremely low levels of light also exacerbate heat stress, highlighting the different ways light stress can affect corals.[684] Potential acclimatisation to changes in light conditions is likely to be species-specific.[685,686]

Seagrass growth and abundance are also highly correlated with availability of benthic light. In combination with other environmental and regional variables, benthic light has been used to help define seagrass habitat assessment zones[687] and to predict seagrass distribution and community types within the Region.[688] Seagrass species vary in their sensitivities to light limitation,[689] and various physiological and morphological effects are observed within days to months of low light conditions.[690,691] Deepwater seagrasses living near their functional limits may be particularly susceptible to decreasing light conditions.[692]



Seagrass growth and abundance are highly correlated with availability of benthic light

At inshore reefs within the Region, water clarity (measured by Secchi depth) has generally remained stable or improved from 2017 to 2023, although it still does not meet annual guideline values at most locations.[579] Satellite remote sensing data show a clear spatial pattern in the optical properties of reef waters: inshore areas are more frequently exposed to sediment and phytoplankton-enriched water (which cause light attenuation) during the wet season, while mid-shelf and offshore reefs typically experience water qualities that facilitate high-light conditions.[363] Analysis of satellite imagery (2002 to 2019) and information on optimum light thresholds for sensitive species suggest that light limitation is experienced by corals and seagrasses at several nearshore locations across the Region, and this varies significantly between years and seasons[597] (Figure 3.10). A broad pattern of increasing nearshore light stress from north to south in the Region may be the result of sediments transported northwards along the coast from rivers in the south.[597] While offshore reefs typically experience less variable light conditions, resuspension of benthic sediments during strong winds can result in light limitation for sensitive species in some locations.[597]

The availability of light at the seabed is below optimum levels in several nearshore locations across the Region, although light levels across most inshore areas have generally remained stable or improved over the past 5 years.

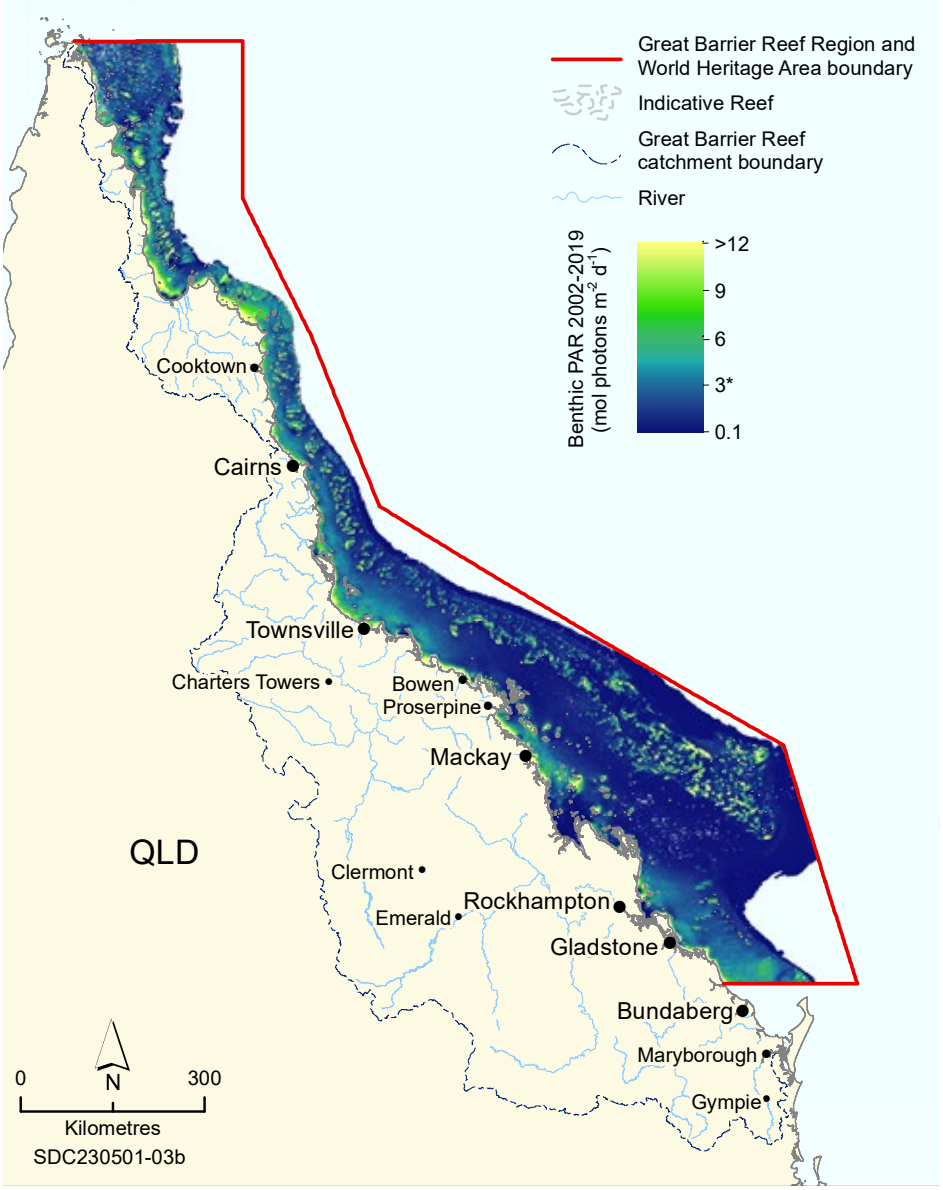


Figure 3.10 **Benthic photosynthetic available radiation, daily average, 2002 to 2019**

Benthic photosynthetic available radiation (bPAR) is the amount of light available for photosynthesis reaching the sea floor. Sufficient light is required for corals, algae and seagrasses to thrive, and poor water quality can restrict the amount available (asterisk on scale indicates the long-term minimum light requirement for seagrasses).[693] bPAR data from remote sensing has been used in developing a benthic light index for use as a water quality indicator.[597] Source: eReefs and Magno-Canto *et al.* (2019).[694,695]

3.3 Condition and trends — chemical processes

Three chemical processes are graded in terms of changes over the past 5 years due to human activities and consequential effects on ecosystem function. Processes to do with ocean pH and ocean salinity retain a good condition grade, while nutrient cycling is again poor.

The full assessment summary is in Section 3.7.2.

3.3.1 Nutrient cycling

Nutrients are fundamental for the growth and survival of organisms and are a vital component of ecosystem function.[696] Nutrients transfer from the physical environment to organisms through food chains, and back to the environment via decay or death.[317] In marine ecosystems, the major nutrient cycles are carbon, nitrogen and phosphorus.[697,698]

Carbon cycling includes carbon transformation and use by photosynthesising primary producers (Section 3.4.3), microbes,[698,699] and calcifying corals [700] and algae such as *Halimeda*.[234] Primary producers take up dissolved forms of nitrogen and phosphorus (phosphate), while animals gain these nutrients by consuming other organisms. These nutrients are also found in particulate forms, often attached to fine sediments, that are not immediately available for biological uptake but can be mobilised by remineralisation.[701]

Nutrient cycling occurs on widely varying spatial and temporal scales.[702,703] Nutrients are delivered to the Reef lagoon from the Catchment via land-based runoff and groundwater [704] (Section 6.5), through upwelling (which brings nutrients in from the deep ocean), via the air from dust [705,706] and fires, and through nitrogen fixation (Figure 3.11). Seabird-derived nutrient inputs are also important for island reefs.[74,707] Nutrients are exported from the Reef lagoon through burial [708] and denitrification.[702,709]

Land-derived nutrient influx to the Region largely occurs during the wet season. Most dissolved nutrients are quickly taken up biologically or bound chemically to particles in the ocean. In years of large river flow, land-derived nutrients can be transported vast distances. Uptake of dissolved nutrients creates a pool of nutrients held within the water column in the form of phytoplankton and other types of suspended particulate matter.[702,711]

Some studies show that the frequent resuspension of sediments within estuaries and the coastal zone helps promote rapid cycling of particulate, largely mineralised nutrients by microbial communities.[710,712] Catchment wildfires are known to influence the transport of nutrients to the marine environment, through effects on runoff water quality (Section 6.3.2) and the atmospheric transport of limiting nutrients and trace metals.[713] Deposition of fire-derived nutrients via rainfall has the potential to cause phytoplankton blooms,[714] as has been recorded in recent years in southern Australia.[713,715] The extent to which increasing fire frequency may be influencing nutrient cycling in the Region is a knowledge gap.

Upwelling is a key source of nutrients in the southern Great Barrier Reef, for example, in the Swain Reefs and Capricorn Channel.[716] In the north, the narrow gaps between outer barrier reefs funnel nutrient-rich water into fast-flowing currents that promote the growth of *Halimeda* bioherms (Section 2.3.8). There is no systematic *in situ* monitoring of nutrient concentrations in offshore areas, and current understanding of the spatial extent of upwelling influence relies on modelled data (Figure 3.11).

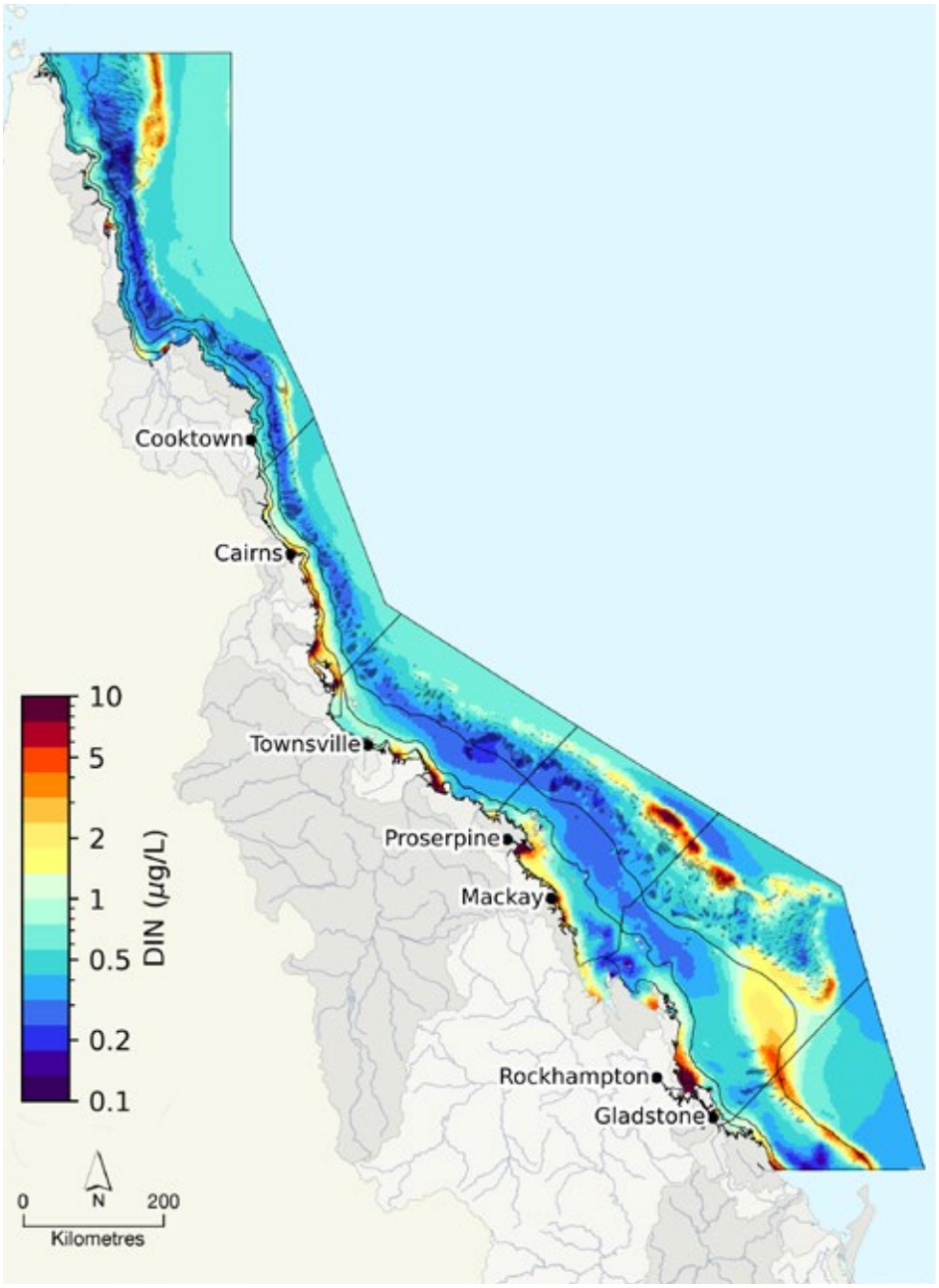


Figure 3.11 **Modelled annual average dissolved inorganic nitrogen (DIN) near the surface, 2011 to 2018**

This map highlights coastal areas influenced by flood plumes and offshore areas believed to be influenced by upwelling. Dissolved inorganic nitrogen availability is a key driver of primary production, for example, by phytoplankton, which is measured as chlorophyll-*a* concentration (Figure 3.12). Source: Lawrey (2023). eReefs BGC Seasonal plots for Scientific Consensus 2023 [Source code]. Australian Institute of Marine Science, Townsville. https://github.com/open-AIMS/ereefs-scientific-consensus-wq-plots-2023, using data from eReefs 4 km resolution model output. Model includes latest data available in December 2023.[710]



Seabirds play an important role in nutrient transport. © Matt Curnock 2022

Nutrient limitation constrains growth and productivity.[697] Nutrient concentrations are naturally low in the open ocean, and nitrogen is often the main limiting nutrient.[697,717] Scarcity of nitrogen can curtail the growth potential of organisms, making the nitrogen cycle central to the productivity of marine ecosystems [718,719] Phosphorus, iron,[720,721] sulfate,[722] vitamins, and various micronutrients can also limit or co-limit particular organisms.[697] Changes in the relative availability of different nutrients can exacerbate impacts of nutrient limitation.

Some marine microbes, notably cyanobacteria in the genus *Trichodesmium*, can fix gaseous nitrogen directly from the atmosphere.[723] *Trichodesmium* is a major contributor of nitrogen to marine ecosystems [724,725] and is increasing in abundance on the Reef in response to increasing sea temperatures and phosphate availability.[356] The extent to which the increase has been driven by increased anthropogenic inputs of phosphorus and other nutrients is not yet known.[356,724]

Nitrogen fixation occurs on coral reefs, by cyanobacterial mats, bacteria and reef-associated seagrasses, and in other habitats, such as seagrass meadows.[726,727] Coral reefs thrive under low-nutrient conditions [266,728,729] by fixing nitrogen from the atmosphere and efficient recycling of nitrogen and carbon.[317] The productivity of zooxanthellae is highly dependent on available nitrogen, so efficient nitrogen cycling within the coral holobiont (Section 3.4.6) may be crucial for sustaining primary productivity in coral ecosystems.[730] Elevated temperatures stress corals by limiting the efficiency of their internal nutrient cycling.[731] The presence of excess nutrients in coral ecosystems can favour competitors like macroalgae over corals.[732]

On a regional to global scale, coral reefs are important hotspots of marine sulfate emissions, which play a role in cloud formation and affects regional climates.[722] These processes could be disrupted under future climate change [722] (Section 6.3.2).

The inshore Reef has a chronically elevated nutrient status

Compared to historical conditions, the inshore Reef has a chronically elevated nutrient status.[276,710] Additional information on nutrient loads entering the Region since 2019 is provided in Section 6.5.1. Elevated nutrient availability is correlated with macroalgal abundance, low coral cover and low coral recruitment.[276] Changes in nutrient ratios,

particularly increases in nitrogen relative to phosphorus, can also exacerbate coral stress and decline.[733,734] Phytoplankton productivity, aided by nutrient availability in the inshore and mid shelf, is linked to improved survival of crown-of-thorns starfish larvae (Section 3.6.2).[276,735] High nutrient levels contribute to reduced light availability for seagrasses and corals through the proliferation of phytoplankton in the water column, and may increase the susceptibility of corals to disease[276] (Section 6.5.2).

Microbial communities (bacteria) are promising candidates for potential indicators of environmental nutrient status.[712] Recognition of the centrality of microbes in nutrient cycling has led to important advances over the past 5 years in analytical capabilities, including genomics and 'big data'. This has led to the discovery of new microbial functional groups and emerging conceptual perspectives on their role in nutrient cycling.[719]

The available suite of nested physical and biogeochemical models for the Reef and Catchment are instrumental in integrating knowledge of nutrient cycling and other key processes with *in situ* observations from field research and monitoring.[248,703,736,737] Notably, they have been applied to investigate the impact of rivers on marine water quality [738] and to establish targets for land-based runoff that are more ecologically relevant (Section 6.5.1).

Although substantial and ongoing changes to nutrient cycling since European settlement continue to affect inshore habitats, this process is understood to have been generally stable since 2019. There have been important advances in our understanding of nutrient cycling and in its integration into decision-making through improved models since 2019.

3.3.2 Ocean pH

Carbon dioxide concentrations in our atmosphere, and consequently our oceans, are increasing as a result of anthropogenic activities.[536] When carbon dioxide is absorbed by seawater a series of reactions occur which affect ocean acidity and carbonate chemistry (reducing the availability of carbonate).[540] Collectively these processes are referred to as ocean acidification.

Over the last 140 years, the average pH of surface waters around Australia and globally is estimated to have declined by about 0.12 units, which is equivalent to a 30 per cent increase in acidity.[540] The rate of decline in ocean pH has been particularly rapid in recent decades.[540] Alongside changes in pH, saturation levels of both aragonite and calcite (forms of calcium carbonate crystal) are decreasing in Australia's oceans.[359]

In line with global and Australian trends, progressively increasing concentrations of carbon dioxide and decreasing values of pH and aragonite saturation were recorded within the Region over the 10 years from 2009 to 2019.[739] Ocean acidification has significant implications for marine life across the Region, affecting growth,[338] reproduction,[341] behaviour [339,340] and physiology [740] across a wide variety of species.[741,742]

Calcifying species, those which produce calcium carbonate skeletons and shells, such as corals, molluscs, crustaceans and coralline algae,[281,743,744] are considered particularly vulnerable to acidification. As carbonate concentrations decrease, calcification becomes more challenging and the tendency for calcium carbonate crystals to dissolve increases,[745] leading to overall decreases in calcification on coral reef ecosystems.[746,747,748,749]

Seawater chemistry experiments at a natural coral reef site in the southern Great Barrier Reef demonstrate that ocean acidification may already be affecting the growth of coral reefs in the Region.[748,750] In the north, decreases in net ecosystem calcification and

increased dissolution observed on reef sites at Lizard Island between 2008 and 2016 have also been attributed in part to ocean acidification.[751] Changes in densities of crustose coralline algae, macroalgae and coral juveniles in coastal areas of the Great Barrier Reef have been linked to reduced aragonite saturation.[281] Skeletal density of coral is susceptible to changes in seawater carbonate concentrations and warming,[752] and researchers are working to untangle the details of these effects.[753,754,755,756]

Calcium carbonate sediments in lagoons and intereefal areas are likely to be even more sensitive to dissolution under increasing acidity than living calcifiers, due to various physical properties of sands, such as grain size and surface area.[757,758] Sea cucumbers (and potentially other deposit feeders) speed up the dissolution of calcium carbonate by ingesting lagoon sediments, a process that may contribute to localised buffering of ocean acidification.[750,759]

Abundance of calcifying zooplankton has been observed to reflect seasonal patterns in aragonite saturation within the Region. This may be a direct consequence of seasonal changes but could also suggest that calcifiers are sensitive to the changes in aragonite saturation at the values already being observed.[359]

Ocean pH around Australia has declined over the past century, particularly rapidly since the 1980s,[540] and ecosystem impacts attributed to ocean acidification have been reported from within the Region. Impacts are expected to increase under predicted future scenarios: models suggest that surface ocean pH may decrease by a further 0.1 to 0.4 units and dissolved carbonate ion concentration by up to 50 per cent by 2100.[359,741] On a global scale, coral reefs could shift towards net dissolution during this century.[746,749,760]

Ocean pH has declined within the Region, in line with global and Australian trends. It is likely that the rate of decline has increased in recent decades, driven by progressive ocean uptake of carbon dioxide due to increasing emissions. Ocean acidification has significant implications for coral reef ecosystems.

3.3.3 Ocean salinity

Ocean salinity is a measure of the dissolved salts in sea water, often expressed as parts per thousand. The average salinity of the ocean is 35 parts per thousand (that is, each litre of sea water contains 35 grams of salt). Ocean salinity is driven by variations in the water cycle, including precipitation and evaporation, patterns of ocean mixing and terrestrial freshwater flows.[761,762] Salinity is naturally more variable in coastal areas, where freshwater flows from rivers and coastal runoff have a significant influence, particularly during the wet season and following flood events.[363] Fresh water is less dense than sea water, so low-salinity plumes tend to remain near the sea surface in unmixed inshore waters, which can lead to sharp gradients in salinity with depth.[363] Inter-annual changes in salinity within the Region have been linked to large-scale climate drivers, such as the El Niño–Southern Oscillation.[739,763]



Global climate change is altering and intensifying the water cycle, affecting ocean salinity

Salinity determines the distribution of both marine and estuarine species at all trophic levels. Changes in salinity can affect growth, respiration, photosynthesis, behaviour, reproduction and enzymatic capacity, ultimately affecting ecosystem structure and function.[764,765] Within the Region, low salinities affect seasonal fish community composition in estuaries,[766] limit coral growth rates, cause reduced flowering in seagrasses[767] and may decrease survival of crown-of-thorns larvae.[768] Low-salinity events associated with

floodwaters can cause extensive mortality in a range of reef species, including corals, crustaceans, molluscs, sponges, fishes and seagrasses.[572,765,767] Coral mortality as a direct result of low salinity has been limited to depths of up to 2 metres on reefs closest to rivers during major flood events.[185] Experiments suggest that while juvenile corals are highly sensitive to low salinity, they may have some potential to acclimatise following short-term exposure.[769] Low salinity compounds the effect of increasing temperatures on coral condition and survival,[570] whereas high salinities may increase temperature tolerance in some species.[770] Furthermore, low salinity combined with increased organic matter may contribute to outbreaks of coral disease.[578]

Global climate change is altering and intensifying the water cycle and these changes affect ocean salinity.[761,762] On a large scale, open ocean waters in the subtropical Pacific are becoming saltier at the near surface, and this pattern is predicted to continue under future projections.[762,765] Consistent with this, measurements from 2 fixed stations within the Region recorded increasing seawater salinity from 2009 to 2019, although seasonal decreases were associated with high freshwater inflow during particularly wet summer months.[739]

In inshore areas within the Region, changes in salinity are largely influenced by freshwater inflows. Freshwater discharges are naturally high in the Wet Tropics region, where flows have been relatively close to the long-term average over the past 5 years. Freshwater flows in the Burdekin, Mackay and Whitsunday regions were higher than the long-term average during 2019 and 2023.[579,771] Low-salinity flood plumes, in combination with other acute disturbances, have affected the condition of inshore coral communities in the Region over this period.[185] The projected increases in extreme rainfall associated with climate change[540] suggest the impacts of low salinity may increase in future for inshore areas within the Region.

Wider ocean patterns suggest that salinity may slowly increase in offshore areas within the Region, while inshore areas are subject to seasonal decreases in salinity as a result of freshwater input. Over the past 5 years, freshwater influence has been slightly above average overall with regional variation.

3.4 Condition and trends — ecological processes

Maintaining critical ecosystem functions is of vital importance to the health and resilience of the Reef's habitats and ecological communities.[772] Ecosystem functioning can be considered in terms of a suite of complementary and interconnected ecological processes.[772]



Ten ecological processes are graded in terms of changes over the past 5 years due to human activities and consequential effects on ecosystem function. Primary production remains in very good condition, and 5 other processes (microbial processes, particle feeding, herbivory, competition and connectivity) remain in good condition. Four processes (predation, recruitment, symbiosis and reef building) continue to be graded as poor.

The full assessment summary is in Section 3.7.3.

3.4.1 Microbial processes

Microbes play fundamental roles in the functioning and stability of ecosystems (Section 2.4.6) and respond rapidly to changes in environmental factors,[773] such as currents, temperature, and water quality. They are central to capturing and converting nutrients into available forms that drive the productivity of marine food webs and enable the efficient cycling of nutrients on coral reefs growing in nutrient-poor waters (Section 3.3.1).[728] Microbes are critical to primary production,[774] and calcification of microbial mats is an important component of reef-building processes (Section 3.4.8), helping bind and stabilise coral reef frameworks.[775,776]



Microbial communities respond rapidly to environmental fluctuations

Microbial communities can influence the health of other organisms through symbiotic relationships, for example, as crucial components of the coral holobiont [773,777] (Section 3.4.6). Microbial communities vary through time and respond to environmental fluctuations and drivers, particularly temperature and nutrients.[712,778] This applies to both coral-associated and free-living planktonic microbes.[712,779] Rising temperatures are altering microbial communities, which has implications for nutrient cycling, disease prevalence and coral susceptibility to bleaching.[356,777,779,780] A general trend of increasing microbial biomass and energy use (microbialisation), previously observed in response to local stressors, is expected as the climate changes.[777,781,782] Ocean acidification threatens microbial calcification, which has negative implications for reef-building processes.[776]

The microbial community includes viruses, which are not well studied but are known to play direct and indirect roles in nutrient cycling and induce disease on reefs and in other ecosystems.[783] Pathogenic microbes carried by plastic pollution can promote disease in marine environments.[784] Higher levels of land-based runoff have been associated with reduced richness and diversity of bacterial communities on inshore reefs in the Region.[712] As a result, the relative abundance of different bacterial groups has been suggested as an indicator of the contribution of land-sourced nutrient enrichment of Reef waters.[772] Carbon compounds produced by macroalgae support bacterial communities that harm corals, thereby helping algae compete for space.[712]

Since 2019, microbial processes have been an area of active research interest, and knowledge in this area has made important advances, but the processes remain poorly understood.[712] For example, between 2016 and 2022, at one location in the Region, change in diversity was observed for archaea (Section 2.4.6) but not for bacteria.[251] Microbes have been proposed as an emerging essential ocean variable in the Global Ocean Observing System.[785] Genomic techniques (Box 2.1) and a new open access database for the Reef have significantly enhanced our insight into microbial communities and their functions, particularly in pelagic environments.[786]

Environmental stressors associated with a warming climate and land-based run-off have led to changes in microbial processes across the Region that may be ongoing. Although knowledge has advanced considerably since 2019, microbial processes remain poorly understood.

3.4.2 Particle feeding

Particle feeding is undertaken by a wide range of organisms that feed on plankton and dead organic matter from either the water column or sea floor. Particle feeders include worms and sea squirts that use mucous nets to adhere to particles; reef building corals, sea fans, feather stars, worms and some jellyfish that passively feed from passing water currents; bivalves, sponges and some barnacles that actively create currents to feed from; and baleen whales, manta rays and some fishes that are active particle feeders.[787]

Particle feeding octocorals (gorgonians, sea whips, sea pens and soft corals) are the second most common group of macrobenthic animals on the Reef after hard corals.[318] Sponges have shown potential as a natural collection point for sampling environmental DNA.[788] On a reef scale, it is estimated that sea cucumbers may bioturbate (turn over) 64,000 tonnes of sediment per year,[789] which may partially buffer the impacts of ocean acidification through its contributions to reef biogeochemistry.[772] A single oyster can filter more than 200 litres of sea water per day, and oyster beds play a vital role in coastal ecosystems.[790] Particle feeding can assist corals under heat stress or in turbid waters. [772]

Particle feeders help keep water clean and nutrients cycling

Despite increasing research on particle-feeding marine invertebrates, gaps in knowledge remain, such as of their tolerance to changing environmental conditions.[790] Threats vary between species, but they include climate change-related ocean warming and acidification, pollution and targeted extraction.[790] The Queensland saucer scallop stock has seen declines in recent years as a result of overfishing compounded more recently by elevated water temperatures.[791,792] Current estimates show the stock to be 15 per cent of unfished biomass,[793] and it is classified as depleted.[794] Increasing water temperature is expected to lower net primary production and result in declines in shallow benthic filter-feeding communities.[795] The larval stages of many invertebrates rely on ocean currents for transport and settlement of their offspring, and changing currents in the future may affect recruitment and distribution of some species.[790]



Yellow tube coral, genus *Tubastraea*, feeding on particles in the water. © Chris Roelfsema 2021

Microplastics, especially those that have accumulated biofilm, are ingested by many particle feeders from shellfish to baleen whales.[796,797,798,799] Evidence suggests transfer to muscular tissue is low for Reef species.[796]

A range of pressures affect particle feeders, and condition varies between species and species groups. No consistent trend has been identified since 2019. Since 2019, cover of some fast-growing species of corals has increased, but condition of corals in some areas remains poor. Long-term declines have occurred in the commercially harvested saucer scallop population, and the stock is currently classified as depleted.

3.4.3 Primary production

Primary production, which refers to the initial synthesis of organic compounds from carbon dioxide and energy, provides the basis for all biological systems. Nearly all primary production within the Region occurs through the process of photosynthesis. Primary producers within the Region include phytoplankton, benthic algae, mangroves, and seagrasses. Many reef organisms, notably including corals, benefit from symbiotic associations with primary producers (Section 3.4.6). Algal symbionts of corals transfer between 40 and 80 per cent of their photosynthetically fixed carbon to their hosts, supporting coral growth and metabolism[800] and contributing to their evolutionary success.[801]

Photosynthesis is closely linked to the availability of light (Section 3.2.7) and generally occurs in the upper water column at depths of less than 100 metres.[672] Rates of primary production depend on available light and the efficiency with which organisms can use it for photosynthesis.[682] The availability of inorganic nutrients, such as nitrogen and phosphorus, is also critical in determining rates of primary production. Within the Region, peaks in primary productivity tend to occur in inshore waters as a result of elevated fluxes of nutrients from river flows and tidal mixing[802] particularly during the wet season.[803] Nutrients are also supplied through inflow from the Coral Sea, upwelling and resuspension of sediments,[802] and via nitrogen-fixing bacterioplankton.[804] In some cases, increased primary productivity can signal a decline in water quality,[363] or it may indicate phase shifts and the presence of prior ecological disturbances.[749]



Primary production supports healthy ecosystems but can also cause imbalances

In lieu of directly measuring primary production, trends in abundance of primary producers may be used as a rough proxy for the condition of this process. Chlorophyll-*a* (Figure 3.12) is commonly used to estimate phytoplankton biomass. Between 2017 and 2022 concentrations of chlorophyll-*a* in most inshore areas within the Region decreased, suggesting a reduction in phytoplankton productivity and improvements in water quality over this period.[363] In the past few years, inshore seagrasses within the Region have shown signs of recovery following previous decline (except for in the southern Fitzroy and Burnett Mary regions, where condition remains poor) (Section 2.4.2).[145] The condition and extent of mangroves (Section 2.4.1) and benthic algae (Section 2.4.3) have remained relatively stable within the Region, which may suggest little change in primary production in these areas. While hard coral cover on offshore reefs has increased overall since 2019, the condition of individual reefs is highly variable (Section 2.3.5), and mass coral bleaching in, 2020 and 2022 likely affected rates of primary production.

Overall, primary production as a process is considered to be functioning well. Some shifts in the type of primary production (less in the water column, more in benthic producers)

may have occurred in inshore areas as a result of improved water quality since 2019. Primary producers in some areas continue to be affected by high nutrient levels, sediment and temperature.

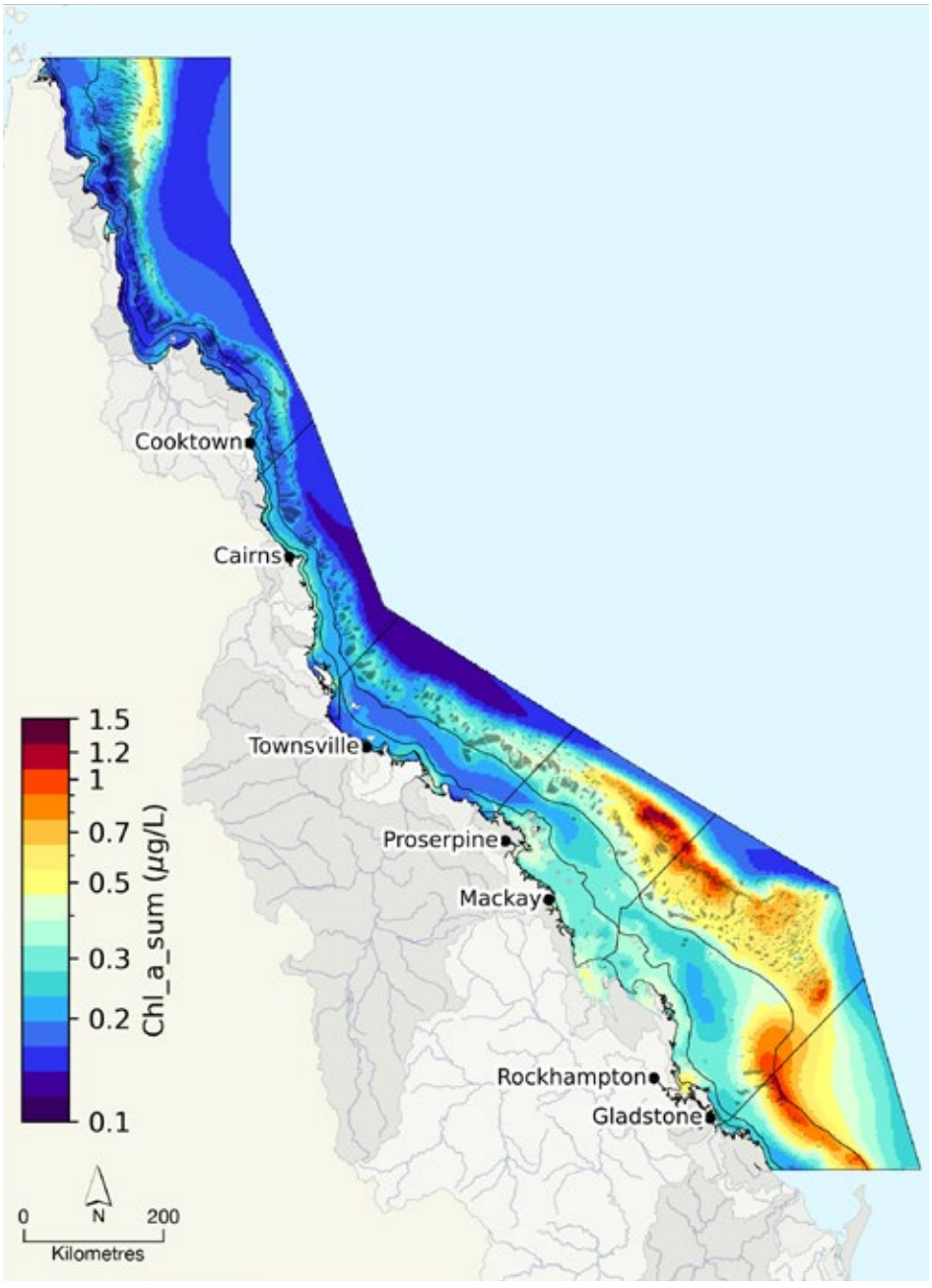


Figure 3.12 **Modelled annual average total chlorophyll-*a* near the surface, 2011 to 2018**

This map highlights coastal and offshore areas with increased annual average chlorophyll-*a* (as an indicator of phytoplankton biomass). Availability of nutrients, such as dissolved inorganic nitrogen (Figure 3.11) is important for photosynthesis. Peaks in nearshore phytoplankton abundance are influenced by increased nutrient supply in river plumes, while offshore peaks are likely driven by inflow of nutrients from the Coral Sea and upwellings. Source: Lawrey (2023). eReefs BGC Seasonal plots for Scientific Consensus 2023 [Source code]. Australian Institute of Marine Science, Townsville. https://github.com/open-AIMS/ereefs-scientific-consensus-wq-plots-2023, using data from eReefs 4 km resolution model output. Model includes latest data available in December 2023.[710]

3.4.4 Herbivory

Herbivory involves the removal and consumption of plant matter. It is a key ecological process for a functional coral reef ecosystem,[805] providing nutrition for the consumer and influencing the location, health and composition of plant communities.[441,806] Marine herbivory includes removal of plant matter by large marine herbivores (such as green turtles and dugongs [142]); cropping, grazing and excavation of benthic algae by fishes[807] and invertebrates; [772] and the consumption of phytoplankton by micro-grazers, such as amphipods and isopods.[808] Herbivory is also observed in early life stages of the coral-eating crown-of-thorns starfish.[349,809,810]



Herbivory plays a critical role in the recovery of coral reefs after disturbance

The dynamic balance between rates of herbivory (algal removal) and primary production (algal growth) is central to the functioning of coral reef ecosystems.[811] Herbivorous fish and other species predominantly target algal turfs and microbes living within reef structures (endolithic algae and microbes),[812] thereby preventing macroalgae from becoming established.[813] In this way, herbivory plays a critical role in the recovery of coral reef communities after disturbance.[814] Grazing of macroalgae on coral reefs is also performed predominantly by herbivorous fishes [807,811] and to a lesser extent by molluscs, echinoderms, and crustaceans,[772] but this grazing is not closely linked to macroalgae biomass.[815] In seagrass meadows, grazing by dugongs and green turtles is important for habitat structure and condition [142] and can aid dispersal and germination of seagrass species (Sections 2.3.4 and 8.3.5).[143,808] Environmental disturbances, such as cyclones and coral bleaching, can benefit herbivores by increasing available algal substrate, but can result in herbivore assemblages with reduced richness that are potentially more vulnerable to chronic localised stresses.[816,817]

Although novel survey methods are providing insights into ecosystem-level patterns of herbivory,[818,819] the process of herbivory is not routinely monitored. As a readily available simple metric, herbivore abundance may give some insight into relative herbivory rates, however the changing area of algal substrate (linked to coral cover) is also a key determinant of the intensity and effectiveness of herbivory on reefs.[820] Herbivory is seen across the Region, from inshore habitats to the depths on the outer-shelf reefs where light penetration allows for photosynthesis and therefore algal growth.[197] Surveyed abundance of herbivorous fishes (such as parrotfish, surgeonfish and rabbitfish) has fluctuated since 2019, although not beyond the normal range of long-term natural variability (Figure 3.13).[386] Documented declines in dugongs [821] (Section 2.4.16) and northern populations of green turtles (Section 2.4.10) may lead to reduced herbivory in the Region.

Despite its central importance to ecosystem functioning, an in-depth understanding of the process of herbivory across the Region and the mechanisms that affect it remains elusive.[811] This process is undertaken by a wide range of species at varying scales and with diverse effects on ecosystem function across different habitats. Overall, herbivory has likely remained stable since 2019. Declines in some populations of dugongs, green turtles and potentially in herbivorous fishes may lead to reduced levels of herbivory in certain areas.



The balance between herbivory and primary production is a key to reef health

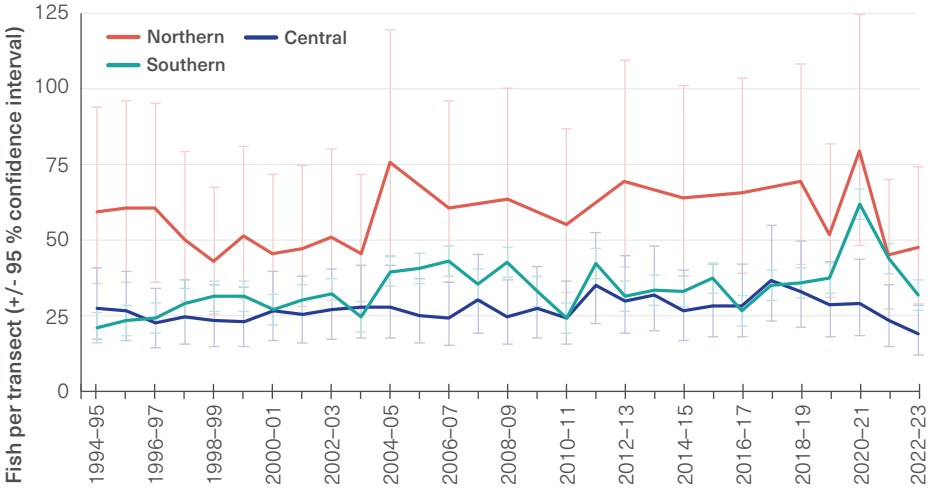


Figure 3.13 **Regional abundance of herbivorous fishes, 1994–95 to 2022–23**

Estimated mean abundance (with 95 per cent confidence intervals) of herbivorous fishes (including parrotfish, surgeonfish and rabbitfish) per transect across northern, central and southern regions of the Reef from 1994–95 to 2022–23 as part of Australian Institute of Marine Science (AIMS) Long-term Monitoring Program surveys. Fish are counted along 50-metre by 5-metre transects, and 15 transects are completed per reef surveyed.[822] The average number of reefs visited in a year was 50. The maximum visited was 69, in 2021–22. Fish estimated to be less than 1 year old (distinguished by size and colouration) are excluded from counts to reduce variability. Source: AIMS Long-term Monitoring Program.[386]

3.4.5 Predation

Predation is the process of animals consuming other animals, and it occurs across varying levels of food webs. The tops of food webs are represented by apex predators, such as great hammerhead and tiger sharks (Section 2.4.8), pelagic fish, birds and marine mammals.[823] Mesopredators (or middle-order predators) include many sharks, emperors, snappers, groupers [400] and marine turtles, which eat other animals but are also eaten by apex predators.

Predation influences the composition and distribution of communities,[824] affects behaviour and the evolution of characteristics in prey species [825] and, importantly, transfers energy from the pelagic zone to the reef environment.[826]

Since 2019, increasing evidence shows that predation may play an important role in controlling crown-of-thorns starfish populations during their planktonic, juvenile and adult life stages. Planktivorous damselfish target crown-of-thorns larvae despite the presence of alternative prey,[827,828] while 26 species of invertebrates have been found to prey upon juvenile crown-of-thorns,[349] including the red decorator crab which can eat up to 5 juvenile crown-of-thorns starfish a day. The peppermint shrimp eats juvenile crown-of-thorns starfish (up to 4 months old) and damages older juveniles, through partial predation.[829] Adult crown-of-thorns starfish are preyed upon by the giant triton snail[830] and various species of fish.[828] Crown-of-thorns starfish densities are reduced in no-take marine reserves (where predators are protected) compared to unprotected areas open to fishing, further suggesting that predation may help to reduce crown-of-thorns starfish outbreaks in the Region.[828]

Several factors affect the process of predation. Disturbance to habitat (for example, following cyclones or coral bleaching) can damage reef structure, potentially benefiting predators by reducing the availability of shelter for prey species.[831] Projected increases in sea surface temperature may see some species moving to cooler habitats to stay within their optimal thermal range[832] or to maintain access to prey.[833] Tiger sharks are known to move to higher latitudes during La Niña and lower latitudes during warmer years.[833] The increase in temperatures may result in higher metabolic rates that need to be maintained,[374] requiring species to eat more to survive. Ocean acidification has been shown to affect sensory systems, affecting how cues are received and processed.[834] For example, prey fish may exhibit decreased directionality and responsiveness, while predators commence their strike from a larger distance, suggesting a higher motivation to feed.[835]

Fishing represents a threat to predation in the Region, through targeted removal of predators.[823] The stock status (in 2020) of predatory fish and shark species fished in the Region is sustainable for some (for example, coral trout and several reef sharks) and depleted for others (for example, Australian snapper, pearl perch and Spanish mackerel) (Section 5.4). Predatory species are more abundant in protected areas.[836] The Region's ecosystems remain impacted by a long history of exploitation of apex predators, and populations of some targeted species remain in poor condition.[49,837]

Natural rates of predation across the ecosystem are likely relatively stable

Evidence suggests there is substantial ecological redundancy among the diverse group of sharks and reef fish that act as mesopredators in the Region.[396,394] Although much less is known about predation by smaller fish of mobile invertebrates (other than crown-of-thorns starfish), natural rates of predation across the ecosystem are likely relatively stable due to the complexity and high functional redundancy of coral reef food webs, [394,772] and effective connectivity between coastal and offshore habitats across the Region.[838]

Depredation, where a predator completely or partially consumes an animal caught by fishing gear, is an emerging interest area.[839,840,841] Shark depredation has been recorded since the 1800s, and recent anecdotal evidence indicates frequency may be increasing in some areas.[407,842,843] The effect of depredation on the Region's ecosystems is unknown; most studies are fisheries specific.[844]

Consideration of the process of predation often focuses on apex predators and mesopredators. Although there is knowledge about predation within other species, such as turtles eating jellyfish [845,846] and invertebrates with varying diets, there is a gap in information regarding the effect of this other predation on prey populations and the Region as a whole.

Predation affects a wide range of taxa that are subject to varying pressures. Although natural rates of predation are likely relatively stable, the Region's ecosystems remain impacted by a long history of exploitation of apex predators and populations of some targeted species remain in poor condition. A large group of predators, the sharks and rays, are in poor condition.

3.4.6 Symbiosis

Symbiosis is a close ecological relationship between 2 or more different species (collectively referred to as a holobiont) and is a particularly common feature on tropical coral reefs. Symbiotic associations are often mutually beneficial to both partners (mutualism)[571] although some symbioses may benefit one partner and be harmless to the other (commensalism) or benefit one to the detriment of the other (for example, parasitism).[847]

Symbiosis facilitates various ecological processes, such as nutrient exchange between symbiotic partners and promotion of biodiversity, whereby host species can support the existence of multiple symbionts, including many thousands of microbes.[848] Well-known examples of symbioses within the Region include the coral–dinoflagellate and sea anemone–clownfish relationships, but many thousands of other associations exist.[672] Coral crabs (genus *Trapezia*) clean and defend their *Pocillopora* coral hosts,[323] while gobies protect the shelters they share with burrowing shrimps.[849] Giant clams have obligate symbiotic associations with photosynthetic dinoflagellates,[285] and they also shelter a range of commensal and parasitic animals in their mantle cavities.[850]

Climate change is severely affecting many symbioses, as increasing sea temperatures and marine heatwaves[647] lead to various host species losing algal symbionts from their tissues in a process called bleaching.[851,852] The underlying mechanisms of coral bleaching are a subject of active research interest.[853] Recent studies have found that heat stress can cause nutrient exchange between symbiotic partners to become unbalanced, contributing to the breakdown of the symbiosis.[854] In sponge–microbe associations, heat stress can also lead to the breakdown of symbiosis and negative consequences for host health.[855,856] Compounding stressors, such as changes in light conditions[683,684] and limited oxygen,[857] have been shown to lower thermal thresholds for bleaching. Elevated nutrient conditions and localised anthropogenic disturbances may also influence bleaching susceptibility in corals[532,571,858] and other hosts.[859,860]



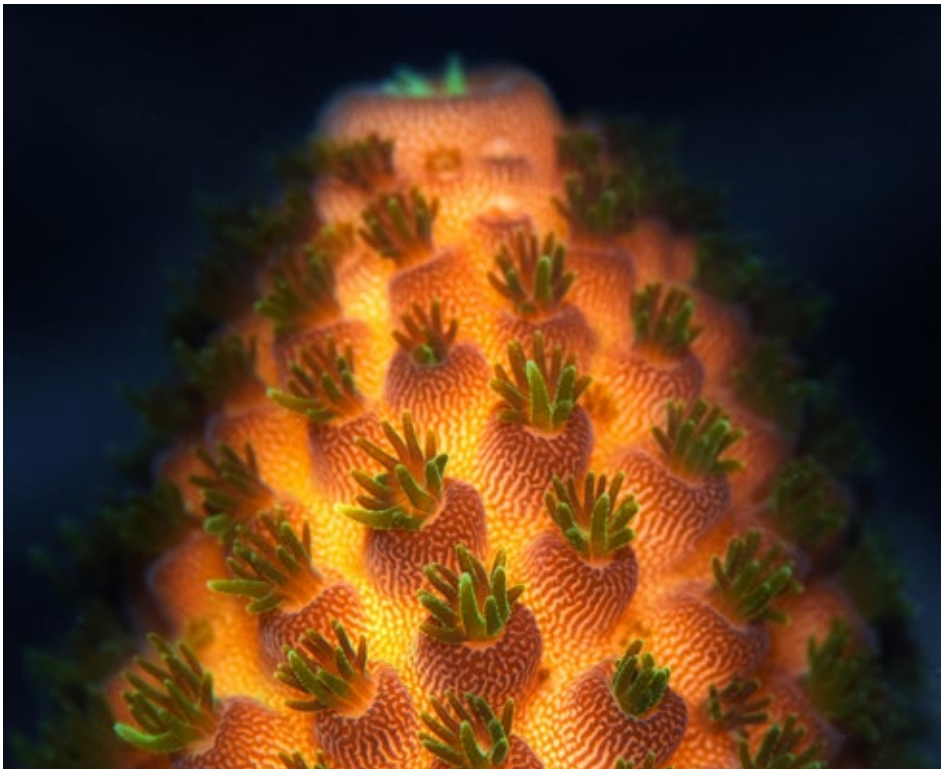
Climate change is severely affecting the key symbiosis between corals and zooxanthellae

Coral survival post-bleaching, particularly when sea temperatures remain high, may be influenced by host genetics,[31] the heat sensitivity of algal symbionts[858,861] and the availability of key nutrients such as iron.[720,721] Shifts in symbiont partners to more heat-tolerant variants were detected in natural populations in response to marine heatwaves, including the 2016 mass coral bleaching event,[858] and have also been induced experimentally under controlled laboratory conditions.[862] Symbiont changes appear to be a species-specific response.[288] In some cases, restructured symbiont communities may be inherited by offspring.[863]

Symbiotic microbial communities, or microbiomes, which encompass bacterial and archaeal populations, play a critical and diverse role within the holobiont unit.[864] The full diversity and complexity of reef microbiomes in supporting symbiosis and other host functions is still being explored.[777,848,865,866] However, members of the microbiome could have an important role in providing a mechanism for adapting to environmental change.[288,867,868]

Due to the inherent interdependencies between symbiotic partners, symbiont abundance and condition and the presence of key threats are used as a proxy for the condition and trend of symbiosis.

Despite some recovery of hard coral cover in offshore reefs over the past 5 years, rates of bleaching and increasing sea temperatures continue to be a major concern. Some evidence exists of shifts in symbiont diversity following the 2016 mass coral bleaching, but responses appear to be species-specific.



Symbiotic algae living within coral tissues contribute to their vibrant colours. © Johnny Gaskell 2019

3.4.7 Recruitment

Recruitment is the process of adding new individuals to populations, and it is fundamental to the maintenance and replenishment of depleted populations. New recruits can be sourced locally (when parents are from the same population) or externally (parents are from a different population).[869,870] Depending on an organism's characteristics, recruits can be live young (for example, dugongs), hatchlings (for example, turtles), planktonic larvae settling onto a reef (for example, corals) or seeds (for example, seagrasses) (Figure 3.14). In the Region, the levels of monitoring and types of data on recruitment vary across different components of the Reef.

Dugong populations south of Mission Beach show evidence of long-term decline. During the 2022 urban coast dugong survey,[522] a few dugong calves were seen in the southern region of the Reef and another 13 were seen in the central region. The proportion of calves, a population health measure, was 6.7 per cent along the urban coast of the Reef, within the range recorded for previous surveys but at the low end.

Humpback whale populations have continued to increase since whaling was banned in Australia in 1985.[504] No monitoring data exist on the abundance of live young, but breeding and calving continue to occur in the Region. The resulting continued growth of the humpback whale population means it is predicted to reach carrying capacity in 2021 to 2026.[504]

Many seabird breeding populations from islands and cays across the Region have shown a decline over the past 4 decades,[486] but key information on nesting success and recruitment to breeding populations is lacking for most species.



Figure 3.14 **Recruitment can be complex, relying on many different habitats and processes**

Of the 6 species of marine turtle found in the Region, only green, flatback, loggerhead, and hawksbill turtles are known to regularly nest there (Section 2.4.10). The southern population of green turtles is considered to be moderately recovered.[443] The breeding population of flatback turtles is considered stable or increased;[473] however, some decreases in nesting populations at Peak Island have been observed.[443] The northern green turtle population is now considered to be in significant decline and very few males are now recruiting to the breeding population.[446] The annual recruitment of young female loggerheads into the adult breeding population on the mainland has declined over the past 2 decades,[470] and recovery of the loggerhead nesting populations on the island rookeries has been negligible.[443,470] Since 1990, the number of hawksbill turtle eggs laid and the number of females at the significant Milman Island rookery have steadily declined.[462] Models have projected that the current rate of decline could lead to loss of nesting at Milman Island within the next 10 to 15 years.[462]

Organisms with a planktonic larval stage, such as corals, crown-of-thorns starfish and fish, tend to produce large numbers of individuals with high likelihood of mortality. Rates of survival at key life stages can make a large difference to population outcomes, and identifying the factors influencing these life stages is crucial for understanding population dynamics.[871] For example, it has recently been discovered that larvae from crown-of-thorns starfish and some corals cue on specific crustose coralline algae to find suitable settlement substrates.[280,872] Presence of particular coralline algae can promote higher or lower settlement of recruits, depending on the algal species.[410,411]

Recruitment of coral is highly variable across the Region.[178,873] Some reefs and certain coral types are showing recovered recruitment levels,[874] while others remain very low.[875] Major reductions in coral recruitment that occurred across the Region following mass coral bleaching events in 2016 and 2017 highlighted that sensitivity of adult brood stocks to repeated episodes of bleaching can seriously impede subsequent recovery.[876] Longer recovery windows since 2019 have led to improvements in recruitment. For example, in 2021, substantial recovery of coral recruitment had occurred at some sites, linked to increases in coral cover driven by branching and tabular *Acropora*.[161,874,875] Inshore reefs often have lower densities of juvenile corals than offshore reefs, particularly in the Burdekin, Mackay Whitsunday and Fitzroy regions.[161,185] The impacts of widespread coral bleaching during the 2023–24 summer on coral recruitment are yet to be determined.

Improvement in coral recruitment has occurred on many reefs since 2019

At the end of 2023, crown-of-thorns starfish populations were still at outbreak levels in the southern section of the Reef (Section 3.6.2), while an emerging primary outbreak in the northern region[877] had likely initiated as a result of several years of elevated recruitment.[183] Recent research has revealed that reproduction and settlement of crown-of-thorns starfish can be enhanced by warming events during the typical summer spawning period.[877]

Marine heatwaves are causing coral bleaching and fundamentally changing habitat structures for coral-associated fishes.[365,878] Habitat loss and fragmentation affects early post-settlement survivorship of some reef fishes.[879] Recruitment of other coral-associated fishes was found to persist following loss of habitat-forming coral species at Lizard Island from consecutive mass coral bleaching events in 2016 and 2017.[370] Recruitment was unaffected 2 years after the loss of corals, and fish were found in a range of alternate reef microhabitats, including live, non-branching, non-preferred corals, algal-turf-covered dead corals and coral rubble.[370] A 10-year study conducted at Lizard and One Tree islands further suggests that some reef fish are resilient to environmental perturbations, with recruitment remaining stable over the studied period.[880]

Monitoring of 4 giant clam species from 1982 to 2017 across 5 reef sites showed that populations of all species declined at 3 sites due to low recruitment and death of old individual clams. However, at 2 sites, a significant juvenile recruitment cohort of giant clam and smooth giant clam followed a mass mortality event and returned the population to pre-disturbance abundance. Some of these individuals lived long enough to reproduce successfully in some years, as evidenced by recruitment.[881] Population abundance of fluted giant clam and horse hoof clam also increased slightly at these 2 sites.

Seagrass recruitment is assessed on the basis of reproductive effort, which is calculated by identifying the presence of reproductive structures (flowers, fruits) and the size of seed banks in seagrass meadows.[882] Seed banks in the Region's inshore meadows have been consistently present and abundant in all regions, particularly in the Burdekin region. Reproductive effort in the Fitzroy and Burnett Mary regions has remained low over the past 5 years in most habitats and declined in 2021–22 relative to the previous period.[145]



Recruitment of corals after disturbance is key to recovery. © Matt Curnock 2021

The persistence of the macroalga *Sargassum* on reefs, especially those located in the Region's inshore area, is likely enhanced by the reluctance of herbivores to consume holdfasts and propagules, though some fish species do. *Sargassum* can also regrow from holdfasts that have sustained significant damage.[883] Overall, since 2019, cover of macroalgae has increased or remained high at several inshore reefs across the Region.[190] Increased cover of macroalgae in some reefs in the Mackay Whitsunday region has been driven by recruitment and settlement of propagules since cyclone Debbie in 2017.[185] In offshore reefs, macroalgal cover across the Region has remained stable over the past 5 years.[277]

The level of knowledge of the condition of, and pressures on, recruitment processes within the Region varies substantially between species and species groups. There are very few data on recruitment for most organisms. Trends in recruitment, where known, are also highly variable between different groups: some are stable (for example, seagrass) and some show declines (for example, dugongs and marine turtles). Improvements in coral recruitment occurred on many reefs; however, trends were highly variable and the impacts on recruitment of widespread severe bleaching during the 2023–24 summer have not yet been determined.

3.4.8 Reef building

Reef building, referring to the growth of coral reef framework structures and associated carbonate rubble and sediments, occurs when net accretion of calcium carbonate by calcifying organisms on the reef exceeds net erosion.[186] Coral reefs are structures of bound and loose calcium carbonate (limestone) with relatively thin veneers of corals and other reef organisms, a variety of which contribute to reef growth.[884] The organisms that contribute to the positive net carbonate budget of a coral reef are primarily the hard corals themselves,[885] which build skeletons of layer upon layer of calcium carbonate crystals.[886] Coralline red algae, certain types of green algae (such as *Halimeda*,[887] Section 2.3.8), benthic foraminifera, sponges, echinoderms, and molluscs are also important contributors to the reef carbonate budget.[100,885] Crustose coralline algae are of particular importance for their role contributing to cementation of the complex and interwoven calcareous framework that makes up the structural foundation of coral reefs, and in hardening the reefs against mechanical breakdown.[885] Microbes are also vital to the cementation process and contribute significant amounts of calcium carbonate to coral reef structures.[776,888,889] This microbial calcification may be highly sensitive to ocean acidification (Sections 3.3.2 and 6.3.2).[890]

Calcifiers in coral reef lagoons and other intereefal areas, such as benthic foraminifera and the green alga, *Halimeda*, produce carbonate material that can be transported and deposited onto nearby coral reefs [885,887] by waves and currents or by the activity of species such as parrotfish.[891] In this way, lagoon calcifiers also contribute to the growth of consolidated reef structures and to the carbonate sediments of coral reefs and reef islands (Section 2.3.1).[100] Generation and accumulation of rubble beds is a core element of reef building. However, increasing coral rubble production, one of the expected outcomes of climate change on coral reefs,[34,186] may lead to persistence of unstable rubble beds that hamper coral recruitment [892] (Section 6.3.2).



Improved understanding of links between coral growth and reef building is vital

Erosion of coral reef structures is both a constant process and an acute function of exposure to severe storms.[544] It is driven by a combination of mechanical breakage due to waves and currents, chemical dissolution if carbonate chemistry is sufficiently disrupted,

and bioerosion.[746,893] Both dissolution and bioerosion are expected to increase with ocean acidification.[894,895] Sea temperature rise and ocean acidification may already be impairing coral reef growth in the Region, and there are significant concerns for the future.[739,748,760,895]

Calcification and reef growth is particularly important against a backdrop of rising sea levels (Section 3.2.5). Rates of calcification are influenced by the abundance of calcifying organisms, light [885,896] and nutrient availability, sea temperature, water flow and the concentration of carbonate ions in sea water.[739,897] Calcification rates at Lizard Island exhibited declines [898] and subsequent slight recovery [751] following cyclones in 2014 and 2015 and coral bleaching in 2016 and 2017. At One Tree Island, which was not affected by the 2016–17 coral bleaching event, ecosystem calcification rates in 2017 were found to be similar to their rates in the 1970s.[899]

Estimates of declining calcification rates differ considerably and are hampered by a lack of continuous long-term datasets that could resolve drivers of change over widely varying timescales.[899] Since 2019, reported increases in cover of fast-growing corals (Section 2.3.5 and 2.4.4) may have had a positive impact on reef-building processes. However, the extent to which coral growth influences overall reef growth and how variable this is between reefs remains uncertain.[900,901]

A general decline in calcification rates is likely to have occurred, due to expected ongoing impacts from ocean warming and acidification. However, in the past 5 years, documented recovery of some key reef-building corals may have moderated this projected long-term trend. Changes in some other reef-building processes, such as dissolution and bioerosion, may also have occurred, but they are only likely to become evident over longer time frames. Increasing coral rubble may be becoming an important driver of reef-building processes on some reefs.

3.4.9 Competition

Competition is the interaction between organisms for limited resources, such as space, food, light and mates, and is one of the key processes influencing community structure on coral reefs.[902] The complexity of competitive interactions on coral reefs may also contribute to their high species diversity.[902,903] In reef habitats, competition is perhaps most evident between macroalgae, coral, and other sessile invertebrates which vie for physical space to colonise hard substrates.[903,904,905]

In healthy reefs, corals dominate over macroalgae, but this dynamic can be upset by environmental changes, such as elevated sea temperatures,[906] increased nutrients, and declines in herbivorous species.[907,908] Among reef-building corals, species-specific responses to climate change [909] and local stressors [910] can increase the competitive advantage of some corals over others,[902] ultimately leading to changes in the structure and function of coral assemblages.[339] In some inshore areas of the Reef, competition with macroalgae is currently hindering recovery of coral communities (Sections 2.3.5 and 2.4.3).[190]



Competitive dominance of corals over macroalgae can be disrupted by disturbances

On coral reefs,[907,911] and more generally,[912] cumulative stressors and increasing disturbance frequency are likely be increasingly favouring fast-growing and opportunistic species at the expense of the often slower-growing species capable of competitive dominance in mature ecological communities. This process results in simplified

ecosystems with reduced biodiversity and low ecological complexity.[913,914] The extent to which such shifts may be occurring in the Region is not well understood.

Competition for resources is also observed among mobile species, such as reef fishes,[915] particularly those with similar diet and habitat requirements. Resource competition can manifest as aggressive interactions between species [905] and lead to species-specific patterns in space use.[916] Loss of reef habitat may exacerbate competitive interactions in coral associated invertebrate [323] and fish [915,917] communities. Impacts can be influenced by the degree of habitat specialisation [917,918] and position in the competition hierarchy [915] of different species.

Increasing sea temperatures, nutrient inputs and changes in species composition and habitat availability may be altering the balance of competitive outcomes in the Region. For example, macroalgae continue to outcompete corals in some inshore areas. Cumulative stressors and increasing disturbance frequency may be increasingly favouring fast-growing and opportunistic species.



Macroalgae and coral compete for space in inshore habitats. © Matt Curnock 2021

3.4.10 Connectivity

The Reef and adjacent Catchment are a linked system with high internal and external connectivity.[36,838,919] This biophysical connectivity within and between land, freshwater and marine ecosystems is pivotal to the health and functioning of the Region's ecosystems. Connectivity is provided in various ways, for example, through water flows from the catchment to sea, flooded landscapes,[364] genetics,[920] species migration,[919] and downstream transport of sediments that nourish beaches and mangrove forests.[36,123,838]

Larger animals, such as fish and sharks, actively move between connected habitats for reproduction and foraging,[364,921] while prevailing water currents are important for connectivity in planktonic organisms [838] and between islands. Marine herbivores can help to connect seagrass habitats, while seabirds play an important role in dispersal of island vegetation. For species with significant connections outside the Region, such as shorebirds (Section 2.4.13) and humpback whales (Section 2.4.14), the condition of distant habitats can directly affect populations in the Region. Connectivity is also a vital consideration in the movement of diseases [922] and parasites [923] into and across the Region.

Connectivity is influenced by many spatial and temporal events and processes and may be interrupted by natural and anthropogenic drivers.[838] For example, most Catchment development (Section 6.4) has occurred in low-lying coastal floodplain areas, leading to losses in connectivity through hydraulic barriers, excessive aquatic plant growth or establishment of invasive species.[36,924] Shifts in the types of sediment delivered from the Catchment can have radical downstream impacts (Section 6.5.2).

Connectivity between coral reefs and other habitats across the Region supports the maintenance of genetic diversity within and between populations, a critical factor in the ability of species' to adapt to environmental change.[29] The influence of connectivity on the resilience and adaptation potential of coral populations is an important area of current research interest.[925] New techniques, particularly genetic analysis (Box 2.1), are providing evidence of population connectivity and breaks in connectivity that indicate genetic separation and could have evolutionary consequences.[838,926] For example, genetic studies on corals have confirmed expectations from connectivity models, showing predominant north-to-south gene flow over the recent evolutionary past.[926]



The Reef continues to be a system with high internal and external connectivity

The central role of ocean currents in structuring patterns of connectivity is illustrated by the identification of 16 spatially separated fish communities along the Reef: 7 occurring in shallow waters (less than 15 metres depth) and 9 in deep water.[252] During the fish spawning season, the East Australian Current (Section 3.2.1) is at its strongest, which may enhance or restrict larval dispersal.[252] Patterns in larval connectivity are highly correlated with the El Niño–Southern Oscillation: larval dispersal is predominantly poleward in central and southern regions during El Niño conditions and predominantly equatorward under extreme La Niña conditions.[927] Potential changes to the El Niño–Southern Oscillation (Box 6.1) may therefore affect population dynamics and patterns of biodiversity in the Region.[927] Reef fish community composition is influenced by connectivity both between reefs and among reefs within a region.[928]

Despite the widespread distributions of many tropical reef species across the Indo-Pacific, their dispersal capability is relatively restricted.[928] Strong cross-shelf trends in dispersal of coral larvae mean that inshore and mid-shelf reefs typically receive more larvae than outer-shelf reefs.[929] Dispersal of coral larvae operates within distinct communities: northern, central and southern.[930] Models show that inshore reefs have more self-recruitment and lower levels of larval export than deeper reefs.[931] Despite disruptions to larval supply caused by widespread coral bleaching, a study found that thermal refugia have the potential to deliver larvae to 58 per cent of the Reef.[158] However, the persistence of these refugia is uncertain[667] (Section 6.3.2). A recent modelling study found that 2 degrees Celsius of ocean warming reduced inter-reef connectivity due to reduced dispersal of coral larvae, resulting in higher local retention.[932]

The Reef continues to be a system with high internal and external connectivity across its diverse ecosystems. Legacy impacts (such as hydrological barriers in the Catchment) have reduced this connectivity, and the emerging impacts of climate change are leading to further declines in some areas and for some key species groups such as corals.

3.5 Condition and trends — coastal ecosystems that support the Great Barrier Reef

Coastal ecosystems include those from the top of the Catchment (defined by the Great Dividing Range) to the marine inshore ecosystems within the Region, including island ecosystems. They are not restricted to waterways or the coastline. The coastal ecosystems referred to in this section are predominantly terrestrial and include: saltmarshes, freshwater wetlands, forested floodplains, heath and shrublands, grass and sedgelands, woodlands and forests, and rainforests.

The condition of the Reef benefits from connections with healthy and functioning coastal ecosystems in the Catchment. Coastal ecosystems support critical processes such as the distribution and cycling of sediments, nutrients and water, and facilitate connectivity, including by providing feeding, breeding and nesting habitat for many marine species. Intact coastal ecosystems can help mitigate coastal erosion and decrease sediment and nutrient loads entering the Region. These coastal habitats are managed, monitored and reported on under a values-based management framework by Queensland Parks and Wildlife Service.

The Region's coastal ecosystems hold deep material and cultural significance for First Nations peoples, who have served as traditional custodians of these places for millennia.[36] Nearly all wetland plant and animal species are reported to have some form of traditional use,[36] which varies through Country and Sea Country with the seasons.[933] The Wet Tropics rainforests exemplify the richness of this enduring connection: the Wet Tropics World Heritage Area is the current home of at least 20 First Nations groups encompassing around 120 clans and 8 languages.[934] Living evidence from floodplain forests, in the form of 'scar trees',[36] and archaeological evidence, such as stone arrangements and other cultural artefacts found within saltmarshes,[935] underscore the longstanding cultural importance of these habitats.

The data on current vegetation extent are compared to the data on vegetation extent before European settlement (Table 3.1). The coastal ecosystems have been grouped based on broad vegetation group classifications.[936] Broad vegetation groups are higher level groupings of vegetation communities and regional ecosystems that provide an overview of major ecological patterns and relationships across Queensland.

Seven coastal ecosystems are graded in terms of changes over the past 5 years and the impact of any changes for dependent species. Heath and shrublands remain in very good condition, while 2 coastal ecosystems (saltmarshes and rainforests) remain in good condition. Four coastal ecosystems remain in poor condition.

The full assessment summary is in Section 3.7.4.

Table 3.1 **Changes in extent of coastal ecosystems within the Catchment, from before European settlement to 2015 and 2021**

The current extent and trend in extent since 2015 of coastal ecosystems is presented (remnant vegetation only, that is, vegetation not previously cleared) and proportion of the total area (before European Settlement) of coastal ecosystems remaining in the catchment. Source: Queensland Department of Environment and Science (2023). Data: Regional ecosystems (v13.0) downloaded 8 Sept 2023 [110]

Coastal ecosystem (remnant)	Total Area before European Settlement (km^2)	Total area remaining (km^2)		Decline in total area remaining from 2015 to 2021 (per cent)	Proportion remaining in catchment (per cent)
		2015	2021		2021
Saltmarsh	2339	2097	2094	0.14	90
Freshwater wetland	1686	1330	1329	0.08	79
Forested floodplains	50,529	29,425	29,285	0.48	58
Heath and shrublands	3212	2998	2995	0.10	93
Grass and sedgelands	11,942	5704	5684	0.35	48
Woodlands and forests	323,527	195,942	194,857	0.55	60
Woodlands	228,923	156,953	156,077	0.56	68
Forests	94,603	38,989	38,779	0.54	41
Rainforests	27,502	17,950	17,939	0.06	65

3.5.1 Saltmarshes

Saltmarshes are important coastal ecosystems that occur mostly in the upper intertidal area of low-gradient marine and estuarine plains.

They are part of a mosaic of habitats, including mangrove forests and seagrass meadows that provide important hydrological connections between terrestrial and marine environments.[919,937,938]

Saltmarsh vegetation typically comprises low-growing herbs, grasses, sedges and shrubs; only occasional emergent trees are present, if at all. Saltmarshes occur discontinuously along the entire Region coastline.[935]



Saltmarshes play a vital role in carbon sequestration

Saltmarshes provide intermittent feeding areas for several marine species, including commercial fishery species, such as bream, whiting, mullet [939] and tiger prawns.[940] They also provide feeding and resting areas for resident and migratory birds.[935] The important role played by saltmarshes in carbon sequestration [117,941] led to their inclusion in the National Ocean Ecosystem Account in late 2022,[127] an important step towards systematic monitoring of saltmarsh condition in the Region.

Saltmarshes have historically been extensively drained and removed, as well as affected by the construction of structures such as roads and causeways that alter their hydrology and drainage, including bund walls used to retain freshwater upslope for ponded pastures.[942] Such structures are now better regulated because of statewide regulatory controls that prohibit the construction of infrastructure like ponded pastures since the early 2000s through the *Policy for Development and Use of Ponded Pastures 2001* (Qld).[943] However, ongoing issues persist in some areas due to the presence of existing structure and reclamation in developed coastal areas.[942] Projects have been successfully

undertaken on a limited scale since 2014, such as removing bunds in the Mungalla wetlands east of Ingham to re-establish connection through culverts.[938,944]

No significant changes in extent of saltmarshes are reported since 2019,[110] although local-scale declines in saltmarsh grass have been detected in recent years.[121] As with mangroves, saltmarshes are dynamic ecosystems known for their ability to adapt to environmental changes, such as rising sea levels (see 3.2.5). However, the ability of marshes to grow vertically by accreting sediment is limited, leaving marshes vulnerable to future sea level rise.[95]

No significant changes in saltmarsh extent have occurred since 2019. However, little is known about saltmarsh condition, which is not currently monitored systematically across the Region. In future, both the extent and condition of saltmarshes are likely to be affected by rising sea levels.

3.5.2 Freshwater wetlands

The freshwater wetland coastal ecosystem includes lacustrine wetlands (lakes) and palustrine wetlands (billabongs, swamps, bogs, springs and soaks), which can be seasonal or hold water year-round. Freshwater wetlands can include rivers, but they are excluded for the purpose of this report. Freshwater wetlands are an important part of the landscape. They provide habitat and breeding areas for a wide variety of species, as well as connection between terrestrial, freshwater and marine ecosystems.[593,938,945] Wetlands are highly productive ecosystems that store carbon, nitrogen and phosphorus, and remove nitrogen to the atmosphere (denitrification), all processes that benefit Reef health.[946,947,948,949]



Sediment trapping and nutrient removal by wetlands support healthy inshore habitats

Assessments of the extents of lacustrine and palustrine wetlands have not been updated since 2019, when approximately 70 per cent of the pre-clearing extent of these habitats remained in the Catchment. The overall condition of freshwater floodplain wetlands in the Catchment area has improved between 2016 and 2022, and they are overall in a good state.[950,951] In the 2021–22 *Reef Water Quality Report Card* local physical integrity and connectivity of wetlands are reported to be in moderate state, while biotic integrity and local hydrology of freshwater wetlands are generally in good state.[950,951] On a regional scale, all natural resource management catchments that have regional reporting available are considered to be in a moderate state.

Freshwater floodplain wetlands are under moderate pressure overall from catchment land use, but no change in overall pressure has been detected at a Catchment scale since 2016.[950,951] Pressure from pollutant inputs is lower than pressure from pest species, loss of native vegetation and changes to water flow patterns, which are each exerting moderate pressure on wetland condition overall. This varies regionally, and the Wet Tropics and Fitzroy regions are considered under more pressure than the Burdekin and Burnett Mary regions. Other threats and pressures on freshwater wetlands include increasing temperatures and changing salinity.[952] The removal of bund walls has been shown to be effective in restoring ecological processes in weed-infested grazing areas.[938]

Overall, the state of freshwater wetlands has not changed significantly since 2019. Pest introductions, habitat modification, water regime changes and pollutant inputs have affected wetlands in some locations within the Catchment.

3.5.3 Forested floodplains

Forested floodplains are intermittently flooded, either tidally or through rainfall and overland flows. They provide a range of ecological processes for the Reef, such as nitrogen and carbon storage in the tree trunks and as soil carbon, and as a sink for pollutants from the adjacent river catchments.[947,953,954] Forested floodplain ecosystems include tea tree swamps dominated by *Melaleuca* trees, which have historically experienced the most significant losses of wetlands in the Catchment and are listed as Endangered under the *Environment Protection and Biodiversity Conservation Act* 1999 (Cth).[947,954,955] The extent of forested floodplains in the Catchment is at 58 per cent of pre-European levels.[110]



Historical land clearing led to extensive loss and fragmentation of forested floodplains

Significant loss and fragmentation of forested floodplains occurred historically as a result of land clearing, but there has been limited change in extent and condition in the past 5 years.

3.5.4 Heath and shrublands

Shrublands in the Region are characterised by dense foliage and low stunted species usually 5 to 10 metres in height and sometimes referred to as 'scrubs', or by an overstorey dominated by multi-stemmed acacia. Heath is dominated by small shrubs with small, hard leaves that occur on infertile or waterlogged sites or coastal areas. It is often difficult to separate open heath from scrub-heath, and in some areas the frequency of fires determines which form predominates.[956]



Coastal urban growth and altered fire regimes threaten these ecosystems

Coastal wet heath and sedgeland wetlands in the Catchment are protected within Cape Melville, Iron Range, Mungkan Kandju and Byfield national parks, and these remain in good condition. Elsewhere, outside protected areas, the condition of these ecosystems has generally fared more poorly due to being exposed to a range of environmental impacts associated with encroachment by competing land uses, especially coastal urban growth, and altered fire regimes.[957,958]

The extent of heath and shrublands has remained stable over the past 5 years as little clearing has occurred across the Region.

3.5.5 Grass and sedgelands

Grass and sedgelands are dominated by a range of non-woody or herbaceous species, and they include tussock and hummock grasslands, sedgelands and forblands (ecosystems dominated by non-grass herbaceous plants). Grass and sedgeland ecosystems occur throughout the Catchment, their distribution driven primarily by soils and climate. Grasses on dune systems are important for the health of the Reef because they stabilise coastal soils, regulate nutrients, and provide a buffer against the erosive forces of wind and rain.[959] Grass and sedgelands also slow the velocity of overland water flows and provide natural hazard protection in some instances. Knowledge gaps exist around the condition of this ecosystem. Land use intensification and invasive species cause the greatest threats to grass and sedgelands.[960]

Significant habitat loss has occurred since European settlement. The limited data available on grass and sedgelands show no recent significant changes to habitat extent.

3.5.6 Woodlands and forests

Woodlands are areas of mature, single-stemmed trees that have between 20 and 50 per cent canopy cover, whereas forests have greater than 50 per cent canopy cover. Woodlands and the woodland understory reduce flood risk by slowing overland water velocity and thereby regulate sediment and nutrient supply to the Reef.[959] Forests contribute to the hydrological cycle through evapotranspiration, cloud formation and rainfall generation.[961] *Pisonia* forests provide critical seabird nesting habitat and help to stabilise sediments on coral cays within the Region.[962]

Since 2019, the Cape York and Wet Tropics regions have the greatest extent of remaining remnant woodlands and forest ecosystems, at approximately 88 and 99 per cent of the extent before European settlement, respectively. The Fitzroy region has the lowest percentage of remnant forest in the Catchment at approximately 32 per cent and the Burnett Mary region has 36 per cent of remnant woodland extent compared to pre-European settlement.[110]



Climate change has increased the frequency and extent of fires

Climate change has increased the extent of burned areas and the frequency of fires, including forest megafires (those that burned more than 10,000 square kilometres), over the past 4 decades.[963]

The extent of historical habitat loss differs between regions, and more remnant habitat remains in northern regions than elsewhere. The extent and condition of woodlands and forests continue to be affected by land clearing and forest fires. Overall, annual clearing rates have reduced in recent years, but vary among regions.

3.5.7 Rainforests

Rainforests are forested ecosystems with closed canopies.[964] Rainforests can be found scattered throughout the Catchment from cloud rainforests of the Wet Tropics to coastal vine thicket rainforests. Rainforests provide a range of ecological processes for the Reef, including nutrient uptake, carbon sequestration, slowing hydrological flows and sediment trapping.[961]

Threats to rainforests are predominantly climate change, land clearing and invasion of fragmented areas by weeds.[965,966,967] Recovery of fire-sensitive communities, especially upland rainforests, from the 2018 bushfires in the Mackay highlands is likely to take decades to centuries.[968]



Wet Tropics lowland tropical rainforest is listed as an endangered ecological community

Since 2019, it is estimated that the Cape York and Mackay Whitsunday regions have the greatest extent of remaining rainforests of 99 and 91 per cent, respectively. In contrast, the Burnett Mary and Fitzroy regions, which have experienced the greatest clearance rates since pre-European settlement, have only 39 and 37 per cent remnant cover, respectively.[110] In 2021, the lowland tropical rainforest of the Wet Tropics was listed as an

endangered ecological community under the EPBC Act based on historical losses due to clearing and resulting fragmentation, and ongoing threats to its integrity and function.

Rainforests are affected by climate change, land clearing and historical habitat loss and fragmentation. The extent of rainforests in the Catchment has remained relatively stable since 2019.



Rainforest at Babinda Boulders in Far North Queensland © Dieter Tracey 2022

3.6 Condition and trends — outbreaks of disease, introduced species and pest species

Four components are graded in terms of their levels of occurrence and impacts on ecosystem function. Grades for outbreaks of disease, introduced species, and other outbreaks remain good. The grade for outbreaks of crown-of-thorns starfish has improved to poor.

The full assessment summary is in Section 3.7.5.

3.6.1 Outbreaks of disease

Diseases are infections of plants and animals caused by pathogenic microorganisms, including bacteria, viruses, fungi and parasites. Although many of these microorganisms are naturally present in the environment and usually do not cause widespread disease, outbreaks can occur when microorganism abundance increases rapidly or if host immunity is compromised.[969,970] Pathogens can be introduced or transmitted to new marine areas in various ways, for example, through imported seafood, vessel biofouling or ballast water discharge.[971]

Disease can have a significant negative effect on population structures, causing rapid population declines and mass mortality or, in extreme cases, hastening species extinctions.[972,973] In habitat-forming species such as corals, disease outbreaks contribute

to loss of coral cover and can lead to flow-on effects for associated species, reef structure and ecosystem function.[974] Disease can also have sublethal effects on host species, including reduced rates of reproduction and growth.[975,976]

At least 8 different coral diseases, including white syndrome, black band and brown band disease, have been reported from various reef building corals within the Region.[974,977,978] Since 2019 major flooding of rivers in the Burdekin region and above-median discharges from some rivers in the Mackay Whitsunday and Wet Tropics regions likely contributed to increased levels of disease observed in inshore areas.[190] Declines in coral cover at reefs in Burnett Mary region in 2022 [178] and Fitzroy region during 2023 [190] have also been attributed to disease.

While not detected in the Region or Australia, stony coral tissue loss disease has continued to spread rapidly through the wider Caribbean since 2019,[979] where it affects at least 25 different coral species and can cause mortality rates of more than 80 per cent in massive corals.[980] This disease poses a significant risk if introduced to the Region. Bacterial biofilms on ships [981] and ballast water [979,982] are both potential vectors of stony coral tissue loss disease.

Prevalence of coral disease and disease outbreaks are frequently linked to environmental stress, including rising sea temperatures,[978,983,984,985,986,987] storm events,[988,989] decreased water quality [990] and nutrient enrichment.[991] Microbial dysbiosis, or a shift in the symbiotic microbiome which favours the establishment of opportunistic bacteria or pathogens, is increasingly implicated in many coral diseases.[164,974,986,992] Within the Region, reduced microbial diversity has been shown to lower coral immunity to disease.[993] Predators can also affect coral disease by damaging protective tissues and exposing corals to infections, transmitting diseases between corals, or acting as reservoirs for pathogens.[994]

Disease prevalence is often linked to environmental stress

White spot disease, which can cause mortality in crustaceans, was first recorded in prawn farms in south-east Queensland.[995] It was subsequently found in wild crustaceans, including in northern Moreton Bay in 2020.[996] While there are currently no known occurrences within the Region,[996] there is potential for transmission from south-east Queensland. Queensland has a movement regulated area (MRA) in place to mitigate the risk of spread. High-risk aquatic animals cannot be moved out of this area. This includes uncooked prawns, yabbies and marine worms. A national surveillance program has demonstrated that all areas of Australia, outside the MRA, have remained free from the virus.[995]

Marine turtles suffer from various pathogenic diseases,[997,998,999,1000,1001] although disease has only been attributed as the cause of death in a small number of stranded marine turtles in the past 5 years.[461] Higher rates of pathogenic disease tend to be reported in immunocompromised individuals, and there may be links between immunosuppression and exposure to environmental pollution.[1002,1003] Generally, non-infectious diseases (for example, from trauma and injuries associated with collision, gut impaction as a result of plastic ingestion, exposure to contaminants) pose a greater risk than infectious diseases to marine turtles within the Region.[1003]

Climate change is projected to lead to further disease outbreaks and may also provide increased transmission opportunities as a result of species immigration and range shifts.[1004] With increasing global warming and poor water quality, disease prevalence may also increase in fish species.[1004]

Since 2019, disease is known to have affected corals and marine turtles within the Region. The incidence of disease is expected to increase with warming temperatures, and consequences could be significant. There are concerns that the Region could be affected by new outbreaks of disease occurring overseas (for example, stony coral tissue loss disease), but these diseases have not yet been observed in the Region.

3.6.2 Outbreaks of crown-of-thorns starfish

Crown-of-thorns starfish are a native coral predator on the Reef, as evidenced by their long fossil record.[1005,1006] Scientists have long debated whether Reef-wide outbreaks of crown-of-thorns starfish are a natural occurrence or whether they are caused or exacerbated by human activities.[900,1007,1008,1009] Life history characteristics of the species, such as exceptional fecundity, naturally encourage population fluctuations and enable crown-of-thorns starfish to quickly reach outbreak proportions when conditions are favourable.[735,1010,1011]

The causes of crown-of-thorns starfish outbreaks on the Reef are complex and remain a subject of ongoing research interest.[735,1010] In addition to the influence of nutrients, oceanographic processes and reduced predation,[1010,1012] temperature has recently been shown to affect reproduction and settlement of crown-of-thorns starfish.[877]

Continued uncertainty around the causes of outbreaks, and the likelihood that the convergence of multiple factors is critical to their initiation and spread,[735] presents a dilemma for Reef managers as to the most effective approach to reduce their impact.[1010,1013] Recent evidence indicates that manual removal of starfish from reefs is the most effective way to mitigate outbreaks,[1014] and can achieve individual reef- and regional-scale coral benefits with timely detection and response.[187,1015]



Crown-of-thorns starfish can cause severe coral losses when they reach outbreak densities.
© Commonwealth of Australia (Reef Authority) 2023, photographer: David Williamson

The Reef has experienced 4 destructive outbreaks of crown-of-thorns starfish since the 1960s. Once established, an outbreak spreads when adult starfish spawn and their larvae are carried by currents to other reefs. Once the larvae settle on a reef, they initially feed on crustose coralline algae before transitioning to a diet of coral tissue and increasing rapidly in size.[735,809,1016] The herbivorous juvenile starfish hide among coral branches and crevices and are mainly active at night, making them difficult to observe and monitor. They can

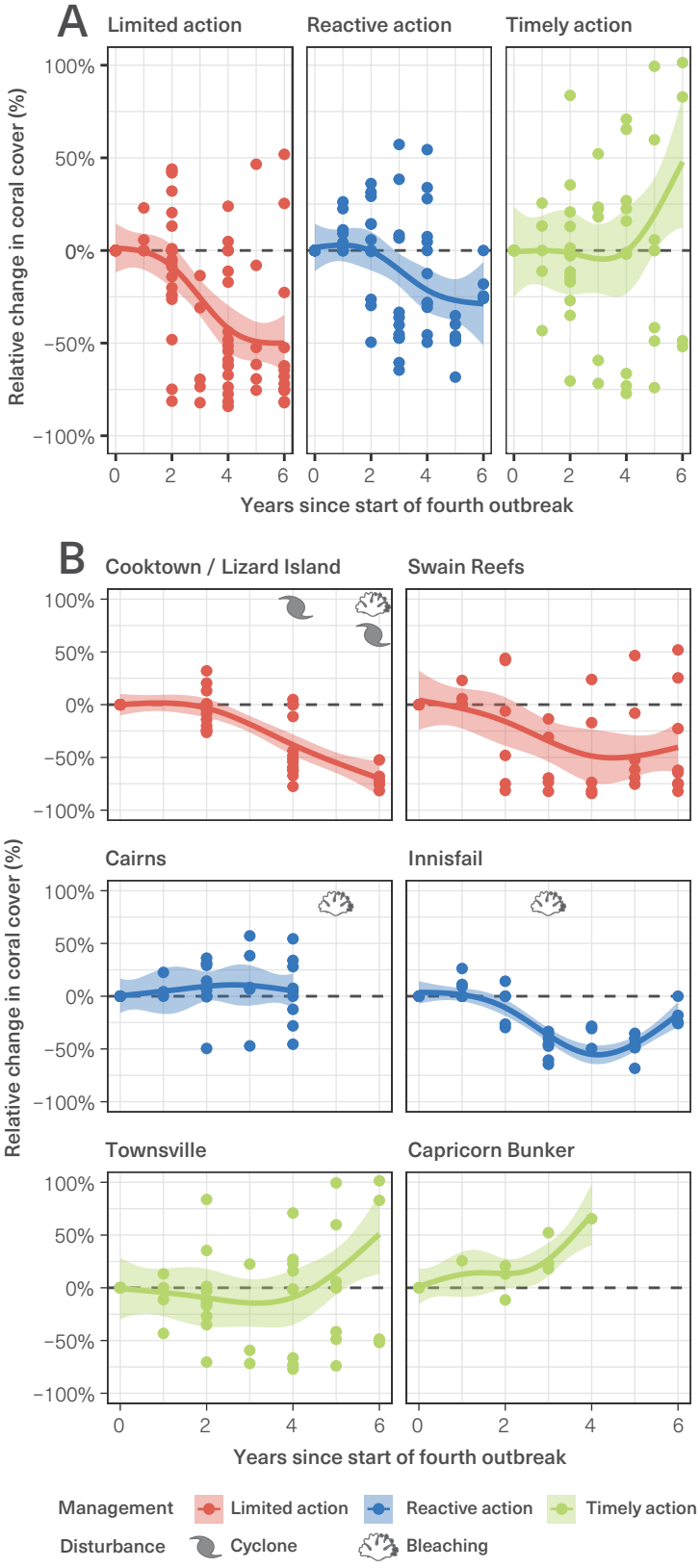


Figure 3.15 **Coral cover change under different crown-of-thorns starfish management actions**

Relative change in coral cover (percentage) according to the type of crown-of-thorns starfish management action implemented (A) and by sector (B): 'Limited action' (red), 'Reactive action' (blue), and 'Timely action' (green). Each point represents the relative change in coral cover at a given reef, up to 6 years following the start of the sector-specific fourth outbreak wave. The trendline is fitted using a generalised additive model, and the transparent ribbon represents the 95 per cent confidence intervals. Disturbance markers indicate timing of events that resulted in sector-wide coral mortality (that is, not all disturbance events). Source: Matthews *et al.* (2024).[187]

remain in this small, cryptic phase for months to years,[1009,1017] and experimental evidence suggests this juvenile stage has high thermal tolerance.[1018] The survival rate of juvenile starfish is key to generating outbreaks, but considerable knowledge gaps persist about this stage of their lifecycle.[809]

An outbreak of crown-of-thorns starfish that began between Lizard Island and Cairns in 2011, has moved south and is still (as of 2023) ongoing in some southern and central reefs. Importantly, some outbreaks in the southern reefs likely initiated independently of the northern outbreak.[1019] Mounting evidence suggests that the Swain Reefs, [1020] Cape Grenville[184] and Townsville–Innisfail sectors[1020,1021] are particularly susceptible to crown-of-thorns outbreaks and may play crucial roles in overall outbreak wave dynamics or initiation. Since 2019, a buildup of crown-of-thorns starfish at Lizard Island [183,184] and Cape Grenville [184] has been identified using a novel survey method, and it may represent the start of a new primary outbreak. This research highlights the potential of new survey methods for detecting outbreaks in the early stages when they are most amenable to management intervention.[184,1022]

Surveys in 2022 indicate there are still ongoing outbreaks on some reefs in the southern region, including in the Swain Reefs. Three surveyed reefs were classified as having severe outbreaks, 2 reefs had established outbreaks and 3 reefs had potential outbreaks. In the southern region, coral cover has decreased since 2021, largely due to ongoing crown-of-thorns starfish outbreaks.[1023] Active targeted culling of crown-of-thorns starfish in the central region has likely contributed to the low numbers of starfish recorded during recent surveys and the increasing coral cover in that region from 2018.[187]

Active management of crown-of-thorns starfish outbreaks began in 2002 with the introduction of the Crown-of-Thorns Starfish Control Program. Culling efforts have become much more effective over the past decade due to several improvements, including adopting an integrated pest management approach,[1024] developing a single shot injection technique, making advances in computer-aided modelling and prediction, and increasing vessel capacity. Since 2019, increased effort has led to suppression of outbreaks at both reef and regional scales, and new evidence demonstrates that the control program is minimising coral loss at target reefs (Figure 3.15).[187]

Crown-of-thorns starfish outbreaks continue to affect reefs across the Region. However, in the past 5 years, increased crown-of-thorn starfish control efforts have reduced the impact of outbreaks on coral reefs, at both local and regional scales.

3.6.3 Introduced species

Introduced species are non-native plants and animals that have been introduced and established beyond their natural range, either intentionally or accidentally as a result of human activities.[1025] Species that threaten biological diversity in their new location are considered invasive (or pest) species.[1026] Many invasive species can also affect cultural, health and economic values where they establish.[1026]

More than 250 non-native marine species have been introduced to Australia,[1027] although this is likely to be an underestimate as cryptic species often go undetected.[1028] Introduced terrestrial and freshwater species also occur within the Catchment.[1029] Range shifts are not typically considered within the definition of species introductions, even when caused by climate change,[1026] although in some cases they can cause similar impacts.[1030]

Invasive species can increase competition for food and space, modify habitats and affect food chains, in some cases preying directly on native species.[1026,1031] Within the Region, for example, marine turtle eggs are preyed on by feral pigs at some nesting beaches,[443] and seabird eggs and hatchlings are vulnerable to predation by non-native rodents.[1032,1033]

Since 2019, 2 new marine non-native species have been identified within the Region. In December 2022, the white colonial sea squirt was detected for the first time on tourism infrastructure within reef habitat in the Great Barrier Reef Marine Park. It has been known to exist in major Queensland ports for at least 5 years [1034] and for at least 10 years in other Australian jurisdictions. This detection was self-reported by a tourism operator at Moore Reef, offshore from Cairns. While invasive marine pests are the responsibility of the Commonwealth Department of Agriculture, Fisheries and Forestry and the Queensland Department of Agriculture and Fisheries, the Reef Authority has a role in managing impacts to Marine Park values. The Reef Authority established an incident management team, which has been working with partnered agencies, tourism operators and Gunggandji Traditional Owners to establish the nature and extent of the outbreak at Moore Reef, which in turn will guide a management response. Complete eradication of the species is considered infeasible due to its rapid growth and high reproductive capacity.[1034]

Since 2019, the black scar oyster has been detected in various locations, including Mission Beach, Mourilyan Harbour, Cairns, Port Douglas, Cooktown and Elim Beach.[1035,1036] This species had not previously been detected in Australia, and its status and invasiveness are still being investigated. Incursions of Asian green mussel have also been detected within the Region (Escape River, 2019; Cairns, 2021) and on a number of transiting vessels, but no populations are known to have become established in the environment.[1037]

Pathways for introducing marine non-native species include biofouling on vessel hulls, internal seawater inlets and marine equipment, transport of larval stages within ship ballast water, and movement of aquaculture equipment and stock.[1031,1038,1039] Pathway management is considered the most effective option for managing biological invasions in marine systems,[1039] in which eradication and control are challenging and have often proved unsuccessful in the past.[1039]

Successful eradications have been undertaken on islands within the Region

Prevention and control can be more effective on islands [1039] due to their natural geographic isolation, while island eradications contribute significantly to global biodiversity conservation outcomes.[1040] Successful eradications have been undertaken on islands within the Region since the mid-1960s.[1041] In 2022, mice were successfully eradicated from North West Island in the Capricornia Cays National Park.[72,1032] However, pathways for island introductions remain, and after the successful mouse eradication, black rats were discovered on North West Island in 2022.[1042] Growing threats from increasing visitation and highly invasive species, such as yellow crazy ants immediately adjacent to the Region in Cairns, Townsville and the Whitsundays,[91,92,93] present new challenges for biosecurity programs across the Region.

Since 2019, new introductions have occurred in both marine and island areas within the Region, while effective eradication programs have occurred on some islands. Biosecurity strategies and management measures are being implemented to help mitigate the risk, although some potential pathways for introducing non-native species remain.

3.6.4 Other outbreaks

Outbreaks of other species include native species (as opposed to introduced species; Section 3.6.3) that can experience a rapid increase in abundance, biomass or population. Outbreaks of the naturally occurring crown-of-thorns starfish and coral disease are described in Sections 3.6.1 and 3.6.2, respectively. Outbreaks and blooms are often a sign of ecosystem stress and can be harmful or lethal to other marine species. Some outbreaks can also pose a threat to human health, either through direct consumption of ciguatoxins in fish, inhalation of microscopic organisms causing the outbreak,[1043] or exposure to toxic cyanobacteria in water.[1044]



A bloom of nitrogen-fixing cyanobacteria, genus *Trichodesmium*, off the central Queensland coast.
© Landsat 8 | NASA Landsat Image Gallery 2019

Trichodesmium is a pelagic cyanobacterium that can create slicks when significant numbers of cells accumulate and float to the water surface. On exposure to sunlight, the cells die, leaving floating pungent slicks that look like sawdust on the surface of the water. Slicks are more common under hot, calm conditions in spring and summer, aided by slow, circulating surface currents.[1045] Phosphorus and iron may also influence *Trichodesmium* growth and bloom formation.[724,1046] Two species of *Trichodesmium* are present within the Region, and *T. thiebautii* is reported as the dominant species at the Integrated Marine Observing System (IMOS) Yongala National Reference Station near Ayr.[251] Data show a long-term increase in *Trichodesmium* abundance has occurred and that seasonally lower abundances are observed during winter periods [358] (Figure 3.16). Modelling and remote sensing analyses suggest that the largest *Trichodesmium* blooms arise in the south of the Region,[1047] and their peak abundance occurs at a water temperature of 26 degrees Celsius, usually in spring.[724] Increased nitrogen fixation rates have been associated with elevated phosphorus conditions [724] and reduced dissolved nitrogen.[804]

Drupella are corallivorous (coral-eating) marine snails that occur naturally within the Region, commonly in aggregations.[1048] In high numbers, *Drupella* can cause damage and mortality in corals through direct predation [1049] and by facilitating the spread of disease.[1050,1051] Overfishing of predators, elevated nutrients and warming sea temperatures may exacerbate outbreaks.[1052,1053] Counts of *Drupella* snails and feeding scars are provided by a number of monitoring programs within the Region.[1054] Since 2019 high densities of *Drupella* have been recorded at some reefs, in most cases at densities below

the threshold where detrimental impact on coral communities is expected,[185] and no significant outbreaks are known to have occurred.

More than 100 species of jellyfishes occur within the Region, most of which are considered harmless.[1055] The most well-known species are those that are dangerous to humans, including the Australian box jellyfish and Irukandji. Jellyfish movements and behaviour are influenced by environmental factors.[1056] Australian box jellyfish are largely distributed close to mainland shores.[1055,1057] Since 2019, modelling suggests that Irukandji presence and abundance near Cairns is highly variable and cannot be explained by environmental predictors, such as wind or rainfall.[1058] Survey approaches using eDNA[1059] and unmanned aerial vehicles [1060] are providing new ways to improve detection of certain life stages and species of jellyfish. While jellyfish blooms are well known globally,[1061] large aggregations of box jellyfish species are relatively uncommon [1058] and no information on trends is available within the Region.

A long-term increase in *Trichodesmium* abundance has continued at the Yongala National Reference Station. High numbers of *Drupella* snails have been recorded at some reefs, but no outbreaks have been reported.

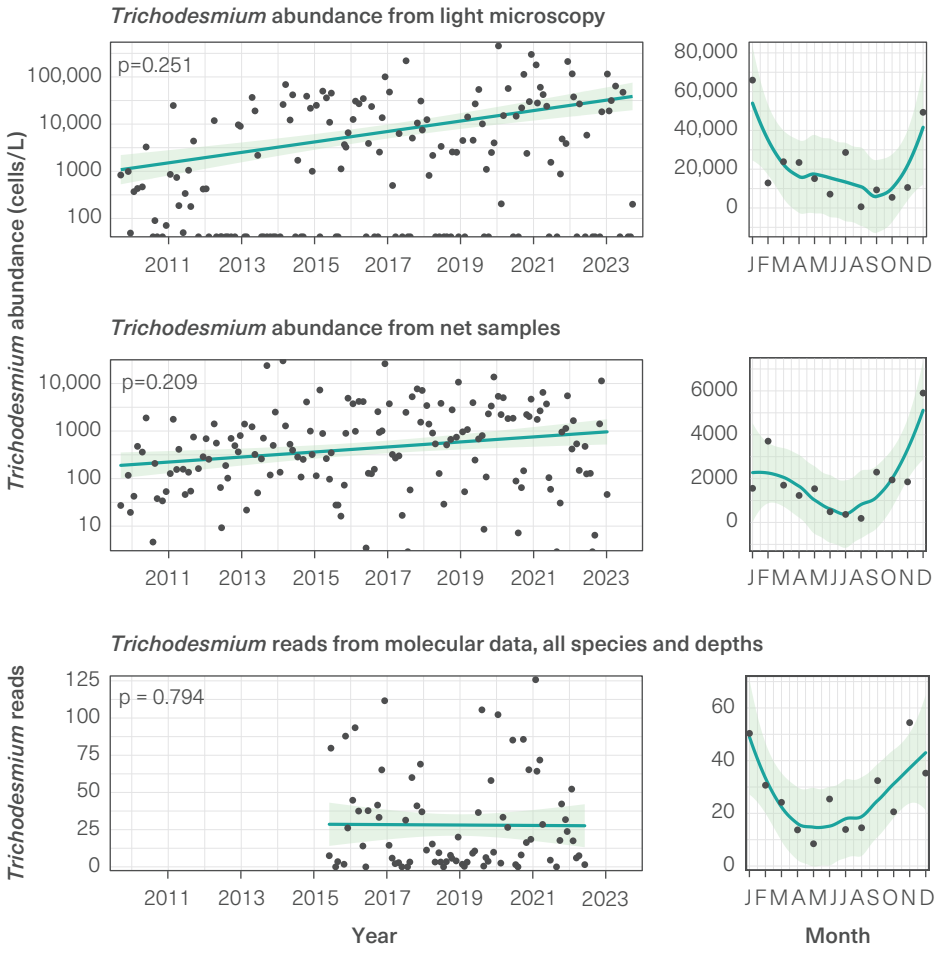


Figure 3.16 ***Trichodesmium*** **abundance, Yongala Integrated Marine Observing System (IMOS) National Reference Station, 2010 to 2023**

Indices of *Trichodesmium* abundance at the Yongala IMOS National Reference Station, from phytoplankton bottle samples using light microscopy (top), zooplankton net samples (middle) and molecular analysis of bottle samples (bottom). Green shading shows 95 per cent confidence interval, p-values indicate whether trend is statistically significant ($p < 0.05$). Left graphs use a linear model, right graphs use a loess smoother. Source: Richardson *et al.* (2023)[251] using data from Australia's IMOS, enabled by the National Collaborative Research Infrastructure Strategy (NCRIS) and operated by a consortium of institutions as an unincorporated joint venture with the University of Tasmania as Lead Agent.

3.7 Assessment summary — Ecosystem health

Paragraph 54(3)(a) of the *Great Barrier Reef Marine Park Act 1975* (Cth) requires *'... an assessment of the current health of the ecosystem within the Great Barrier Reef Region and of the ecosystem outside that region to the extent that it affects that region'.*

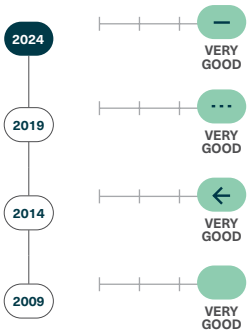
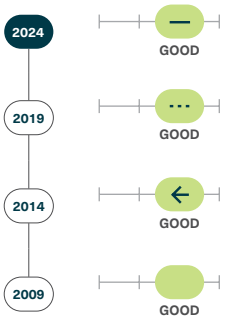
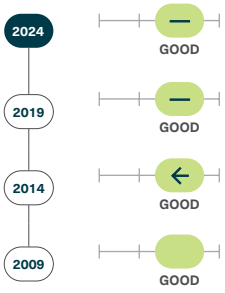
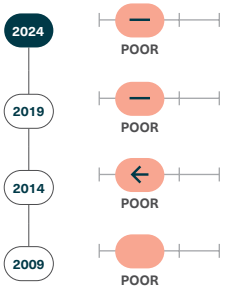
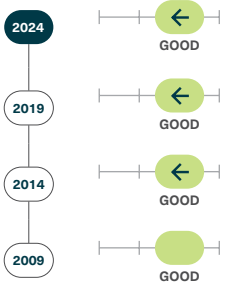
This assessment is based on 5 criteria:

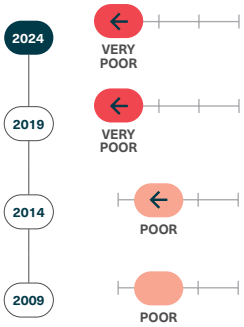
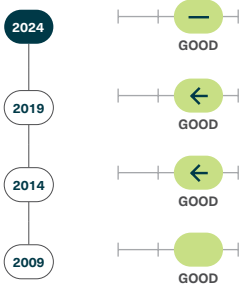
- physical processes
- chemical processes
- ecological processes
- coastal ecosystems that support the Great Barrier Reef
- outbreaks of disease, introduced species and pest species.

3.7.1 Physical processes

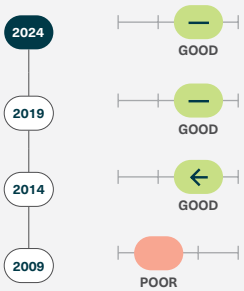
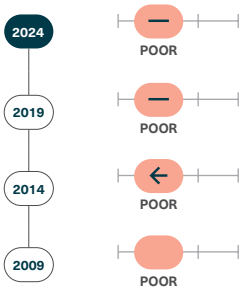
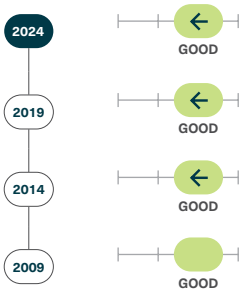
Grading statements — Physical, chemical, and ecological processes		Trend since previous report	Confidence
	**Very Good:** There are no significant changes in processes as a result of human activities.	Improved Stable Deteriorated No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
	Good: There are some significant changes in processes as a result of human activities in some areas, but these are not to the extent that they are significantly affecting ecosystem functions.		
	**Poor:** There are substantial changes in processes as a result of human activities, and these are significantly affecting ecosystem functions in some areas.		
	**Very Poor:** There are substantial changes in processes across a wide area as a result of human activities, and ecosystem functions are seriously affected in much of the area.		
	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

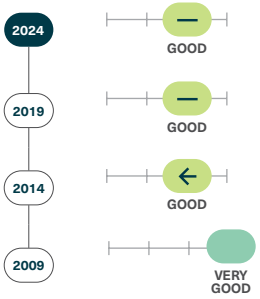
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Physical processes: Most physical processes have remained stable or continued to deteriorate since 2019. Further changes to these processes are expected due to the continued influence of climate change and land-based run-off, which have broad implications for the Region.			

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Currents: Although changes are occurring, currents in the Region continue to connect species and habitats and transport nutrients. Longer-term changes to currents due to climate change are expected.		LIMITED	LIMITED
Cyclones and wind: In the past 5 years, cyclone activity has been relatively low. However, large variation in the numbers of cyclones is expected, and cyclones remain one of the most important drivers of ecosystem change in the Region. A longer-term trend may be emerging of decreasing cyclone numbers and increasing average intensity.		ADEQUATE	LIMITED
Freshwater inflow: Over the past 5 years the average annual freshwater inflow across the Catchment has been just above the long-term average and shown regional variability. Documented and projected changes in rainfall are affecting this process over decades.		ADEQUATE	ADEQUATE
Sediment exposure: Sediment loads delivered during flood events, and resuspension of legacy sediments continue to contribute to the poor state of many inshore coastal and inshore marine ecosystems. Since 2019, some areas have seen improvements in sediment exposure, but other inshore areas continue to be affected by resuspended and catchment-derived sediments.		ADEQUATE	ADEQUATE
Sea level: Sea level has been rising over recent decades, leading to increases in the frequency of high-tide flooding events. Year-to-year changes remain small in the context of inter-annual natural variability. Impacts of sea-level rise will increase in coming decades.		ADEQUATE	ADEQUATE

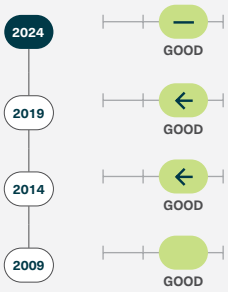
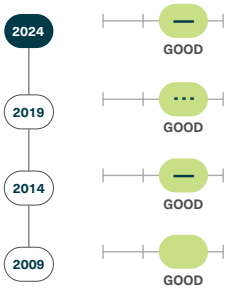
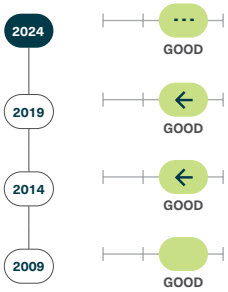
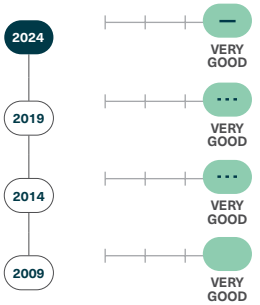
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Sea temperature: Average sea surface temperatures within the Region have continued to increase over the past 5 years, and record high temperatures were recorded in February 2020. Marine heatwaves occurred in 2020 and 2022, triggering mass coral bleaching in both years, although relatively limited coral mortality. Another mass coral bleaching event unfolded in early 2024, after the end of the 2019 to 2023 assessment period.		ADEQUATE	ADEQUATE
Light: The availability of light at the seabed is below optimum levels in several nearshore locations across the Region, although light levels across most inshore areas have generally remained stable or improved over the past 5 years.		LIMITED	LIMITED

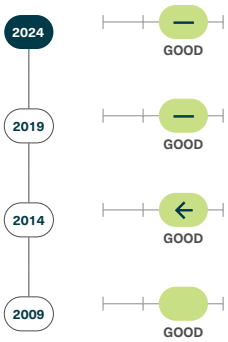
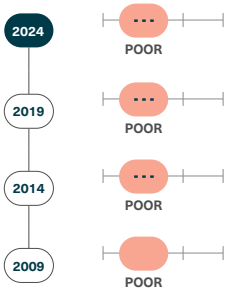
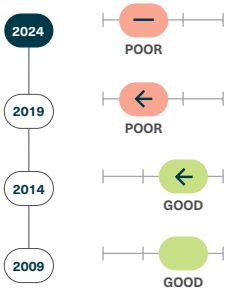
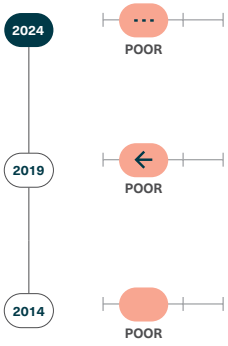
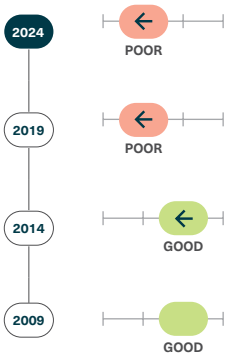
3.7.2 Chemical processes

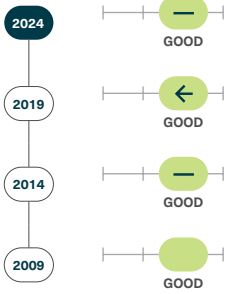
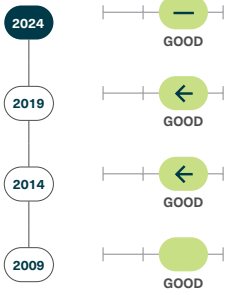
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Chemical processes: The chemical processes within the Reef are generally in good condition. However nutrient cycling continues to be affected by land-based run-off. Ocean pH has decreased as a result of climate change.			
Nutrient cycling: Although substantial and ongoing changes to nutrient cycling since European settlement continue to affect inshore habitats, this process is understood to have been generally stable since 2019. There have been important advances in our understanding of nutrient cycling and in its integration into decision-making through improved models since 2019.		ADEQUATE	ADEQUATE
Ocean pH: Ocean pH has declined within the Region, in line with global and Australian trends. It is likely that the rate of decline has increased in recent decades, driven by progressive ocean uptake of carbon dioxide due to increasing emissions. Ocean acidification has significant implications for coral reef ecosystems.		ADEQUATE	ADEQUATE

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Ocean salinity: Wider ocean patterns suggest that salinity may slowly increase in offshore areas within the Region, while inshore areas are subject to seasonal decreases in salinity as a result of freshwater input. Over the past 5 years, freshwater influence has been slightly above average overall with regional variation.		ADEQUATE	LIMITED

3.7.3 Ecological processes

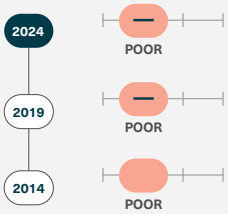
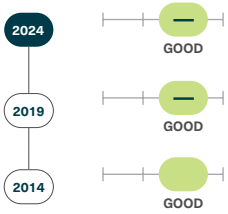
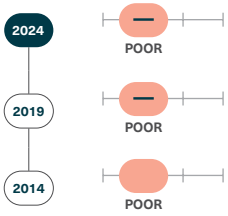
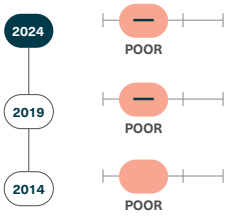
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Ecological processes: Since 2019, most ecological processes on the Reef have remained generally stable. Reef building continues to deteriorate due to the impact of ocean acidification on calcification rates. Trends in recruitment are variable, but declines have been observed in some populations, including dugongs, turtles, and some species of coral.			
Microbial processes: Environmental stressors associated with a warming climate and land-based runoff have led to changes in microbial processes across the Region. Although knowledge has advanced considerably since 2019, microbial processes remain poorly understood.		INFERRED	INFERRED
Particle feeding: A range of pressures affect particle feeders, and condition varies between different species and species groups. No consistent trend has been identified since 2019. Since 2019, cover of some fast-growing species of corals has increased, but condition of corals in some areas remains poor. Long-term declines have occurred in the commercially harvested saucer scallop population, and the stock is currently classified as depleted.		LIMITED	LIMITED
Primary production: Overall, primary production as a process is considered to be functioning well. Some shifts in the type of primary production (less in the water column, more in benthic producers) may have occurred in inshore areas as a result of improved water quality since 2019. Primary producers in some areas continue to be affected by high nutrient levels, sediment and temperature.		LIMITED	LIMITED

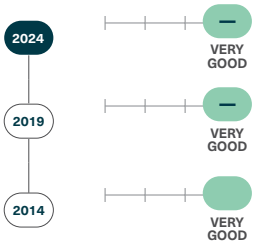
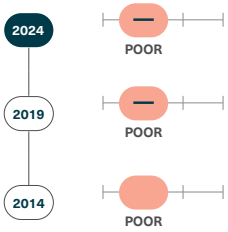
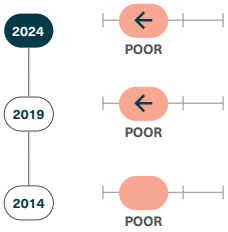
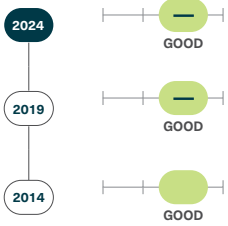
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Herbivory: Despite its central importance to ecosystem functioning, an in-depth understanding of the process of herbivory across the Region and the mechanisms that affect it remains elusive. This process is undertaken by a wide range of species at varying scales and with diverse effects on ecosystem function across different habitats. Overall, herbivory has likely remained stable since 2019. Declines in some populations of dugongs, green turtles and potentially in herbivorous fishes may lead to reduced levels of herbivory in certain areas.			
Predation: Predation affects a wide range of taxa that are subject to varying pressures. Although natural rates of predation are likely relatively stable, the Region's ecosystems remain impacted by a long history of exploitation of apex predators and populations of some targeted species remain in poor condition. A large group of predators, the sharks and rays, are assessed as being in poor condition.			
Symbiosis: Despite some recovery of hard coral cover in offshore reefs over the past 5 years, rates of bleaching and increasing sea temperatures continue to be a major concern. Some evidence exists of shifts in symbiont diversity following the 2016 mass coral bleaching, but responses appear to be species-specific.			
Recruitment: The level of knowledge of the condition of, and pressures on, recruitment processes within the Region varies substantially between species and species groups. There are very few data on recruitment for most organisms. Trends in recruitment, where known, are also highly variable between different groups; some are stable (seagrass) and some show declines (dugongs, marine turtles). Improvements in coral recruitment occurred on many reefs; however, trends were highly variable and the impacts on recruitment of widespread severe bleaching during the 2023–24 summer have not yet been determined.			
Reef building: A general decline in calcification rates is likely to have occurred, due to expected ongoing impacts from ocean warming and acidification. However, in the past 5 years, documented recovery of some key reef-building corals may have moderated this projected long-term trend. Changes in some other reef-building processes, such as dissolution and bioerosion, may also have occurred, but they are only likely to become evident over longer time frames. Increasing coral rubble may be becoming an important driver of reef-building processes on some reefs.			

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Competition: Increasing sea temperatures, nutrient inputs and changes in species composition and habitat availability alter the balance of competitive outcomes in the Region. For example, macroalgae continue to outcompete corals in some inshore areas. Cumulative stressors and increasing disturbance frequency may be increasingly favouring fast-growing and opportunistic species.			
Connectivity: The Reef continues to be a system with high internal and external connectivity across its diverse ecosystems. Legacy impacts (such as hydrological barriers in the Catchment) have reduced this connectivity, and the emerging impacts of climate change are leading to further declines in some areas and for some key species groups such as corals.			

3.7.4 Coastal ecosystems that support the Great Barrier Reef

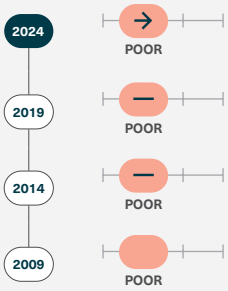
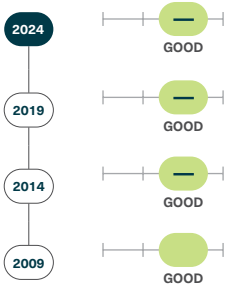
Grading statements — Coastal ecosystems that support the Great Barrier Reef		Trend since previous report	Confidence
	**Very Good:** All major habitats are essentially structurally and functionally intact and able to support all dependent species.	→ Improved — Stable ← Deteriorated ··· No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
	Good: 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.		
	**Poor:** Habitat loss, degradation or alteration has occurred in a number of areas leading to persistent substantial effects on populations of some dependent species.		
	**Very Poor:** There is widespread habitat loss, degradation or alteration leading to persistent, substantial effects on many populations of dependent species.		
	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

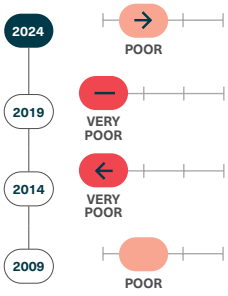
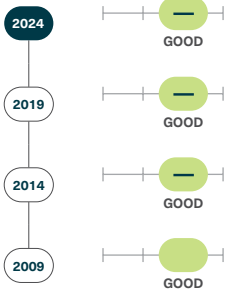
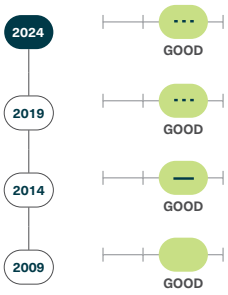
Criterion and component summaries	Grade and trend	Confidence GRADE	Confidence TREND
Coastal ecosystems that support the Great Barrier Reef: An understanding of the condition of most coastal ecosystems remains a significant knowledge gap. The extent of each coastal ecosystem has remained generally stable, but woodlands continue to be affected by clearance, albeit at a slower rate than in 2019.			
Saltmarshes: No significant changes in saltmarsh extent have occurred since 2019. However, little is known about saltmarsh condition, which is not currently monitored systematically across the Region. In future, both the extent and condition of saltmarshes are likely to be affected by rising sea levels.			
Freshwater wetlands: Overall, the state of freshwater wetlands has not changed significantly since 2019. Pest introductions, habitat modification, water regime changes and pollutant inputs have affected wetlands in some locations within the Catchment.			
Forested floodplains: Significant loss and fragmentation of forested floodplains occurred historically as a result of land clearing, but there has been limited change in extent and condition in the past 5 years.			

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Heath and shrublands: The extent of heath and shrublands has remained stable over the past 5 years as little clearing has occurred across the Region.		LIMITED	LIMITED
Grass and sedgelands: Significant habitat loss has occurred since European settlement. The limited data available on grass and sedgelands show no recent significant changes to habitat extent.		LIMITED	INFERRED
Woodlands and forests: The extent of historical habitat loss differs between regions and more remnant habitat remains in northern regions than elsewhere. The extent and condition of woodlands and forests continue to be affected by land clearing and forest fires. Overall, annual clearing rates have reduced in recent years, but vary among regions.		ADEQUATE	LIMITED
Rainforests: Rainforests are affected by climate change, land clearing and historical habitat loss and fragmentation. The extent of rainforests in the Catchment has remained relatively stable since 2019.		LIMITED	LIMITED

3.7.5 Outbreaks of disease, introduced species and pest species

Grading statements — Outbreaks of disease, introduced species and pest species		Trend since previous report	Confidence
	**Very Good:** No records of diseases above expected natural levels; no introduced species recorded; no outbreaks; pest populations within naturally expected levels.	Improved Stable Deteriorated No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
	**Good:** Disease occasionally above expected natural levels but recovery prompt; any occurrences of introduced species successfully addressed; pests sometimes present above natural levels with limited effects on ecosystem function.		
	**Poor:** Unnaturally high levels of disease regularly recorded in some areas; occurrences of introduced species require significant intervention; pest outbreaks in some areas affect ecosystem function more than expected under natural conditions.		
	**Very Poor:** Unnaturally high levels of disease often recorded in many areas; uncontrollable outbreaks of introduced pests; opportunistic pests seriously affecting ecosystem function in many areas.		
	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Outbreaks of disease, introduced species and pest species: Outbreaks of disease are localised and patchy across the Region, but have generally remained stable since 2019. Increased culling effort has reduced the impact of crown-of-thorns starfish, although the potential for new outbreaks remains. Other outbreaks, such as *Trichodesmium*, have increased, but data are limited on a broad scale.			
Outbreaks of disease: Since 2019, disease is known to have affected corals and turtles within the Region. The incidence of disease is expected to increase with warming temperatures and consequences could be significant. There are concerns that the Region could be affected by new outbreaks of disease occurring overseas (for example, stony coral tissue loss disease), but these diseases have not yet been observed in the Region.			

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Outbreaks of crown-of-thorns starfish: Crown-of-thorns starfish outbreaks continue to affect reefs across the Region. However, in the past 5 years, increased crown-of-thorn starfish control efforts have reduced the impact of outbreaks on coral reefs, at both local and regional scales.		ADEQUATE	ADEQUATE
Introduced species: Since 2019, new introductions have occurred in both marine and island areas within the Region, while effective eradication programs have occurred on some islands. Biosecurity strategies and management measures are being implemented to help mitigate the risk, although some potential pathways for introduction of non-native species remain.		INFERRED	INFERRED
Other outbreaks: A long-term increase in *Trichodesmium* abundance has continued at the Yongala National Reference Station. High numbers of *Drupella* snails have been recorded at some reefs, but no outbreaks have been reported.		LIMITED	INFERRED

3.8 Overall summary of ecosystem health

The condition of the Region depends on a range of chemical, physical and ecological processes, the health of connected coastal ecosystems, and impacts of disease and pest outbreaks. Thirty-one ecosystem health components are assessed across those 5 areas, and around 60 per cent remain in good to very good condition; the rest are in poor to very poor condition. Five of the 31 components have deteriorated (but not changed grade) since 2019, including four components across physical processes (sea temperature and sea level), chemical processes (ocean pH) and ecological processes (reef building). These continued declines in ecosystem condition are largely driven by the ongoing chronic effects of climate change, in particular ocean warming.

Sea temperatures have continued to increase over the past 5 years, and this component remains very poor. Record high sea temperatures were recorded in February 2020, and marine heatwaves triggered mass coral bleaching (although not significant mortality) in both 2020 and 2022. Notably, the 2022 event was the first mass coral bleaching event to occur during a La Niña year. Since 2019, the La Niña climatic phase has dominated. This phase is usually associated with cooler weather in the Region so it may have moderated the effect of extreme temperatures. Sea temperature and other physical and chemical processes, such as sea level and ocean pH, will continue to deteriorate as the effects of climate change accelerate.



Marine heatwaves occurred in 2020 and 2022

Sea level is assessed as good but deteriorated. Other physical processes, such as currents, cyclones and wind, sediment exposure, freshwater inflow and light have remained stable since 2019. In the longer term, alterations in many of these processes are projected due to climate change and land-based runoff, and this will have broad implications for the Region.

With the exception of ocean pH, which is assessed as good but deteriorated as a result of increasing atmospheric carbon dioxide concentrations, chemical processes have remained relatively stable since 2019. Ocean salinity is unchanged, while nutrient cycling, which continues to be affected by land-based runoff, remains in a poor but stable condition. Ecological processes have generally remained stable since 2019, although reef building continues to deteriorate due to ocean acidification. Trends in other processes, including particle feeding, recruitment and predation, vary between different taxa. Declines in recruitment have been reported in some populations of marine turtles and dugongs, for example. The condition (and trend in condition) of some ecological processes, such as microbial processes and competition, remain poorly understood.

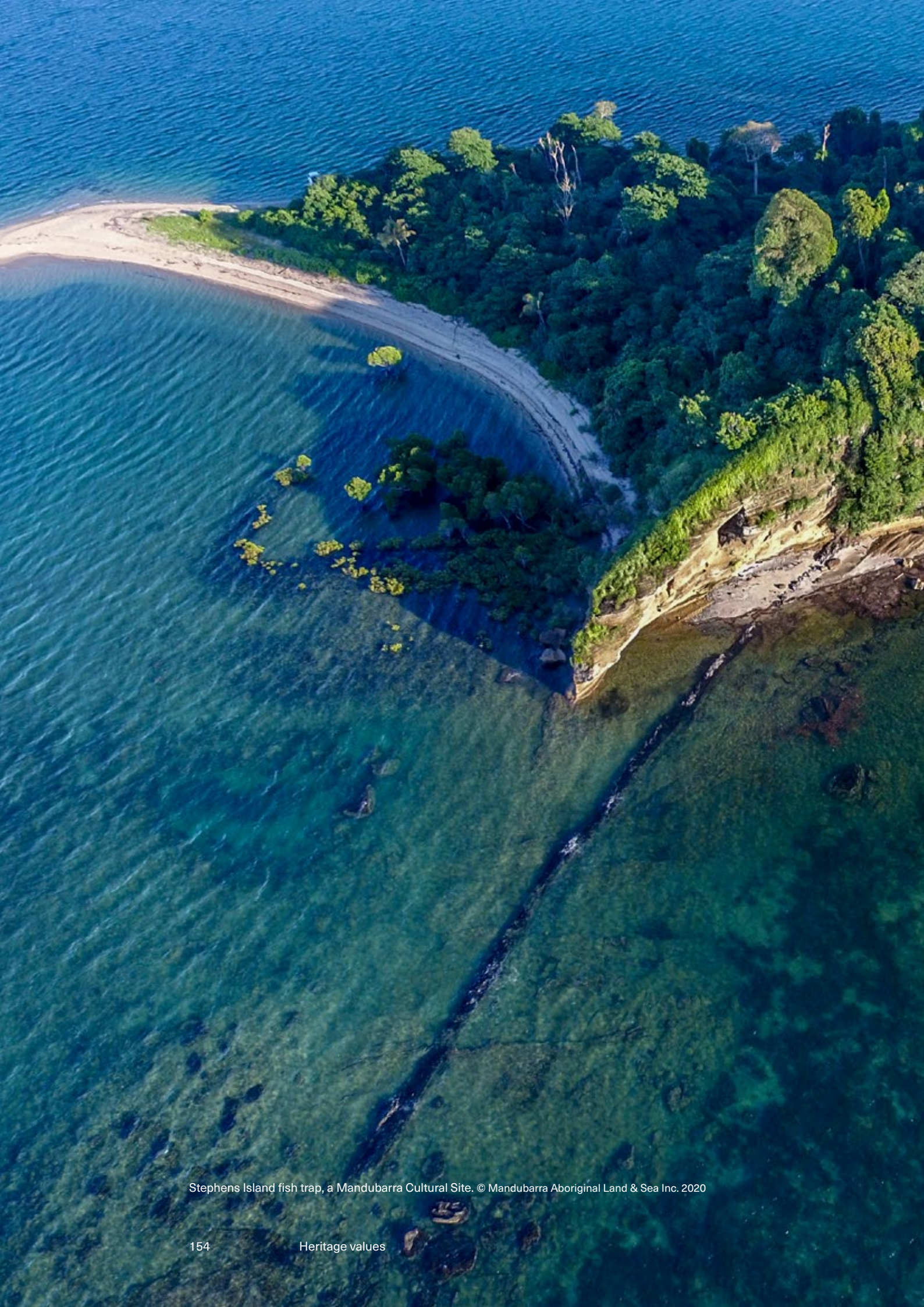


Land clearing and fires have affected woodlands and forests

Coastal ecosystems that support the Reef remain in poor condition overall, though trends in most components have stabilised. Woodlands and forests is the only coastal ecosystem type that continues to deteriorate, which is caused by the ongoing impacts from land clearing (although annual rates have reduced in recent years) and forest fires. Continued modification of these ecosystems will increase sediment inflow, reduce connectivity to the Reef, and reduce the capacity of these habitats to support the Region's ecosystems and species.

Crown-of-thorns starfish outbreaks were suppressed on some reefs

Outbreaks of crown-of-thorns starfish is graded as poor compared to the rating of very poor in 2019. While persistent crown-of-thorns outbreaks at some southern reefs and a new outbreak in the northern region continue to alter ecosystem function on affected reefs, increased efforts in starfish control since the last report have led to both reef- and regional-scale improvements. Outbreaks of disease and occurrences of introduced species are localised and patchy across the Region and considered stable since 2019. Programs to eradicate introduced pests have been successful on some islands. A long-term increase in *Trichodesmium* abundance has occurred, but data on a Region-wide scale are limited.



Stephens Island fish trap, a Mandubarra Cultural Site. © Mandubarra Aboriginal Land & Sea Inc. 2020

Chapter 4

Heritage values



Heritage values

'an assessment of the current heritage values...' of the Great Barrier Reef Region, Section 176(3)(a) of the *Great Barrier Reef Marine Park Regulations 2019* (Cth)



Dent Island Lighthouse. © Commonwealth of Australia (Reef Authority). Photographer: Alicia Moisel 2024

"The island of Jiigurru (Lizard Island) is sacred to the Dingaal Aboriginal people. It is their Country and Sea Country, lying 240 kilometres north of Cairns and 30 kilometres offshore on the northern end of the Great Barrier Reef. Traditional Owners, such as Kenneth McClean and Gareth Deeral, work side by side with western researchers on archaeological areas on the island (Box 4.1).

The Dingaal Aboriginal people have lived in the area for tens of thousands of years, including during times of lower sea levels, when the island may have been part of mainland Australia. How it was formed and its place in songlines and stories, in the furthest regions of the Great Barrier Reef, is being revived and recaptured by Jiigurru Traditional Owner, Gareth Deeral.

"Within my family, I am teaching them about dance, about songlines, about stories — about how Jiigurru was formed, about thunderstorm and why we can still see clouds hovering over Jiigurru when we look out from the mainland."

"Jiigurru is a sacred place where men's business took place. There are sacred sites everywhere there."

— Gareth Deeral, Jiigurru Traditional Owner

It was here that young boys were brought for initiation and other men's business, and important meetings between Elders of neighbouring clans were held. These islands also provided a base for collecting shellfish, fish, turtles and dugongs. Gareth is ensuring his family's songlines and dance are being celebrated, revived and are a part of healing and knowledge sharing.

"We didn't have access over there for a very long time. There are some rock formations that we found when we were out walking on the island, sharks, whales, crocodile formations that you can see so clearly. Visitors don't realise they are sacred sites and move the rocks around," making it important to set up more infrastructure *"so that we can care for Country and care for those sites and educate people about their significance."*

— Gareth Deeral

Source: Caring for Sea Country — Traditional Owner Stories from the Great Barrier Reef [1]



Blue Lagoon at Jiigurru where pieces of pottery have been found (Box 4.1). © Ariana Lambrides 2021

4.1 Background

The assessment in this chapter is based on four components of heritage. These include three components which consider the Region's heritage values (natural, Indigenous and historic heritage values), some of which extend beyond the Region's boundary. These values align with the national heritage domains.[5,1062] The fourth component considers other heritage values, and these are attributes of heritage significance (social, aesthetic and scientific) (Figure 4.1). The combined assessment of these values is the same as the previous Outlook Reports.

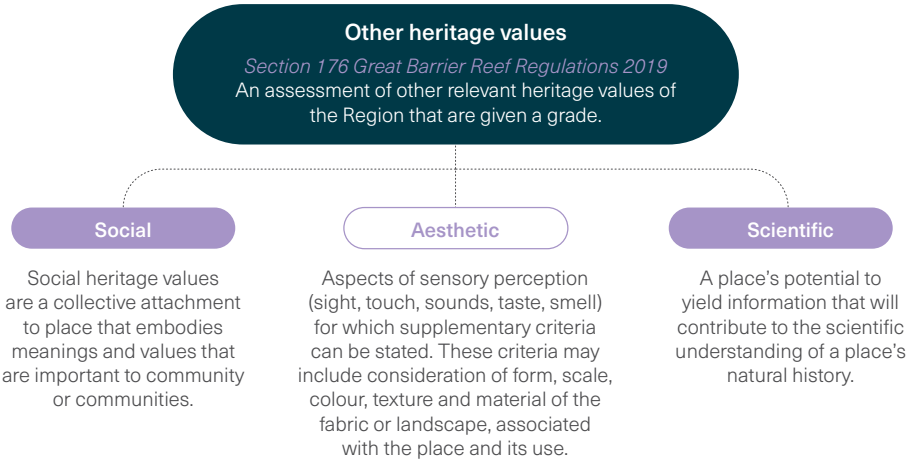


Figure 4.1 **Other heritage values**
The Outlook Report 2024 assesses 'other heritage values' in addition to the components outlined in the Marine Park regulations. Source: Commonwealth of Australia[6,1063] and Pocock *et al.* (2002)[1064]

4.2 Current condition and trends — natural heritage values

4.2.1 World heritage value and national heritage value

The Great Barrier Reef was inscribed on the World Heritage List in 1981 and included on the National Heritage List in 2007. These two listings recognise the Region for the same natural heritage value. In 2019, the Outlook Report refined the assessment of the Reef's natural heritage value to focus on the five components that reflect the four natural criteria for which the Reef was inscribed on the World Heritage List. Table 4.1 highlights the alignment between the components and criteria against the related Outlook Report assessments.

Properties are inscribed on the World Heritage List to recognise their outstanding universal value. Outstanding universal value means the property's cultural and/or natural significance is 'so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity'.[1065]

The Reef is recognised globally as a natural area of outstanding universal value

Table 4.1 **World heritage criteria relevant to the Reef and how they are assessed**

This table summarises how the Outlook Report 2024 chapters contribute to the assessment of the world heritage criteria; more detail is shown in Appendices 3 and 4.

Component (subsection) of Chapter 4	Current world heritage criteria	Outlook Report assessment of natural heritage values
Natural beauty and natural phenomena	(vii) contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance	The natural beauty and aesthetic value of the property are assessed in Chapter 4 and Chapters 2 and 3 inform an assessment of natural phenomena
Major stages of the Earth's evolutionary history	(viii) be outstanding examples representing major stages of Earth's history, including the record of life, significant ongoing geological processes in the development of landforms, or significant geomorphic or physiographic features	The major stages of Earth's evolutionary history are assessed in Chapter 4 and informed by Chapters 2 and 3
Ecological and biological processes	(ix) be outstanding examples representing significant ongoing ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals	Ecological and biological processes are assessed in Chapters 3 and 8
Habitats for conservation of biodiversity	(x) contain the most important and significant natural habitats for *in situ* conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation	Habitats and biodiversity are assessed in Chapters 2, 4 and 8
Integrity	Integrity refers to the property's wholeness and intactness. Integrity and safeguards are additional conditions to maintain outstanding universal value.	The integrity of the property is assessed in Chapter 4 and Appendices 3 and 4

4.2.2 Natural beauty and natural phenomena (criterion vii)

The natural beauty and natural phenomena of the world heritage property is intrinsically linked to the Region's biodiversity and ecosystem health (Chapters 2 and 3) and the community's perception about the Region's aesthetic values (Section 4.5.2). Evidence presented in these sections is considered in the assessment of natural beauty and natural phenomena.

The Reef continues to be a superlative natural phenomenon above and below the water which can be measured by the condition of its biodiversity and ecosystem health. For example, humpback whale numbers continue to recover [505] (Section 2.4.14). Ongoing use of the Region's iconic beautiful places is critically important to support local and international economies, human wellbeing, and stewardship.[1066] Safe access for the public and conservation of spectacular scenery has seen ongoing commitment from managers. For example, since 2019 managers have performed health checks of island national parks, developed the Whitsunday Island walking tracks, installed additional public moorings and no-anchoring areas and upgraded the camping grounds on North West Island.[38,72,1067]

While the Reef's abundance and diversity of shapes, sizes and colours have not significantly changed since inscription, some land and seascapes have deteriorated. Hard coral cover, for example, has improved since 2019, but this recovery is dominated by a few fast-growing groups of corals.[174] Impacts to other iconic ecosystems (such as the southern regions of seagrass meadows, Section 2.3.4) and species (such as marine turtles, Section 2.4.10; and dugong, Section 2.4.16) have been observed since 2019.

Climate impacts that cause shifts from dominance by corals to other organisms such as turf algae,[1068,1069,1070] are likely to affect the colours and patterns on fishes.[1066,1068,1071] Fish assemblages on future reefs are likely to be less vibrant, even if coral cover remains high but dominated by highly robust corals, such as *Porites*.[1068,1072] This change in the array of colours on reefs could represent a loss of intrinsic and aesthetic value to humans and may also affect ecological processes, such as camouflage from predators.[1068]

The Reef's natural beauty depends on the way in which people perceive the aesthetic values of the Reef (Section 4.5.2). This perception can be affected by major events, such as mass coral bleaching, and the ways in which these events are communicated to the public.[1073,1074] While the majority of respondents in one survey considered the aesthetic beauty of the Reef as outstanding in 2021,[1075] there is some evidence of declines in the perception of the condition of the Reef's natural beauty since mass coral bleaching events in 2016 and 2017.[1076,1077] In one survey, there was a significant decline in tourists' perceptions of the Reef's aesthetic beauty and their overall satisfaction with their experience among those who visited after the 2016 and 2017 events.[1077] Perceptions of threats to the natural beauty of the Reef are also affected by these major events (Section 9.3.1).

'Beautiful' is the most common word associated with the Reef

A 2021 sentiment analysis revealed that 'beautiful' is the most common word associated with the Great Barrier Reef.[1075] People continue to prefer the naturalness of the Reef, being the degree of wilderness, pristineness or state of minimum human influence,[1066] over artificial scenes. However, human interventions in response to localised impacts have modified the natural beauty below the water. Since 2019, managers and partners have completed active reef restoration, for example, at Green Island and Bait Reef.[32,38,1067,1078] Also for the purposes of interventions, artificial reefs have been installed in some degraded natural reef ecosystems. Underwater artwork has been installed in the Reef to provide novel aesthetic opportunities, but the degree to which they contribute or detract from natural beauty and natural phenomena remains unknown.

Taken as a whole, the Region's natural beauty and natural phenomena endures and many elements necessary to maintain outstanding universal value have remained stable since 2019. However, localised deterioration of some underwater vistas by degraded coral assemblages and seagrass meadows has occurred.



Aesthetic beauty above and below water at Arthur Bay. © Matt Curnock 2021

4.2.3 Major stages of the Earth's evolutionary history (criterion viii)

Contained within the structures of its reef formations and diverse ecosystems, the modern Great Barrier Reef holds outstanding examples of the Earth's evolutionary history.[1079] Geological coring has revealed a complex history of reef growth and regression as sea levels rose and fell through a sequence of ice ages during the Pleistocene epoch.[1080] Between coral reefs, the lagoon floor (Section 2.3.6) preserves records of ancient shorelines and river courses. [205,1081] The diversity of reef islands (Section 2.3.1) reflects the varied geometries and relative sea level histories of the reefs on which they formed.[97] This evolutionary history not only has intrinsic value but represents a vital repository of data that can inform evidence-based responses to environmental challenges, such as climate change.[775,1082]

Since 2019, important advancements have extended our scientific understanding of the Reef's evolution. These include insights into the origin of the Reef itself. One study links the formation of K'gari (formerly Fraser Island) around 800,000 years ago, and its consequential interruption of longshore drift, to the preconditions for coral formation in the Region.[1083] Recent studies have considered sea temperatures,[1084] turbidity,[775,1085] tectonically driven subsidence of central parts of the continental shelf [1086,1087] and other environmental factors affecting the geomorphology and growth history of the Reef since the last ice age.[1088] Other studies have explored the influence of reef platforms on the development and evolution of seafloor features [1089] and of reef growth patterns [1090] during periods of low sea level, such as the last glacial maximum. *Halimeda* bioherms (Section 2.3.8), recognised for their contribution to the Reef's outstanding universal value,[1079] have also been a focus of study.[234,1091] More recent geomorphological changes have also been documented, such as the development and growth of low wooded islands.[100,123] Taken together, these findings underscore the importance of the Reef as a living archive of key chapters in the Earth's evolutionary history.



Recent research has advanced understanding of the Reef's origins

The Reef is considered resilient with respect to the geological and geomorphological processes that have shaped and link the Region's habitats across the continental shelf to the continental slope and abyssal plains.[97,186] However, the effects from climate change, such as ocean acidification (very high risk), sea-temperature increase (very high risk) and sea-level rise (very high risk) present a threat to this world heritage criterion. The combined impacts on key organisms[1092] are likely to affect not only ecosystems (Section 6.3.2) but also reef structures.[1093] For example, if not effectively mitigated, climate change will lead to reduced growth and diminished structural integrity of some reefs. Persistent rubble beds will become more widespread, reducing the structural complexity of reef habitat.[1094]

The Reef's ability to change and adapt to shifting environmental conditions over millennia has made it a living document of major stages in the Earth's evolutionary history. However, if current trajectories of climate change continue unabated, declining ecosystem condition and damage to key features, especially coral reefs, will erode the Region's outstanding universal value.

4.2.4 Ecological and biological processes (criterion ix)

Ecological and biological processes contribute to the Reef's outstanding universal value. The assessment of this criterion considers whether processes maintain the structure and function across the whole of the property in the face of external pressures.

At a Region-wide scale, ecological and biological processes continue to operate. Reefs, islands, cays and the mainland remain connected by functioning ocean current systems and weather patterns (Section 3.2.1). However, the greatest threats to the Reef's processes continue to be the effects of climate change on ocean pH (good condition but deteriorating), sea temperature (very poor and deteriorating) and sea-level rise (good but deteriorating) (Chapter 3). Other oceanographic processes, such as upwellings of cold water, may amplify ocean acidification and have additional or consequential effects on coral resilience to other stressors.[532,1095] Warming oceans may have reduced the reproductive capability of some adult fish and warming of beaches negatively affects recruitment in marine turtles (Section 2.4.10). Declining breeding populations of some seabird species (Section 2.4.12) may also be attributed to inadequate food supplies due to warming sea surface temperatures.



At a Region-wide scale, ecological and biological processes continue to operate

Overall, the condition of sediment exposure as a process has been stable since 2019, with some locations showing improvement and others continuing to be affected (Section 3.2.4). Sediment loads delivered during flood events and resuspension of legacy sediments continue to contribute to the poor condition of many inshore coastal and inshore marine ecosystems.

The global significance of the Reef continues to be underpinned by the form and structure of its organisms, as well as the interconnectedness of the Reef's complex physical, chemical and ecological processes. Since 2019, many ecological processes have been stable or shown no consistent trend (for example, particle feeding, predation, recruitment and competition).

4.2.5 Habitats for conservation of biodiversity (criterion x)

The Reef supports tens of thousands of marine and terrestrial species, many of which are of global conservation significance. The assessment of the Reef's habitats for conservation of biodiversity comprises all habitat values (Chapter 2) on a property-wide scale.

The Outlook Report 2019 identified that widespread loss and degradation of key habitats (coral reefs and seagrass meadows) had occurred in that reporting period and found the overall condition grade for habitats to support species was poor. In 2024, coral reefs and seagrass meadows show improved trends, including the grade for coral reefs shifting from very poor to poor borderline good. Multiple other habitats remain in good condition, noting confidence in some grades is broadly inferred due to limited data. However, overall, habitats to support species remain in poor condition.



Condition of coral reefs and seagrass meadows have improved since 2019

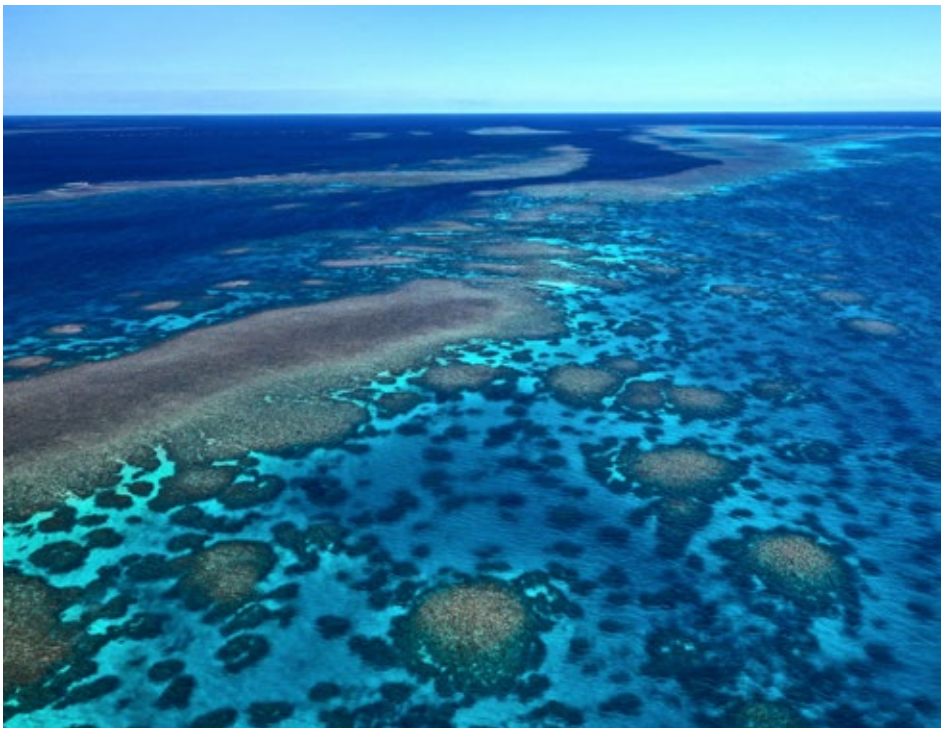
The most immediate and priority threat from climate change is thermal extremes that cause mass mortality of corals and other organisms. Since 2019, further research has

increased understanding of the effects of ocean warming on the condition of habitats, and the marine and terrestrial species they support. The present-day frequency and severity of climate change-related impacts are increasing and interacting with the other key factors influencing the values of the Region (Sections 6.4 to 6.6), compounding their effects.

At the time of inscription in 1981, some 400 species of corals in 60 genera were known to occur in the Region.[1096] It is now known that these numbers are likely to be much higher. New techniques, such as genomic sequencing, are providing new insights into biodiversity and the ability of species to cope with climate change (Sections 2.1 and 2.3.5). While the condition of some values at the Region-wide scale have improved (seagrasses, corals and crocodiles) since 2019, others have declined (some populations and species of marine turtles and dolphins). This range reflects the vast size of the ecosystem, being unparallelled in latitudinal extent. However, human-induced climate change continues to challenge the integrity of the World Heritage Area; its size is becoming a less effective buffer against global impacts. The potential implications on the Reef's intactness are assessed in Section 4.2.6 and Appendix 4. The Region's long-term outlook is discussed in Chapter 10.

4.2.6 Integrity

Integrity — a measure of the wholeness and intactness of a place's natural heritage value[1065] — is an important prerequisite for a natural heritage property to be inscribed and continue to be on the World Heritage List. The Great Barrier Reef is one of the richest and most complex natural ecosystems on Earth; the Region also supports a variety of uses by people.[1096] The United Nations Educational, Scientific and Cultural Organization (UNESCO) recognises that human activity within the listed place may be consistent with the Region's outstanding universal value, where it is ecologically sustainable. The assessment of the Region's integrity examines the interaction between its biodiversity and ecosystem values and human activity (Appendix 4). This assessment also considers the adverse impacts of human activity on the outstanding universal value, the safeguards against the impacts and the management regime of the place.[1065] The current condition (and trends in condition) of biodiversity and ecosystem health also informs the integrity grade.



The Reef is big, beautiful, diverse, complex and interconnected. © Johnny Gaskell 2022

The insightfulness to include virtually the entire Great Barrier Reef within the world heritage property at inscription has helped sustain the integrity and diversity of the Region's marine ecosystem.[1096] Recognising the diversity of the Region is crucial in the assessment of the property's integrity, while noting that some areas are being increasingly affected by climate change more than others.[1097] This diversity is evident in the spatial extent of the habitats within the world heritage property regardless of their proportion of the Region and prominence. Large areas of the Reef are lagoon floor habitat (more than 60 per cent), with continental shelf, seagrass meadows, and coral reefs the next most extensive areas and a range of other habitats making up the rest.[1098]

For the first element of integrity, the property remains whole and intact; the condition of many elements that make up the four natural world heritage criteria are stable. Rising sea temperatures have likely affected most habitats and species (Chapter 2), processes (Chapter 3) and heritage values (Chapter 4). In turn, human activities in the Region have changed and continue to pivot and adapt to the changing Reef environment. Marine heatwaves have triggered six mass coral bleaching events on the Reef (Section 2.3.5).[48,49] Recovery of coral cover has been recorded in offshore reefs, but inshore reefs remain in poor condition (Section 2.4.4).[190] The threats to the values of the Reef (Chapter 9) do not operate in isolation. Cumulative impacts result from the interaction of effects from one or more threats as well as past, present and reasonably foreseeable future influences.

The second element of integrity, the human element, includes the management and domestic policies for protection of the property. An effective protection and management system is essential to conserve the Reef for present and future generations.[1096] An independent assessment of management effectiveness is included in Chapter 7. It found the Region generally continues to be well managed. However, since 2019, declines have occurred in the effectiveness of some aspects of the tools currently used to manage the external factors influencing the Region's values (Chapter 6). Particularly in terms of achieving outcomes related to the protection of Reef values and reduction of threats to these values.



Climate change remains the most pervasive and persistent threat to the Reef's integrity

Climate change remains the single most pervasive and persistent influencing factor impacting the values of the Region. While the effectiveness of managing climate change has increased since 2019 (Chapter 7), it remains partially effective. Overall, the Reef has a complex governance system that was established when there was very limited understanding of the impacts of climate change on the Reef. The governance system may not be agile enough to adapt to rapidly evolving climate change impacts. Research science on climate adaptation supports the implementation of contemporary Reef management.[1097] The frequency of testing and deploying proactive interventions in the Reef has increased, and a large research and development program is underway to explore other novel solution (Section 5.6.1). Since 2019, novel partnerships have increased between local tourism operators, managers, and researchers applying resilience-based and adaptive management. More scientific analysis is required to measure the success, feasibility and scalability of interventions.[1078,1099] Globally, these types of projects have been hindered by limited scalability and cost-efficiency.[1078]

The integrity of the world heritage property continues to be good but borderline poor. However, without additional national and global action on the greatest threats to the Reef through this critical decade and beyond,[182,1100] the protective capacity of size as a buffer will continue to be eroded by persistent and broadscale impacts on the Region and adjacent areas. The effectiveness of local and regional scale management actions is ultimately affected by the success of actions to address external influencing factors (for example, climate change).

4.3 Current condition and trends — Indigenous heritage values

Indigenous heritage is living heritage which First Nations people continue to practice, providing meaning to everyday life and contributing to the ongoing wellbeing of communities.[2,1101] Traditional Owners view Indigenous heritage as everything in Sea Country. This includes physical (tangible) and non-physical (intangible) expressions of Traditional Owners' relationships with Country, people, beliefs, knowledge, law, language, symbols, ways of living, sea, land and objects; all of which arise from Indigenous spirituality, including heritage places (sites) and values.[1102] Indigenous heritage values are also recognised nationally as a standalone heritage domain (Section 4.1).[1062]

Indigenous heritage is living heritage that contributes to the wellbeing of communities

Under the *Strong Peoples — Strong Country Framework*, connections between Country, people, and culture are reflected in six strongly connected 'hubs' that show how the health and condition of the Reef is connected to quality of life (Figure 4.2).[1103] The framework



Figure 4.2 **Strong Peoples — Strong Country**

The *Strong Peoples — Strong Country Framework* [1103] identifies six key hubs relevant to Strong Peoples — Strong Country: country health; people's health; heritage and knowledge; culture and community; education; and empowerment and economics. Source: Artwork for Strong Peoples — Strong Country: © Luke Mallie 2018, Mallie Designs. Licensed for use by Reef 2050 Integrated Monitoring and Reporting Program partners.

reflects the Traditional Owner worldview that quality of life is connected inseparably to and underpinned by their Land and Sea Country. In this way, the condition of nature is inseparable from the cultural identity of First Nations peoples. Therefore, the natural heritage values assessed in Chapters 2 and 3 are fundamental to the condition of the Region's Indigenous heritage values and Traditional Owners' connection to Land and Sea Country. Similarly, many threats affect Indigenous heritage values through their impact on natural heritage values (Chapter 9). For example, climate change related threats, poor water quality from runoff, coastal development, crown of thorns starfish outbreaks and direct use affect Indigenous heritage values.[1102]

In 2021, a survey of approximately 2490 residents living near the Region identified that people value the Reef because of its rich Traditional Owner heritage.[1075] More generally, people value the Reef because it provides a place where people can continue to pass down wisdom, traditions and a way of life.[1075]

In the Outlook Report, information on Indigenous heritage values is assessed under four discrete components.

- cultural practices, observances, customs and lore
- sacred sites, sites of particular significance and places important for cultural tradition
- stories, songlines, totems and languages
- Indigenous structures, technology, tools and archaeology.

These are considered in addition to natural heritage values assessed in Chapters 2 and 3. In reality, these components are interconnected, and the description of each value should be viewed in this context (Figure 4.3).

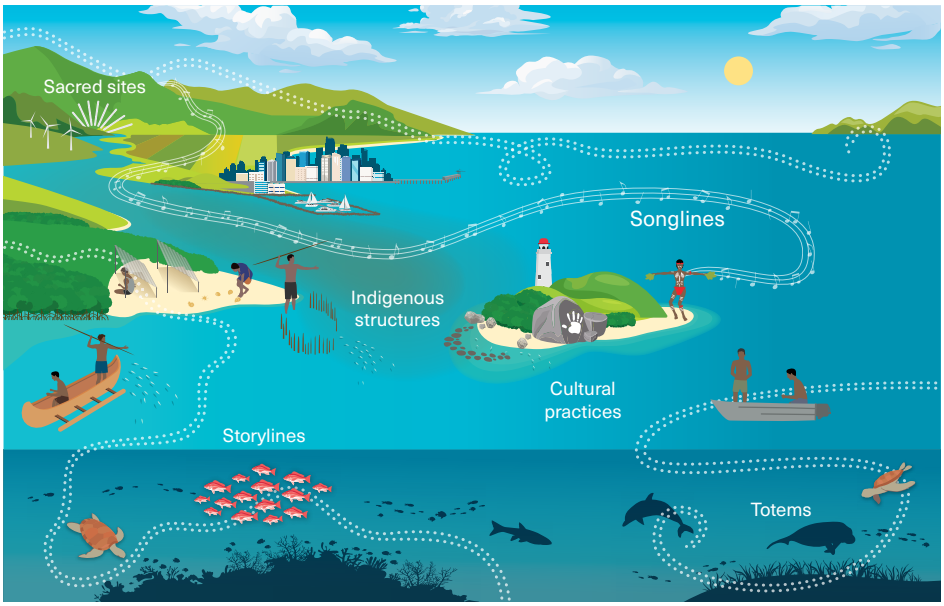


Figure 4.3 **Nature is inseparable from Indigenous cultural identity**
Songlines, stories, cultural practices, significant places, totems, structures and other elements of tangible and intangible Indigenous heritage weave people and the natural world together.

The Outlook Report assesses some, but not all, attributes of Indigenous heritage identified in the *Strong Peoples — Strong Country Framework* (Table 4.2). The framework was developed to help monitor Indigenous heritage values and was designed in a Traditional Owner led process for the Reef 2050 Integrated Monitoring and Reporting Program. It aims to measure progress in achieving Traditional Owner objectives and actions in the *Reef 2050 Long-Term Sustainability Plan,* and the *Aboriginal and Torres Strait Islander*

Heritage Strategy for the Great Barrier Reef Marine Park.[1104] A small number of Traditional Owner groups along the Reef coastline are currently piloting the implementation of the framework and therefore data is not yet available for many attributes of the framework.

Table 4.2 **Attributes of the *Strong Peoples — Strong Country Framework* mapped to the criteria and components considered in the Outlook Report**

Strong Peoples — Strong Country Framework		Great Barrier Reef Outlook Report	
	Attributes	Related Criteria or Components	Chapter
Country health	Healthy animals Healthy coral Other habitats	Species and populations of species Corals Coral reef habitats Habitats to support species	2
	Clean salt water Clean fresh water	Ecosystem health — Chapter 3 Land-based runoff — *Section 6.5*	3 6
	Being on Country "You to Country" health	Not assessed in Outlook Report	
People's health	Access to traditional medicine Access to traditional foods	Sacred sites, sites of particular significance and places important for cultural tradition — *Section 4.3.2*	4
	Spirituality	Cultural practices, observances, customs and lore — *Section 4.3.1*	
	Social and emotional wellbeing Cultural wellbeing	Not assessed but some attributes considered in social aesthetic heritage values — *Section 4.5.1*	4
	Access to medical services Know your mob	Not assessed	
Empowerment and economics	Traditional Owner-led caring for Country Greater level of management Ownership Better policy Employment on Country More Traditional Owner-led businesses Equity in opportunities Learning from Elders Rights, interests, and goals Career opportunities and pathways Better roads, internet, and buildings	Not assessed but some attributes considered in evaluation of existing protection and management measures — *Section 7.3.13*	7
Education	Learning from Elders Career opportunity pathways Training Passion to learn Two-way learning	Not assessed in the Outlook Report	
Culture and community	Language Arts, song and dance Kinship, family, totems	Stories, songlines, totems and languages — *Section 4.3.3*	4
	Lore and ceremony	Cultural practices, observances, customs and lore — *Section 4.3.1*	4
	Tool making, hunting and gathering	Indigenous structures, technology, tools and archaeology — *Section 4.3.4*	4
	Traditional Owner voices at all levels Involvement and ownership of community activities Local mentorships Cultural authority	Not assessed but some attributes considered in evaluation of existing protection and management measures — *Section 7.3.13*	7

Strong Peoples — Strong Country Framework		Great Barrier Reef Outlook Report	
	Attributes	Related Criteria or Components	Chapter
Heritage and Knowledge	Oral history	Stories, songlines, totems and languages — *Section 4.3.3* Cultural practices, observances, customs and lore — *Section 4.3.1*	4
	Western science	Indigenous structures, technology, tools and archaeology — *Section 4.3.4*	4
	Knowledge of culture and heritage Managing knowledge and heritage Protecting knowledge and heritage Access to heritage sites Traditional Owner knowledge transfer	Not assessed but some attributes considered in evaluation of existing protection and management measures — *Section 7.3.13*	7

4.3.1 Cultural practices, observances, customs and lore

Cultural practices, observances, customs and lore are aspects of Indigenous heritage values that are passed down from generation to generation. Cultural practices place a critical role in the identity of First Nations peoples and helps maintain their connections to their Land and Sea Country, ancestors and way of life. This component includes skills, folklore, rituals, spirituality and intellectual traditions. Approximately 20,000 years ago, the sea level around the Australian coast was around 120 metres lower than present.[608 1105] Traditional lands would have extended out to the continental shelf; these areas are now underwater.[15]

Cultural practices, observances, customs and lore is largely intangible and can be difficult to record. Some Great Barrier Reef Traditional Owner groups manage databases and records of these values. For example, Mandubarra Traditional Owners have compiled their own internal, restricted-access cultural heritage database to record site-specific traditional knowledge, which is directly managed by Mandubarra Aboriginal Land and Sea Inc. (Section 8.5.2). Some values have been recorded in Sea Country values mapping.[76]



Traditional Owners maintain connections to their Country, ancestors and way of life

One of the greatest threats to this type of Indigenous heritage is loss of Indigenous knowledge if Elders and knowledge holders pass away or if knowledge transfer does not occur. This issue was exacerbated by limitations on gatherings and intergenerational interactions during the COVID-19 pandemic,[1106] despite generally successful community-led responses that ensured good direct health outcomes.[1107,1108] The pandemic had indirect effects on the mental health and wellbeing of First Nations peoples, amplifying pre-existing disparities and stressors.[1106,1109] Cultural practices are also being affected by the impacts of climate change, for example changes in the location and seasonal availability of traditional foods leading to a loss of cooking practices.[1110]

Other contributing threats include difficulties Traditional Owners face in exercising their cultural and customary rights and responsibilities. For example, if access to an area important for cultural observance is blocked (by infrastructure) or reduced (through increased or possibly conflicting use and visitation by other users) it affects the ability for transfer of that knowledge to younger generations. Overall, it is assumed that cultural practices, observances, customs, and lore are being maintained across the Region.



Access to Sea Country is important, including for Indigenous rangers © Mandubarra Aboriginal Land and Sea Incorporated

4.3.2 Sacred sites, sites of particular significance and places important for cultural tradition

Sacred sites, sites of particular significance and places of cultural tradition are tangible aspects of the Region's Indigenous heritage values. Knowledge of the locations of sacred sites is not widely shared outside of Traditional Owner groups to respect cultural traditions and protect the sites. Some groups are progressing formal Sea Country values mapping for their Country, in collaboration with managers.[76,78] These projects provide a Traditional Owner-led approach to identify, prioritise and protect cultural heritage values, including culturally important sites (Section 8.5.2). Sacred sites can include story places where ancient spirits lived. Marbaymba is a story place near Rattlesnake Point in Jalunji-Warra Sea Country where the rainbow serpent lives, access is restricted under the *Nature Conservation Act 1992* (Qld).[1111,1112] Other culturally significant sites include burial sites, scar trees, midden sites, camp sites, shelter huts, stone artefacts, as well as places of significance during and post colonisation.[76,78]

Sea Country values mapping projects can help protect cultural heritage values

Middens are key sites of importance to First Nations peoples and have archaeological significance.[120,1113,1114] They are often material remains of historically important communal food preparation areas, burials and toolmaking areas. Sacred sites, sites of particular significance and places important for cultural tradition are more vulnerable to direct human pressure if near development or intensive use areas. Damage to cultural sites (whether intentional, unintentional or by illegal activities), can result in the loss of irreplaceable tangible heritage and can have intangible implications, such as inability to undertake cultural practices. For example, fishing and collecting cultural practices are affected if fish trap rocks are moved and the trap is no longer functional. Other examples include cutting down or defacing scar trees and the inscription of graffiti onto petroglyph panels. Sea level rise may cause flooding or erosion of culturally significant sites such as middens and burial sites.[1110]

Cultural identity and knowledge systems have been influenced by the movement of goods and people across porous boundaries for millennia, contributing to the complex and multilayered relationships of Traditional Owners with their Sea Country. Many sites of cultural significance are nodes within traditional trade networks where people came together for cultural exchange and commerce.[1115] Recent research has expanded our knowledge of the network of maritime trade and cultural connections between the Reef's Traditional Owner groups and the peoples of Torres Strait, New Guinea, and the western Pacific,[1116,1117] an area known as the Coral Sea Cultural Interaction Sphere.[1118] Overall, sacred sites, sites of particular significance and places of cultural tradition are not well known outside of Traditional Owner groups.

4.3.3 Stories, songlines, totems and languages

Knowledge of the environment and an inherent responsibility of First Nations peoples to maintain all living species, places or objects is passed down through generations in stories, songlines, totems and languages.[1119] These values form part of the cultural knowledge held by Traditional Owners. Managing agencies, such as the Reef Authority, are working with Traditional Owners to ascertain whether it is desirable or appropriate to share knowledge for reporting and management purposes.[1120]

A songline is a track across the land, sky or sea following a journey of a Creation Ancestor.[1104] Songlines are recorded in Creation stories, songs, paintings and dance. A knowledgeable person is able to navigate across the land by repeating the words of the songs describing the location of landmarks, waterholes, and other natural phenomena. First Nations people could navigate vast distances by singing the songs in the appropriate sequence. Songlines that bind land and sea country together can also provide information about the history of an area. For example, the Gunggandji language name for Fitzroy Island is Gulnyjarubay, which means 'fist', and indicates that what used to be the 'wrist' and 'arm' of a once big mountain on previous coastal plains had been submerged by the rising sea.[1121]



A songline is a track following a journey of a Creation Ancestor

The inherent location-based importance of stories, songlines, totems and languages, which can span land and sea, means other uses and pressures on an area can break, damage or displace these values.[338] Because rising sea levels and other disruptive natural phenomena could threaten communal survival, First Nations peoples have placed a high value on codifying memories of such events and collective responses to them.[1122] Ancient stories survived relatively intact over many generations because they effectively communicated vital information.[1122,1123,1124]

A totem is a natural object, plant or animal that is inherited by individual members of a clan or family as their spiritual emblem. Totems are an important part of the cultural identity of First Nations peoples and can be incorporated in song, dance, music, and tools.[1102] Totems are central to the way that Traditional Owners care for Country by putting people in direct custodial relationship with a species.[1125] Totems define the roles and responsibilities of people and their relationships — with each other, to creation and the landscape of their Country. First Nations people have a responsibility to play an active role in managing their totem physically and spiritually, such as by reducing impacts and protecting its condition, and conducting ceremonies. For example, the Badjgal (green sea turtle) is an important totem of the Mandubarra peoples and activities that impact this species would be of concern to the Mandubarra peoples.[76] Mandubarra people are managing their Country and their totems through a Traditional Use of Marine Resources Agreement.

Across the Region, managers (and western scientists) do not have a comprehensive understanding of which plant or animal species are important totems to Traditional Owner groups. Through knowledge sharing, where culturally appropriate, Traditional Owners and others can work collaboratively towards the sustainable management of totem species. Overall, recorded knowledge is lacking and the condition of this component is inferred as poor.

4.3.4 Indigenous structures, technology, tools and archaeology

First Nations peoples have diverse knowledge, language and social systems that have fostered technologies and culture for more than 50,000 years.[1126,1127] Many of these tools and technologies remain an important part of the living heritage of First Nations peoples and continue to be used today.

At the end of the last ice age, significant changes in sea level placed many older cultural sites below current sea levels. Now submerged archaeological records represent human occupation of the continent until 7000 years before present, but this record remains largely undiscovered.[15,1128]



Scientist working with Traditional Owners of Jiigurru (Lizard Island). © Sean Ulm 2022

Evidence of the capacity to plan and make open-sea voyages lasting several days has been shown to have been possible at least 50,000 years ago.[1129] This capacity also extended to the use of visually prominent landscape features for navigation and an ability to locate freshwater to maximise survival in new lands, including the Region.[1130] Through ancient maritime networks, northeast Australian First Nations communities were intimately engaged with peoples, knowledges, and technologies across the Coral Sea region.[1117,1131]

Scientific technology, including radiocarbon dating, provides insights as to the age of recently uncovered artefacts.[1132] For example, pottery sherds uncovered on Lizard Island (Jiigurru) are the oldest securely dated ceramics found in Australia (Box 4.1).[1117] Likely manufactured on the island, they reveal an ongoing connection with Melanesian peoples of the Torres Strait and New Guinea for at least 2000 to 3000 years.[1117,1126] A variety of locally sourced and manufactured quartz artefacts have also been found on the island.[75] Periodic yet sustained exploitation of marine resources on Jiigurru (Lizard Island) appears to have occurred over at least the past 5790 years.[75,1113,1117] Evidence also suggests the knowledge of food plant cultivation in Torres Straits may have extended into northern Australia.[1133]

BOX 4.1

Jiigurru and new ways of working

Working with Traditional Owners, western scientists have studied changes in the ancient environment and human history of Jiigurru (Lizard Island) over decades. This is a unique collaboration between the Dingaal Traditional Owners of Jiigurru, and a consortium of experts from Australian universities and research organisations. The collaboration has been an ongoing opportunity to nurture and empower cultural recognition of the Traditional Owners, in community and to the broader Australian community.

"We've been learning a lot about western science and they have been learning and adapting to our ways too," says Gareth Deeral (Jiigurru Traditional Owner).

There are many middens (sometimes very large campsites of food and settlement remains such as marine shells and bones for fish and turtle) on Jiigurru, that were built up over thousands of years. They tell rich stories of 'thousands of ancient feasts.'

They are stories of *"peoples who traded technologies and lore, creating song lines and connections across the seas,"* says Professor Ian McNiven, an anthropological archaeologist at Monash University.

The pottery sherds found on Jiigurru are highly symbolic and show the influence that may have been brought in from neighbouring communities and countries. It highlights the movement of people, goods and ideas across the Coral Sea at least 2000 to 3000 years ago, and that ancient Australia was not closed to outside influences. However, the scientific analysis on the sherds reveals that they were made from local materials, which shows that the technologies were here, and that First Nations people made the sophisticated vessels.

"The influence may have come from somewhere else but those old views that 'anything sophisticated must have come from elsewhere' are still represented in discourse about Australia's First Nations peoples. There haven't been thousands of sherds found here so this might represent very restricted use in this area," Professor McNiven says.

A small sample can tell a big story. Whether it's a water sample, a fish bone fragment, a shell, or a rare pottery sherd, the scientific knowledge that emerges from these analyses can provide so much information about what Sea Country may have been like, how it may have changed. Synergy and connection between First Nations knowledge and stories and western scientific methodology signal a new way of working between cultures.

Gareth notes the partnership is a respectful and mutual one, with research lead, Professor Sean Ulm, anthropological archaeologist at James Cook University, meticulously following cultural protocols and custom, engaging with Traditional Owners and Elders to establish a respectful and deep two-way understanding.

Source: Caring for Sea Country — Traditional Owner Stories from the Great Barrier Reef [1]

Pottery sherds uncovered on Jiigurru are the oldest ceramics found in Australia

Boomerangs, originally considered by researchers to be solely a hunting tool are now considered to have a multifunctional role, including fighting, digging, making music, and retouching of lithic (stone) tools.[1134]

The integrity of coastal archaeological deposits is compromised by a history of changing sea levels, climate change, cyclones, storms, tsunamis and contemporary human impacts, which present complex challenges for the identification and conservation of these sites.[1127] Despite these challenges, research into coastal midden complexes in central Queensland has provided insights into the history of changing human use of the coastal landscapes and resources of this area.[120] Limited other archaeological work has been reported in the Region since 2019.

More than 179 fish traps and weirs have been documented across Queensland, with most in the Region comprising singular, arc-shaped rock enclosures typically located at points and estuaries.[1135] Stone arrangement complexes are frequently found on the Australian mainland and islands, such as the two kilometres of looping u-shaped stone structures and adjacent stone middens documented in the Narrows near Gladstone.[1136] These complexes are associated with ceremonial and ritual activities.[120,1137] In Far North Queensland, some stone arrangements have Melanesian, Torres Strait Islander and Aboriginal influences, indicating cultural connections beyond the Region.[1131,1137] Fish traps and other structures located within and adjacent to the Region may be affected by rising sea levels.[1110]

Although there have been some improvements since 2019, most cultural heritage places often lack mapping and robust site monitoring programs for impacts to these sites. Knowledge of early settlement and migrations resulting from sea-level changes has increased significantly since the Outlook Report 2019.

4.4 Current condition and trends — historic heritage values

Historic heritage values relate to the occupation and use of the Region since the arrival of Europeans and other migrants. Historic heritage is the tangible and intangible evidence about lightstations, lighthouses, wrecks, voyagers, associated artefacts and other places of significance that are not on the National Heritage List.[1138]

The assessment of the Region's historic heritage value does not include the heritage values on Queensland islands or parts of the Catchment (above low water mark). However, an exception is applied where values are critical to transmitting (sharing) knowledge about the condition (and trend in condition) of the Region's historic heritage value (for example, newly discovered shipwrecks in the intertidal zone). Sites of particular significance to First Nations' people's truth telling (for example, missions, the influence of First Nations people on managing Country, marine or coastal landscapes as sites of frontier violence in the colonial period) are components of Indigenous heritage values, and not included in this assessment.

All heritage artefacts undergo natural deterioration. For the purposes of this assessment, a declining trend in condition should be interpreted as deterioration being faster than expected. Generally, natural deterioration through usual processes is considered stable.[12]

4.4.1 Commonwealth heritage value

Five properties in the Region are on the Commonwealth Heritage List: Low Island and Low Islets lightstation; the lightstations on Dent Island, Lady Elliot Island and North Reef (Figure 4.4); and the Shoalwater Bay Military Training Area. No new places in the Region have been added to the Commonwealth Heritage List since 2019.

The condition (and trend in condition) of Commonwealth heritage values are assessed against the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act) criteria (processes, rarity, research, characteristic value, aesthetic characteristics, technical achievement, and Indigenous tradition). Not all places are included for all criteria; only the relevant places are assessed (and noted) against each criterion.



Commonwealth Heritage listed lighthouse at North Reef Island. © Commonwealth of Australia (Reef Authority). Photographer: Alicia Moisel 2024

Since 2019, annual inspections of the Region's historic heritage values were completed on all three Commonwealth islands.[38,72,1067,1139] The management strategy for Commonwealth heritage listed places and properties was updated in 2022, as a requirement under the EPBC Act.[1140] An independent assessment of management effectiveness for the Region's historic heritage value is discussed in Chapter 7.

Historic heritage values were inspected annually on all three Commonwealth islands

Low Island and Low Islets lightstation: The lightstation on Low Island is about 15 kilometres north-east of Port Douglas. As well as the lightstation structures, the island is included on the Commonwealth Heritage List because of its significance to the Kuku Yalanji and Yirrganydji Traditional Owner groups as part of their Dreamings. No new evidence is available regarding the condition of the island's Indigenous heritage values.[1141] The current condition of the lightstation has been monitored by managers through an annual monitoring and maintenance program. Between 2021 and 2023, infrastructure works were completed on the residence on Low Island (of the former assistant lighthouse keeper) [1067] and exterior works on the 'boat shed' and historic diesel fuel tank. In 2022,

temporary works protected the historic gravesite that became vulnerable to the significant threat of erosion. Works to relocate the gravesite commenced in late 2023. Managers continue to prepare the first management plan for the listed place required under the EPBC Act. Published long-term condition data remains a gap.

Dent Island lightstation is located on Dent Island in the Whitsundays. The **Lady Elliot Island lightstation** is located on Lady Elliot Island, 75 kilometres north-east of Bundaberg. Managers are confident the condition of the historic heritage value of these place's remain good and improving, but published data are limited. The management plan for the Dent Island heritage place is under review, with publication delayed until later in 2024.[1141]

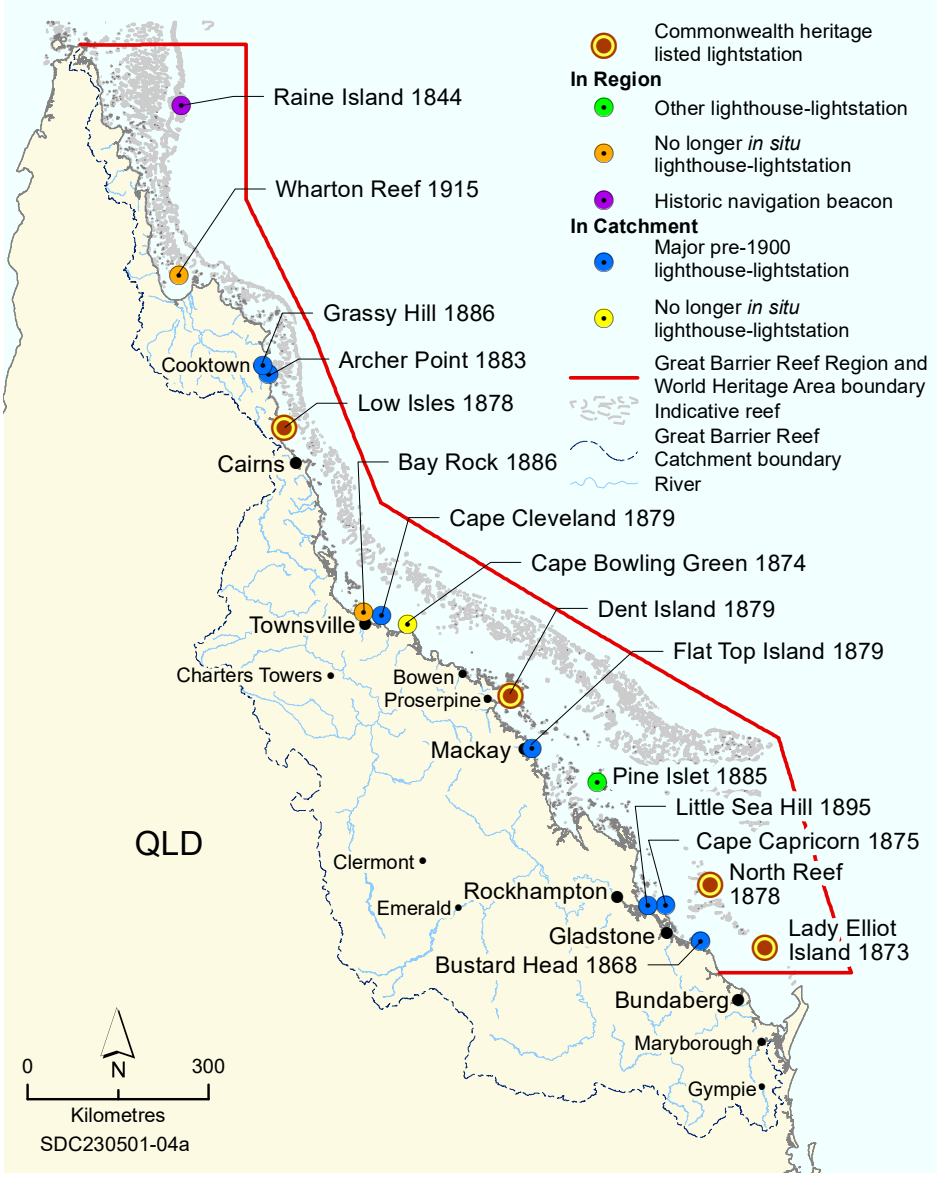


Figure 4.4 **Historic lightstations and lighthouses in the World Heritage Area**

The historic lightstations and lighthouses in the World Heritage Area demonstrate a phase in the evolution of maritime travel through the treacherous waters of the Great Barrier Reef. Few lighthouses remain *in situ* in the Region; many have been relocated to the mainland for the preservation and display. This figure identifies a portion of the known places in the Catchment that are related to maritime navigation. Source: Adapted from the Australian Department of Climate Change, Energy, the Environment and Water (2023),[1143] the Queensland Department of Environment, Science and Innovation[1144,2023] and Lighthouses of Australia (2023).[1145]

BOX 4.2

Historical aid to navigation

Raine Island, a Queensland island outside the Region, is close to the northern tip of the Reef. In 1844, convict stonemasons constructed a beacon as an aid to navigation on the island for ships journeying between Australia and Asia through the Torres Strait. The significance of this place to the Region is through its connection to voyages through the Region (Section 4.4.3) and the shared natural heritage and Indigenous values of the land and sea (Sections 4.2 and 4.3). The Raine Island Beacon was listed on the Australian Heritage Database in 1982 and the Queensland Heritage Register in 1992.[1143,1144] The Raine Island Beacon is one of the oldest colonial stone buildings in Queensland. More than 900 legible inscriptions have been carved or painted inside the beacon, providing an important record of human movement and activity in the area. While many inscriptions are from the crews of British Admiralty and other European vessels, many are also Wuthathi, Erubam, Meriam and Ugaram Le names, and represent significant shared heritage value.[38] In 2019, the condition of the maritime and mining heritage value was noted of 'significant concern' with a declining trend.[38,1148] The beacon required urgent work to maintain its structural integrity.[38,1148,1149] In 2022, extensive restoration works commenced but the COVID-19 pandemic hindered progress. The work was done under the careful supervision of Meriam Nation and Wuthathi cultural advisors to maintain the cultural integrity of the site.



Raine Island Beacon Restoration Works © Queensland Government 2022, 2023

North Reef lightstation: North Reef is located about 77 kilometres north-east of Curtis Island off Gladstone. This lightstation is managed and maintained by the Australian Maritime Safety Authority (AMSA) as an operational aid for navigation. In 2022, the ground floor of the North Reef tower was refurbished and the structure was repainted.[1142] The AMSA North Reef Lightstation Heritage Management Plan, as required under the EPBC Act, is currently under review with publication anticipated in late 2024. As management plans do not report on condition, published long-term condition data remains a data gap.

Shoalwater Bay Military Training Area: This Commonwealth heritage place reflects the boundaries and values of the Shoalwater and Corio Bays Area Ramsar wetland and the military training area owned by the Australian Department of Defence. The place spans marine and terrestrial ecosystems and is partly within the Region. While condition data for the heritage place is not published, the Department of Defence maintains a presence in the Region throughout the year, conducting ongoing environmental management and monitoring activities. The biennial Talisman Sabre military exercises (Section 5.3)

also generate unpublished condition data. The assessment of the value relies on the assessment of the Region's biodiversity in Chapter 2.

Shoalwater Bay is an important habitat for several iconic marine species of conservation interest, including humpback whales, dugongs, and green, hawksbill and loggerhead marine turtles. The condition (and trends in condition) of these species vary. For instance, the east coast humpback whale subpopulation continues to increase (Sections 2.4.14 and 8.3.7), whereas southern dugong populations are experiencing long-term decline (Sections 2.4.16 and 8.3.6). Seagrass meadows and seagrass are associated habitat of these marine species. In 2022–23, seagrass abundance in Shoalwater Bay declined to its lowest levels in 8 years.[149] This decline is linked to regional water quality conditions (Sections 2.3.4 and 2.4.2).[149] The seagrass abundance score decreased in 2021–22 to the lowest level on record, reaching very poor for the first time in the Fitzroy region, then recovering slightly to poor in 2022–23.[149]

4.4.2 Other historic lightstations and lighthouses

Lighthouses and aids to navigation, both historic and modern replacements, are scattered throughout the World Heritage Area, including Queensland islands. For the purposes of this assessment, only historic heritage values located on a Commonwealth island, reef or cay are assessed. Condition reporting on the historical significance of aids to navigation, floating and temporary lights, light ships and other related infrastructure in the Region is a data gap.[12]



Restoration of the Pine Islet lighthouse is being planned

Pine Islet lightstation was located on Pine Islet, a small rocky island east of Sarina in the Percy Isles. The lighthouse was relocated in 1995 and the Pine Islet site remains dilapidated.[72] A local stewardship restoration project of the lighthouse in the Mackay marina is being planned; information on its current condition is a data gap.[1146 1147]

Lightstations and lighthouses outside the Region are well documented. In contrast, a systematic record of historic places in the Region, and places in the Catchment related to the historic heritage of the Region, is not available. Figure 4.4 therefore identifies only a portion of the historic lightstations, lighthouses and other historic places in the World Heritage Area.

4.4.3 Historic voyages and shipwrecks

In the Region, historic shipwrecks and their associated artefacts older than 75 years, or those declared to be historic, are protected under the *Underwater Cultural Heritage Act 2018* (Cth) regardless of whether their exact location is known. Protected zones have been declared around 6 historic shipwrecks in the Region: SS *Yongala*, HMS *Pandora*, SS *Gothenburg*, SS *Llewellyn*, HMCS *Mermaid* and the *Foam*. Since 2019, little new information about these wrecks has become available due to minimal inspections or site recordings. Because historic shipwrecks are in a dynamic marine environment and likely to be subjected to accelerated natural degradation and human activities, the condition of these values is assumed to be declining. The routes taken by historic voyages through the Region are also generally poorly known.[12]

In 2021, researchers analysed archived material from an unidentified shipwreck. Inspections recorded several decades ago located the material on Great Detached Reef (Reef 11–244[1150]), approximately 10 kilometres south of Raine Island. The study reinforced

the opinion that the material is from the *Aert van Nes*, which wrecked on the Great Barrier Reef in 1854. In the same area, numerous vessels were reported to have been lost during the same period which resulted in the building of the Raine Island Beacon (Box 4.2). The study did not rule out the possibility of two separate wrecks in the same location.[1151]

Archaeologists believe a Detached Reefs shipwreck to be the *Aert van Nes*

Experts are concerned that ongoing changes in the management regime of underwater archaeology gives rise to deficiencies in condition data.[1152] Further change in management may also follow if the international UNESCO Convention on the Protection of the Underwater Cultural Heritage (2001) is ratified by the Australian Government.[1153] An independent assessment of the effectiveness of management of the Region's historic heritage (including underwater archaeology) is included in Chapter 7.



City of Adelaide shipwreck on Magnetic Island. © Nick O'Carroll 2024

4.4.4 World War II features and sites

World War II features and sites in the Region include aircraft wrecks (located underwater, on Commonwealth islands, or in intertidal areas), as well as forts and structures on Commonwealth islands.[1154] As with historic shipwrecks, aircraft wrecks and their associated artefacts older than 75 years, or those declared to be historic, are protected regardless of whether their exact location is known. Most World War II features and sites are on the mainland or on Queensland islands outside the Region.

All World War II aircraft wrecks are protected

Limited progress has been made since the Outlook Report 2019 in systematically recording the majority of World War II features, sites and associated artefacts. For this reason, the condition (and trend in condition) of this historic heritage value must be inferred. Information is lacking around the condition of physical and social dimensions of sites, such as jetties for loading and unloading, convalescence facilities or hospital ships moving through the Region, sites or artefacts associated with other wars, and other types of defence heritage in the Region.[12]

4.4.5 Other places of historic significance

Other places of historic significance in the Region include tangible components, such as structures, ruins or wrecks. Intangible historical components are also significant to the Region's heritage values, such as: sites of significance to Kanaka labour, historical aspects of the Reef as a world-class tourism destination, or the history of scuba diving on the Reef.[12]

Reef names honouring prominent people document their connections to the Reef

Reef names and the associated stories honouring prominent people connected to the Reef also provide an important record of the individual's historic significance. For example, in 2019 the name Joe Baker Reef (20–374) was assigned. Its namesake was a marine sustainability advocate who was instrumental in achieving the World Heritage listing for the Great Barrier Reef in 1981, among other visionary work. In 2023, an unnamed reef in the Preservation Zone near Raine Island was named Kenchington Reef (11–091) in recognition of the late Professor Richard Kenchington. Professor Kenchington was one of the first staff appointments to the Great Barrier Reef Marine Park Authority in 1977 and was foundational in developing the zoning system for the Reef. A reef in the 'pink' zone was specifically chosen as it encompasses many key aspects of the system he championed.[1155]



Maritime archaeologist inspects artefacts on an unidentified shipwreck in the far northern Great Barrier Reef. © Matt Curnock 2021

4.5 Current condition and trends — other heritage values

Heritage values include a place's natural and cultural environment having aesthetic, historic, scientific or social significance, or other significance, for current and future generations of Australians. Therefore, as well as a component being a natural, Indigenous or historic heritage value, a place may also have 'other' heritage value — social, aesthetic or scientific attributes.

4.5.1 Social heritage values

Social heritage values are defined as a collective attachment to place that embodies meanings and values that are important to a community or communities".[1156] Australians report the Great Barrier Reef as a national icon with which they personally identify and are proud of its world heritage status.[1075]

The social heritage values of the Great Barrier Reef are affected by the condition of the Reef's ecosystem values, by changes to general social conditions and changes to social conditions specific to interactions with the Reef. Since 2019, the two largest changes to general social conditions affecting the social heritage values have been a rising global sense of urgency for climate action and the COVID-19 pandemic. The *Sixth Intergovernmental Panel on Climate Change Report*, released in 2023 included clear warnings on the anticipated risks of global warming without immediate action, and issued an urgent call to action.[1157] These two factors have caused broad and specific changes in the Reef's social heritage values.



The Region's beautiful places foster wellbeing, Hideaway Bay. © Rohana Rogan-Darvill 2021

The Social and Economic Long-Term Monitoring Program (SELTMP) is a key source of information for changes in the Reef's social heritage values that relate to people's perceptions and attitudes. This program collects primary data using survey methods focused on a subset of Great Barrier Reef human dimension indicators relating to social, economic, cultural and governance aspects of the Reef.[1075]

A healthy Reef provides benefits to people and communities and fosters wellbeing

The social heritage values of the Reef constitute aspects of the wellbeing of local, regional, state, national and international communities. A healthy Great Barrier Reef provides material and non-material benefits to people which result in wellbeing outcomes. These benefits accrue to people that interact with the Reef, through livelihoods, relaxation and enjoyment and, in turn, influence mental and physical health and prosperity. These benefits also affect people remotely: from the Reef's prominence in the Australian national identity and further afield to the intrinsic value of the existence of the Reef as a world heritage treasure for humanity. These material and non-material benefits are part of an individual's life satisfaction, relevant across the wellbeing indicators. Community relationships with a healthy Reef have consequential and cumulative impacts, which are difficult to quantify. The flipside of strong place attachment and wellbeing attributed to connection to the Reef emerges as 'ecological grief', expressed when the Reef's health declines. [1075,1158,1159]



Bleached reef (detail). Ghostnet Collective 2024 © Marion Gaemers. Made from ghost net and beach found rope. Image © Marion Gaemers 2024

The assessment of the Region's social heritage values considers: access; aesthetics; appreciation, understanding and enjoyment; human health; personal connection; equity; empowerment; employment and income (Figure 4.5).[1160]



Figure 4.5 **Values of importance to human wellbeing**
Values of importance to assessing the social heritage of the Region are intrinsically linked to human wellbeing. Source: Great Barrier Reef Marine Park Authority (2017)[1160]

Access refers to people's ability to enter and use the Reef and its resources in the past, present and future. Accessing and interacting with nature improves physical and mental health and general wellbeing.[1075] The COVID-19 pandemic affected people's access to the Reef and the impacts varied depending on a person's residential proximity to the Reef and different state regulations. The restrictions on movement made access easier for people that live near the Reef and proportionately more difficult for those living further away and unable to travel. All international travel to Australia, and therefore the Reef, was suspended from March 2020 until February 2022; and resumed with a range of restrictions. During this time, there was a diversion of people away from centralised workplaces and large population centres to regional areas, with the largest internal migration to Queensland (Section 6.2.2).[1161]

In 2021, more than two thirds of surveyed Catchment residents do not see access to the Reef as a problem.[1075] The majority of respondents (83 per cent) reported visiting the Reef at least once in their lifetime and half had visited within the preceding 12-month period. Catchment residents predominantly access inshore areas of the Reef, estuaries and waterways.[1075] In general, people continue to enjoy good access and continue to visit the Reef.

The **aesthetic heritage** values important to wellbeing are discussed in Section 4.5.2.

Understanding the ecology of the Reef and people's relationships to it has implications for personal connection, empowerment, and stewardship.[1160] Some Social and Economic Long-Term Monitoring Program results suggest a medium knowledge of the Reef. This value also considers people's perceptions about Reef management and scientific knowledge. Another indicator of understanding is people's perceptions of the health of the Reef, threats, and threat severity, including climate change (Section 9.3).[1162] Residents' perceptions about management of the Reef vary widely. The overall average suggests dissatisfaction with how the Reef is managed, encompassing responses ranging from very positive views to the very negative end of satisfaction with Reef management. Slightly more than 50 per cent of those surveyed felt there was a lack of opportunity to have a say how the Great Barrier Reef is managed, with 70 per cent reporting they did not feel they have any influence over how the Reef is managed.

The two most highly trusted sources of information about the Reef are scientists and the Great Barrier Reef Marine Park Authority;[1075] newspapers and social media were the least trusted information sources. The level of trust in scientists for information, while reported as high in 2021, has decreased since the 2017 survey but is still higher than in 2013. In 2021, trust in the Reef Authority as an information source was at similar levels to 2017.[1075]

Human health can be linked to visiting the Reef, which in turn, provides benefits to wellbeing. Most survey respondents who had visited the Reef in their lifetime reported that their visit had made them feel physically better. They reported both physiological and psychological benefits from the Reef, including helping them unwind and destress, feeling restored and relaxed, being alert and better able to concentrate.[1075]

People's feelings of strong **personal connection** to the Reef continues.[1075] In general, individuals who visit the Reef report a strong feeling that the Reef is part of their identity; a sentiment that has remained the same since 2017. Most Catchment residents (90 per cent of those surveyed) expressed pride that the Great Barrier Reef is a World Heritage Area and have a strong sense of belonging to where they live. Feelings of pride in the Reef were slightly lower in 2021 than in 2017. Residents place high value on the mere existence of the Great Barrier Reef and its biodiversity. Of respondents who had visited the Reef in the past 12 months, less than 14 per cent viewed the Reef as in poor or very poor health. People perceived coral and seagrass to be in poorer health than beaches and islands.

Equity relates to fairness in the distribution of benefits and impacts across the community. It is both intra- and intergenerational, meaning there are considerations for social equity within each generation, as well as between generations. Approximately three quarters of Catchment residents surveyed place a high value on the bequest value of the Great Barrier Reef (bequest meaning passing on benefits to the next generations).[1075]

Empowerment is the process that enables people and groups (such as businesses, community groups, individuals and Traditional Owners) to undertake actions and participate meaningfully in the protection and management of the Great Barrier Reef. Empowerment is interconnected with, and results from, a combination of the other social heritage values. A good indicator of empowerment is the ability to successfully engage in stewardship activities. In 2021, general stewardship sentiment towards the Reef is reported to be high, while actual knowledge and feelings of personal capacity to effect change are low.[1075,1163] Approximately 90 per cent of survey respondents reported engaging in simple best practices relevant to Reef health. People's understanding of the threats to the Reef, particularly climate change, has increased since the Outlook Report 2019, while feelings of empowerment to address these issues are low. In a national survey, approximately 75 per cent of respondents agreed that action should be taken to help the Reef and supported the use of large-scale restoration and adaptation technologies.[1162]

Employment and income potential of Catchment residents may be affected by Reef health. In 2021, respondents mostly did not feel that their employment prospects or financial situation would be negatively affected, or that they would choose to relocate out of the Region, if the health of the Reef declined. While respondents did not think a decline in the health of the Reef would make living in the Region undesirable, about half felt their lifestyle would be negatively affected (Section 6.2.1).

Enquiries into the human dimensions of the Reef have been notably extended since 2019. This additional evidence contributes to the social heritage values of the Region being in a good condition.

4.5.2 Aesthetic heritage values

Aesthetic heritage values refers to people's perceptions of the beauty of a site or object and is one of the criteria for which the Great Barrier Reef is inscribed on the World Heritage List (Section 4.2.1). While aesthetic heritage values are strongly influenced by visual appearance, all the senses play a role. Aesthetic values influence the way in which people value and enjoy the Reef.[1160]

Early European explorers helped shape their society's perceptions of the Reef through evolving awareness and appreciation — not only of its value as a sheltered route for shipping and source of economic opportunities, but also as a place of scientific interest and aesthetic splendour.[1164]



94 per cent of residents rate the Reef's aesthetic beauty as outstanding

In 2021, a survey of 2488 Catchment residents demonstrated that 94 per cent of respondents consider the aesthetic beauty of the Reef as outstanding.[1075] These results have remained stable since 2013. Residents within the Wet Tropics and Mackay Whitsunday regions rated the beauty of their region more highly than Townsville and Fitzroy residents.[1159] These surveys do not identify if the respondents are considering aesthetic beauty above or below water; or if they are based on visual or other sensory criteria. While residents rated the aesthetic beauty as outstanding, they were cognisant of the threats that the Reef faces (Section 9.3.1).

Since 2019, some progress has been made towards understanding the tangible elements of the Region's aesthetic heritage values. Several studies specific to the Great Barrier Reef have developed methods for measuring aesthetic values, including cross-cultural comparisons of aesthetic perceptions, using artificial intelligence and non-expert views for rating aesthetic value. However, these methods have not yet been applied systematically to measuring aspects of aesthetic value in the Region.[1165,1166,1167,1168]

Aesthetic beauty is linked to the condition of the Region's ecosystems. Community perceptions of specific habitats, areas or other aspects of the Reef's aesthetic beauty remain a knowledge gap. The perception of the aesthetic beauty of the Reef remains high, despite some declines.



A tranquil scene of mangroves submerged at high tide © Johnny Gaskell 2021

4.5.3 Scientific heritage values

Scientific heritage value is not well defined. However, in general terms it is a place's potential to yield information that will contribute to the scientific understanding of the place's natural history.[1169] When coupled with the meaning of heritage being 'our legacy from the past, what we live with today, and what we pass on to future generations',[1170] the scientific heritage value of the Reef encompasses human knowledge of the land and sea.

The history of the Great Barrier Reef dates back to the initiation of reef growth in the Region approximately 450,000 to 670,000 years ago.[1083,1171] Several active periods of reef growth occurred, with the bulk of the present-day Reef being laid down between 5500 and 8500 years ago.[884] Through the Reef's Indigenous history, knowledge is preserved



Historical photograph taken at Low Isles during the 1928–1929 Great Barrier Reef Expedition, led by Sir Charles Maurice Yonge. © Commonwealth of Australia (Reef Authority) 1928

in stories and songlines that have been passed down through generations (Section 4.3). Cultural memories recall periods of sea level change,[76] which are likely to date from at least 10,000 years ago.[1123] Traditional Owner knowledge of the land and sea, therefore, pre-dates accretion of the contemporary Reef. The long-term nature of various biological monitoring programs and oceanographic observation platforms within the Region add significant value to science by the data they provide.

The Reef's prominence through long-term studies and scientific literature is strong

Reef scientific heritage is preserved at the Queensland Museum in the form of coral archives, with the world's largest collection of field photographs, coral skeletons and vouchered tissue samples. The Coral Bank project is creating a curated genomic and taxonomic repository to inform understanding and conservation of the Great Barrier Reef.[1172] Improvements in scientific knowledge continue to advance through participation and training in field scientific surveys.[58] Less clear is whether there have been recent changes in the extent to which the living history of science on the Reef is being captured, catalogued and communicated.

In the twenty-first century, the marine science research and management community provides a measure of Australia's focus on transmitting the scientific heritage value of the Region to future generations. Scientific understandings learnt from the Great Barrier Reef also improves the scientific heritage value of the Region in terms of its benefit for other marine properties worldwide and assists their management. The Reef's prominence through long-term studies and scientific literature is strong. Between 2019 and late 2023, at least 680 scientific journal articles specific to the Great Barrier Reef have been published.[1173] The Reef's scientific heritage value is in good condition and has continued to improve.

4.6 Assessment summary — Heritage values

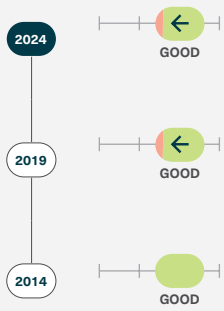
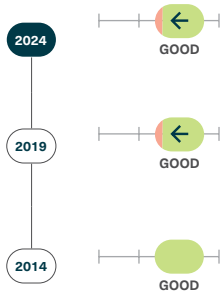
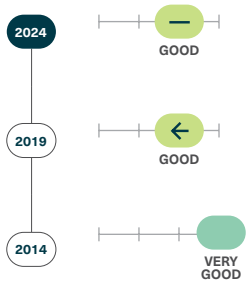
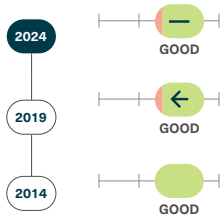
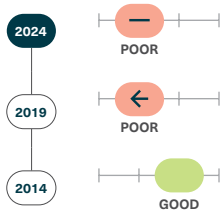
Section 176(3)(a) of the *Great Barrier Reef Marine Park Regulations 2019* (Cth) requires '... *an assessment of the current heritage values* ...' of the Great Barrier Reef Region.

The assessment of the Reef's heritage values has been considered against their inherent components and attributes, namely:

- natural heritage values — world heritage value and national heritage value
- Indigenous heritage values
- historic heritage values — Commonwealth heritage values and other historic heritage values
- other heritage values.

4.6.1 Natural heritage values — world heritage value and national heritage value

Grading statements — Natural heritage values		Trend since previous report	Confidence
	**Very Good:** All elements necessary to maintain the outstanding universal value are essentially intact and their overall condition is stable or improving. Available evidence indicates only minor, if any, disturbance to this element of outstanding universal value.	→ Improved — Stable ← Deteriorated ··· No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
	**Good:** Some loss or alteration of the elements necessary to maintain the outstanding universal value has occurred, but their overall condition is not causing persistent or substantial effects on this element of outstanding universal value.		
	**Poor:** Loss or alteration of many elements necessary to maintain outstanding universal value has occurred, which is leading to a significant reduction in this element of outstanding universal value.		
	**Very Poor:** Loss or alteration of most elements necessary to maintain the outstanding universal value has occurred, causing a major loss of outstanding universal value.		
	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

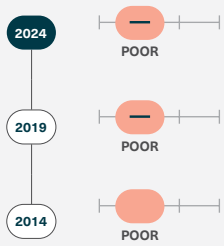
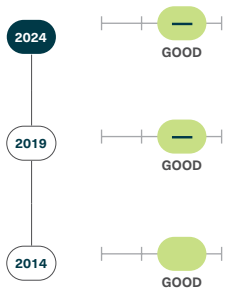
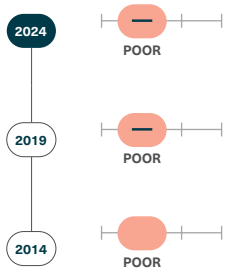
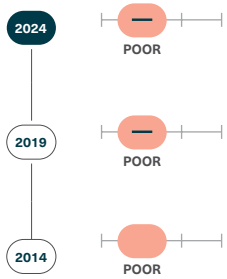
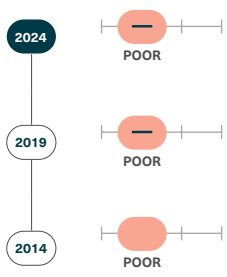
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Natural heritage values — world heritage value and national heritage value: The Reef's world heritage and national heritage value represents the outstanding universal value of the Region. Outstanding universal value remains; however, the grade is borderline with poor because the condition of the property has deteriorated to varying extents with respect to criteria vii, viii, ix and x. While the property remains whole and intact, ecosystem resilience is deteriorating and the property's size is becoming less effective as a buffer against these disturbances.			
Natural beauty and natural phenomena: Taken as a whole, the Region's natural beauty and natural phenomena endures. Iconic species, such as humpback whales, show signs of recovery but some land and seascapes have deteriorated. Some species and populations of marine turtles, southern regions of seagrass meadows, and potentially coral diversity in some locations have declined since 2019, resulting in the condition of this component being good borderline poor. Much of the evidence is inferred from the assessments in Chapters 2 and 3.			
Major stages of the Earth's evolutionary history: The modern Great Barrier Reef remains a rich geological repository for records of the Earth's recent evolutionary history. Understanding of this history has continued to advance since 2019. Over the coming century, the geomorphological resilience of coral reefs will be under increasing pressure due to rising sea temperatures and ocean acidification. Despite the broader trajectory toward degradation, key processes have remained stable since 2019.			
Ecological and biological processes: At a Region-wide scale, ecosystem processes continue to function, and many remain stable since 2019. Overall, the size and diversity of the property means many processes show no consistent trend (e.g. recruitment, predation, particle feeding).			
Habitats for conservation of biodiversity: While the condition of some values has shown improvement, others have declined since 2019. The size of the property continues to buffer the effects of human-induced climate change, but scale is not an infinite buffer to persistent broadscale impacts to the Region.			

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Integrity: While the property remains whole and intact, the condition of many elements that make up the four natural world heritage criteria continue to be a concern. Overall, the Reef's processes and habitats have remained stable, and aesthetics remain good and stable. However, some decline in safeguards has occurred related to how well aspects of some external factors influencing the Region (coastal development and land-based runoff) are managed. The effectiveness of managing for climate change has generally increased, albeit remaining partially effective.	2024 GOOD 2019 GOOD 2014 GOOD	LIMITED	LIMITED
Natural heritage values: This component has been absorbed into the assessment of the processes and habitats criteria.	2014 GOOD		

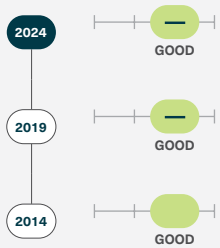
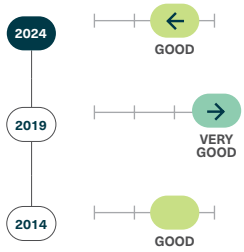
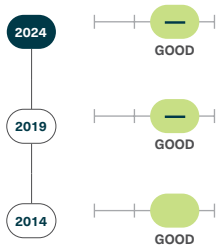
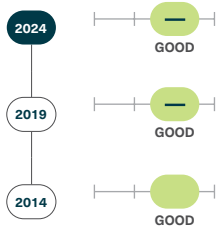
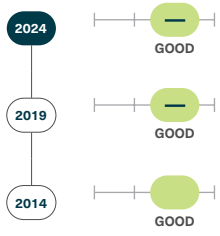
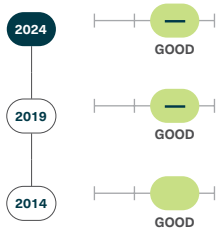
4.6.2 Indigenous heritage values

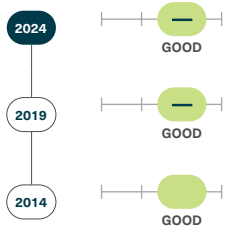
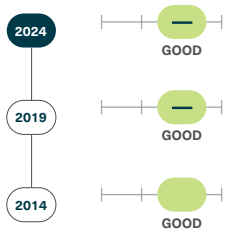
A series of statements apply to Indigenous, historic and other heritage values, standardising the allocation of grades for all components and attributes examined in the assessment, as well as the grade for the criterion.

Grading statements — Indigenous, historic and other heritage values		Trend since previous report	Confidence
VERY GOOD	**Very Good:** Heritage values have been systematically and comprehensively identified and included in relevant inventories or reserves. Known heritage values are well maintained and retain a high degree of integrity.	Improved Stable Deteriorated No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
GOOD	**Good:** Heritage values have been mostly identified and included in relevant inventories or reserves. Known heritage values are generally maintained and retain much of their integrity.		
POOR	**Poor:** Heritage values have not been systematically identified. Known heritage values are degrading and generally lack integrity.		
VERY POOR	**Very Poor:** Heritage values have not been identified. Known heritage values are degraded and lack integrity.		
OR	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

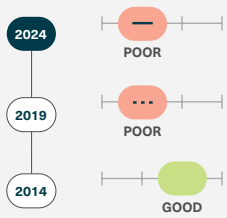
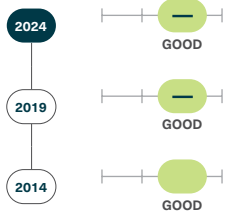
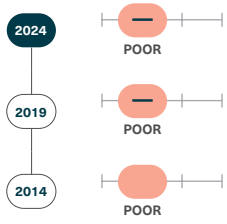
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Indigenous heritage values: First Nations peoples are increasingly reasserting their role in Sea Country management and the protection of Indigenous heritage across the Region. The condition and trend of Indigenous heritage values are tied closely to those of natural heritage values. Knowledge of condition remains limited.			
Cultural practices, observances, customs and lore: Loss of Indigenous knowledge is a threat to this component. The COVID-19 pandemic created challenges for intergenerational knowledge transfer, despite community-led responses resulting in positive direct health outcomes. It is assumed that cultural practices, observances, customs, and lore are being maintained across the Region, supported in part by improved collaborative management of Land and Sea Country.			
Sacred sites, sites of particular significance and places important for cultural tradition: The locations of sacred sites are not well known outside of Traditional Owner groups. Some groups are progressing Sea Country values mapping, but understanding and recognition of these important areas in management frameworks remains inadequate. Recent research has expanded our knowledge of the network of maritime trade and cultural connections between the Region and neighbouring societies.			
Stories, songlines, totems and languages: This component includes cornerstones of identity and modes of knowledge transfer passed down through many generations over thousands of years, highlighting the resilient living culture of First Nations people in the Region. Loss of Indigenous knowledge, including oral traditions held by Elders, and pressures that affect populations of totemic species or break connections across Land and Sea Country, all contribute to an inferred poor condition of this component.			
Indigenous structures, technology, tools and archaeology: Intensive study of a few isolated sites has increased knowledge for this component, offering key insights into cultural practices, traditional resource use, and historical developments (though over a very limited geographic area). The earlier archaeological record from when sea levels were lower and First Nations people inhabited what is now Sea Country, remains virtually unknown in the Region.			

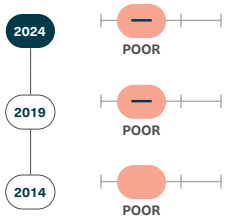
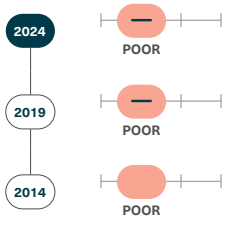
4.6.3 Historic heritage values — Commonwealth heritage values

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Commonwealth heritage values: The condition of the five places in the Region included on the Commonwealth Heritage List is considered good. Published evidence continues to be lacking.			
Processes: The five Commonwealth heritage places in the Region remain *in situ*. Managers infer each place retains a high degree of integrity. Published evidence of condition is lacking. In 2024, the inference is for good condition rather than the very good of 2019; similar information has been used in the assessment, but the conclusion is different.			
Rarity: Three places are listed for their rare attributes: Lady Elliot Island lightstations, North Reef lightstations and Shoalwater Bay Military Training Area. Condition and trend are inferred by managers; published data are not available. The condition of the identified threatened species in the Shoalwater Bay heritage place have continued to decline since 2019.			
Research: The Shoalwater Bay Military Training Area is listed for research attributes. Condition data are not published; condition and trend are inferred by managers.			
Characteristic value: The Dent Island and Lady Elliot Island lightstations undergo annual maintenance programs but published condition evidence remains a data gap. Hence, it is inferred they retain a high degree of integrity.			
Aesthetic characteristics: The aesthetic characteristics of the Lady Elliot Island lightstation remain in good condition following ongoing maintenance and management. Condition and trend data are not published.			

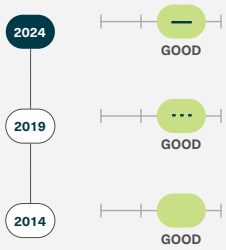
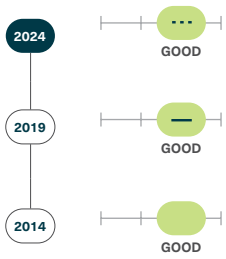
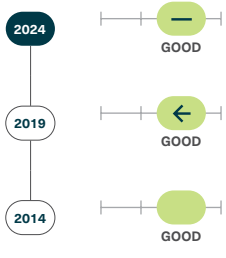
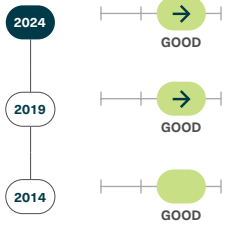
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Technical achievement: The technical attributes of the Lady Elliot Island and North Reef lightstations have not been modified. Condition data are not systematically published.			
Indigenous tradition: Low Island retains its importance as part of the Sea Country of the Kuku Yalanji and Yirrganydji Traditional Owner groups. No new published data are available; therefore, condition and trend are inferred.			

4.6.4 Historic heritage values — other

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Historic heritage values: Gaps in systematic identification and reporting remain for many historic heritage components in the Region. Condition and trend can only be inferred.			
Commonwealth lightstations: The condition of the four lightstations in the Region included on the Commonwealth Heritage List are inferred to be in good condition. Managers infer a stable trend; however, there is a lack of published evidence.			
Other historic lightstations and lighthouses: The site of the former Pine Islet lightstation remains dilapidated. Generally, condition reporting on this component is data deficient.			
Historic voyages and shipwrecks: The six historic shipwrecks in protected zones in the Region are well recorded. Condition is inferred due to minimal available evidence since 2019. Managers infer it to be poor based on their understanding of changing environmental factors. Data gaps continue to exist for other sites, associated artefacts and routes of voyages.			

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
World War II features and sites: Limited progress has been made since the Outlook Report 2019 in systematically recording the majority of sites and associated artefacts.		 INFERRED	 INFERRED
Other places of historic significance: Many elements have not been systematically identified or recorded for this historic heritage value. Since 2019, naming of 2 reefs has honoured 2 prominent people's historical contributions to the protection of the Reef.		 INFERRED	 INFERRED

4.6.5 Other heritage values

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Other heritage values: The Region's scientific heritage value is underpinned by the sharing and creation of knowledge. The Australian people's concern about the declining condition of the Reef remains. Their connection to its environment and natural beauty continues to be strong.			
Social heritage values: People continue to see the Reef as part of their personal and national identity and value its importance. An expressed willingness to undertake actions for Reef health, in turn, supports human wellbeing. However, there is also evidence of feelings of uncertainty and an increased awareness of the threats to the Reef, with a general lack of specific knowledge in how to help address and mitigate these threats on a personal level.		 ADEQUATE	 LIMITED
Aesthetic heritage values: Aesthetic beauty is aligned to perceptions of the condition of the Region's ecosystems. The perception of the aesthetic beauty of the Reef remains high, despite some declines in the condition of underpinning habitats and species.		 ADEQUATE	 LIMITED
Scientific heritage values: The long history of Traditional Owners living on, and researchers studying, the Reef is significant. The Reef's prominence in scientific literature and long-term studies continues to increase.		 ADEQUATE	 ADEQUATE

4.7 Overall summary of heritage values

Great Barrier Reef's heritage values are assessed against several criteria: natural (world heritage and national heritage), Indigenous, historic (Commonwealth and other), and other heritage (social, aesthetic, and scientific) values.



The World Heritage Area remains whole and intact, but its integrity is being challenged

The Great Barrier Reef remains whole and intact and maintains many of the elements that make up its outstanding universal value, as recognised in its World Heritage listing. Since it was inscribed as a World Heritage Area in 1981, significant components that underpin the four natural world heritage criteria have deteriorated. The size of the World Heritage Area is becoming a less effective buffer against the global impacts of human-induced climate change, which continues to challenge its integrity. Without additional national and global action to tackle the greatest threats to the Reef through this critical decade and beyond,[182,1100] the protective capacity of size will continue to be eroded by persistent and broadscale impacts on the Region and adjacent areas. The effectiveness of local and regional scale management actions is ultimately impacted by the success of actions to address external influencing factors, for example climate change.



Threats to nature are threats to Indigenous heritage values

Indigenous heritage includes tangible and intangible heritage and is inseparable from the condition of the Reef's natural components. Many threats, such as those from climate change, affect Indigenous heritage values through their impact on natural heritage values. Loss of Indigenous knowledge, including oral traditions held by Elders, is an ongoing threat; however, the living heritage of First Nations peoples across the Region remains resilient.

The COVID-19 pandemic created challenges for intergenerational knowledge transfer, despite community-led responses resulting in positive direct health outcomes. Collaborative management of Land and Sea Country, and efforts to map and document sites of cultural importance are advancing in some areas, but understanding and recognition of these important areas in management frameworks remains inadequate. As recognition of the wealth of undocumented Indigenous heritage has increased, it has underlined the limited knowledge in this area. Overall, an inferred condition of the Region's Indigenous heritage value has resulted in a continued grade of poor.



COVID-19 affected generational knowledge transfer

The historic heritage values of the five properties listed on the Commonwealth Heritage List that are in the Region are graded as good, having been identified and included in a relevant inventory. Components of historic heritage encompassing other lightstations, shipwrecks, aircraft wrecks and other places of historical significance remain in poor condition. The condition and trend assessments for most places and artefacts are based on limited published evidence. Positive progress has been made since 2019 towards gathering information on shipwrecks and aircraft wrecks including the possible identification in 2021 of a previously unknown shipwreck as the remains of the *Aert van Nes* which wrecked on the Great Barrier Reef in 1854.

Published condition information is limited for many places of historical significance

Other heritage values, including social, aesthetic and scientific, are considered in good condition overall. The significance of the World Heritage Area still transcends national boundaries and remains a source of pride for the Australian public. Notable progress has been made since 2019 in understanding the human dimensions of the Reef, particularly around societal attitudes and how people value and benefit from it. The public value the importance of the Reef and continue to see it as part of their personal and national identity. Perception of the Reef's aesthetic beauty remains high, despite some declines in the condition of habitats and species.

Actions to support the Reef's health contribute to human wellbeing

People have expressed willingness to undertake actions for Reef health, which in turn, supports human wellbeing. While increased awareness of the threats to the Reef is evident, there is also a general lack of specific knowledge about how to help address and mitigate these threats on a personal level. The Region's scientific heritage value continues to grow. Ongoing efforts are dedicated to preserving the legacy of pioneering science in the Region to ensure its enduring impact on future generations.



The Great Barrier Reef Ocean Swim 2023. © Great Barrier Reef Ocean Swim Series. Photographer: Calypso Imagery | Brent Paterson



Chapter 5

Commercial and non-commercial use

Commercial and non-commercial use

'an assessment of the commercial and non-commercial use...' of the Great Barrier Reef Region, s 54(3)(c) of the *Great Barrier Reef Marine Park Act 1975* (Cth)



The beauty of the Great Barrier Reef attracts visitors from all over the world © Chris Roelfsema 2021

"When tourism occurs on Country, with First Nations traditional Custodians driving innovation and sustainable culturally safe practices, it is beneficial for our people. I want to build a legacy for our next generation and tapping into some of these industries and opening up corridors for some of them to walk through the world with ease. Tourism creates a corridor for young people to get a job and move into other industries."

— Victor Bulmer, a Mandingalbay Traditional Owner and collaborator with Mandingalbay Indigenous Tours in Far North Queensland

"Pretty nice hey! It's a sea cucumber. This one here is called a pineapple sea cucumber because the skin of it looks like a pineapple. You have about three main types, a pineapple cucumber, a black sea cucumber and the local red sea cucumber. What you're looking at here is something that was traded between our people and other cultures for thousands of years."

— Jacob, cultural guide with Dreamtime Dive and Snorkel

Indigenous employment is important for young mob to find their way to stable employment pathways. Jacob, a cultural guide on Cairns-based Dreamtime Dive and Snorkel, exemplifies how culturally safe tourism is a vehicle to building capability. It is a culturally safe workplace for First Nations professionals. Young cultural guides are mentored by a senior First Nations employee. Jacob shares knowledge handed down over the generations and gives tourists a more direct experience of First Nations Culture and his own relationship to Sea Country.

"My passion for the Reef and the marine life it holds will never go away because it is a part of me and makes me who I am. Being a Master Reef Guide and an Indigenous Australian, I can be a role model and show them no matter how hard that it may be, if you carry yourself with pride for your culture and the respect of your family, your buma (people) and your Country, you can be all that you can be."

— Dustin Maloney, Master Reef Guide

"This is one way to come back on Country, and to bring my family and other mob back on Country, to where we belong. Sometimes when our people come back, it is the first time in their lives that they have been back to their own Sea Country."

— Robert Congoo, an entrepreneur and Ngaro, Gia and Kalkadoon man who runs cultural tours in the Whitsundays region

Source: Caring for Sea Country – Traditional Owner Stories from the Great Barrier Reef [1]



Red sea cucumber in the hands of a cultural guide. © Winangali 2023

5.1 Background

For tens of thousands of years, the Region has been used by Traditional Owners through their continued connection to their Land and Sea Country and traditional use. Since European settlement, the use of the Region's ecosystem has increased through a combination of direct commercial and non-commercial uses (Reef-dependent users) (Figure 5.1). The Region also supports non-Reef-dependent users who require access through (or to) the area, but do not directly use the natural heritage values of the Region.

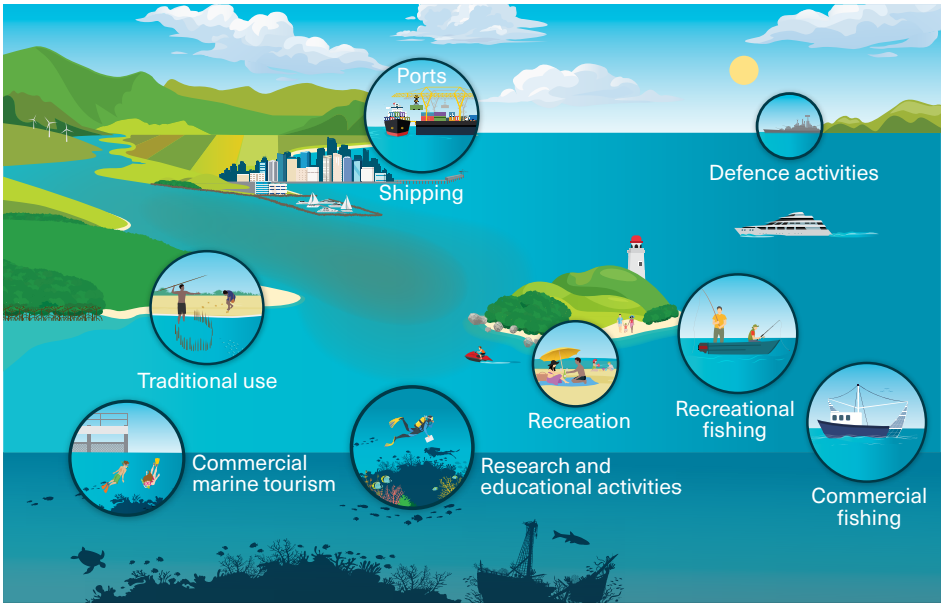


Figure 5.1 **Commercial and non-commercial uses**
A range of uses occur in the Region; some depend directly on the Reef's natural heritage values and resources.

This assessment of commercial and non-commercial uses examines the current condition (and trends in condition) of the major uses of the Region and forms the basis for the Chapter 6 assessment of direct use, a factor that influences the Region's values (Section 6.6). The assessment is based on two assessment criteria:

- economic and social benefits of use
- impacts of use on the Region's values.

For more than 40 years, government management plans and policies have had to balance the protection of the Region with the needs of communities and industries that depend on the Reef for traditional use, social and cultural purposes and livelihoods. Factors influencing the Region (Chapter 6) have changed and intensified over the years, increasing the challenge for management. Management has been, and continues to be, based on the best available scientific information and intergenerational knowledge. Chapter 7 assesses the effectiveness of management tools in more detail.

Use of the Reef contributes significant social and economic benefits

Commercial and non-commercial uses collectively form an important part of the social and economic fabric that supports the adjacent communities in the Catchment and the broader Australian and international communities. The economic and social benefits for each commercial and non-commercial use is considered in terms of its benefit to the community and the natural ecosystem more broadly.

All commercial and non-commercial uses, Reef-dependent or not, have the potential to conflict with the long-term protection, conservation, and function of the Reef's natural and Indigenous heritage values. Well-managed uses can also lead to positive outcomes, including through conservation education. Therefore, management of these uses is factored into the assessment of their potential impacts.

Tourism, fishing, other recreational use and scientific activities contribute significantly to the Australian economy. However, between 2020 and 2022, management of the COVID-19 pandemic affected each use. There has not been an updated quantitative estimate of the economic values across and between the commercial and non-commercial uses of the Region since 2017.

5.2 Commercial marine tourism

Commercial marine tourism is the largest Reef-dependent commercial industry within the Region, contributing significantly to the economy. Commercial marine tourism experiences in the Region range from kayaking and snorkelling adventures and fishing charters (Section 5.4) to overnight experiences on reef-based pontoons or islands.

5.2.1 Current condition and trends of commercial marine tourism

Within the Region, tourism is concentrated into about 7 per cent of the area. Tourism visitation to the entire Great Barrier Reef Marine Park (Marine Park) in 2023 was approximately 2.13 million total visitor days.[1174] Tourists commonly visit the Cairns and Whitsunday planning areas, which are regulated by plans of management. Visits to these two areas contributed to more than 86 per cent of tourist visits to the area in 2022 (Figure 5.2).[1174,1175,1176]

Since 2019, the Region's commercial marine tourism industry faced significant hardship during the global pandemic. Between early 2020 and the end of 2021, visitation to the Region was down by about 42 per cent on 2019 volumes due to COVID-19 management. Visitation in the 2022–23 financial year was 10.4 per cent less than the 7-year pre-pandemic average of 2.45 million visits and up 63.6 per cent on the 2021–22 financial year visitation levels.[1174] The change in visitation was due to domestic and international border restrictions during COVID-19. Historically, the Cairns area attracts significant numbers of international visitors. Therefore, disruptions due to COVID-19 were obvious in the Cairns planning area which experienced a downturn in visitation by nearly 70 per cent. Visitation in the Whitsunday planning area declined by 54 per cent during the pandemic. By the end of 2022, visitation had recovered in Cairns and the Whitsundays to 74 and 105 per cent of pre-pandemic 2019 levels, respectively.



Tourism industry is recovering from the impact of the COVID-19 pandemic

The border closures also redistributed tourists from international hubs such as Cairns towards domestic destinations in the southern parts of the Region that are closer to large population centres in south-east Queensland. While visitation in both the Mackay–Capricorn management area and Whitsunday planning area decreased in 2020 (by 41 and 54 per cent of 2019 levels, respectively), the proportion of the total Reef visitation to each location increased by 4 per cent. In comparison, the proportion of total visitation to the Cairns planning area decreased by 12 per cent in 2020.[1174]

The pandemic appears to have influenced the use of bareboats — the hire of self-guided vessels. Bareboat activities are historically most popular in the Whitsunday planning area and less so in the Hinchinbrook planning area. However, usage in Hinchinbrook area had a notable increase between 2019 and 2021 (from 176 to 1203 visitors per year), reflecting an approximate 2-fold increase from the previous peak (2016).[1174] The change is assumed to be associated with the COVID-19 public health restrictions on the number of persons in gatherings and in close contact.

The pandemic also caused significant operational impacts on the commercial marine tourism industry; such as, increased fuel costs and shortages in skilled staff. Although tourism to the Region is rebounding, it is expected to take several years before it returns to widespread pre-pandemic volumes. National forecasts suggest stabilisation of domestic travel in 2023 after strong growth in 2022, and that international travel to Australia will exceed pre-pandemic levels in 2025.[1177] In 2023, the marine tourism industry continues to experience difficulties in attracting, training and retaining staff (Section 7.3.1). Since 2019, the industry continues to consider product diversification, including reef rehabilitation through site stewardship [32,1078] and novel aesthetic opportunities by installing underwater artwork (Section 4.2.2).

Tourist perceptions of the Reef can be affected by major events, such as mass coral bleaching. These events, and the ways in which the events are communicated to the public, may affect visitation to the Reef. A 2017 survey of Reef tourists showed declines in the overall satisfaction with their Reef experience and in their perceptions of its aesthetic beauty after the 2016 and 2017 mass bleaching events.[1077] Negative emotional responses to the Reef, such as sadness, disgust and fear, by tourists increased after the events, and this result was not influenced by whether they had personally observed the impacts. However, the bleaching events also lead to expressions of empathy for the Reef through increased ratings of place values, identity and protective sentiment. How these changing perceptions affect the condition and trend of commercial marine tourism remains a knowledge gap.

The condition (and trend in condition) of First Nations tourism in the Region is not well reported. Special tourism permissions within the Marine Park that are reserved for Traditional Owners remain unallocated.[1175,1176,1178] Through program and management initiatives sponsored by Reef managers and government, partnerships and engagement of First Nations peoples and the broader marine tourism industry in the Region continue to strengthen.[1179,1180] Since 2019, Reef mangers have made improvements towards implementing co-management principles recognising Traditional Owner aspirations in commercial activities in the Region (Chapter 7).[1120,1181,1182]



Wildcat, a commercial marine tourism operator, at Brampton Island. © Mark Fitz 2023

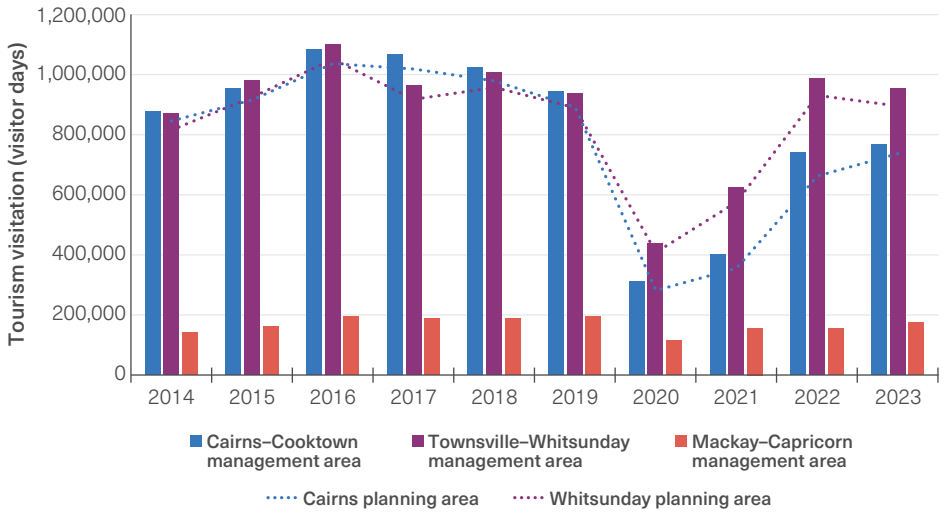


Figure 5.2 **Number of tourism visitor days, 2014 to 2023**

A 'visitor day' is a visit by one tourist for one day. These tourism visitor day statistics are the total visitation days (including full days, part days and exempt data) and do not include standalone activities (for example, coral viewing, scenic flights or bareboats). Visitation data are captured by the Reef Authority in two spatial areas — management areas (Section 1.6) or planning areas. While visitation data are captured for the Far Northern management area and the Hinchinbrook planning area, volumes are significantly lower (each less than 8000 visitor days per year) and are not included in this figure. During the COVID-19 pandemic, log-books were not mandatory, yet compliance remained at about 99 per cent of tourism operators lodging returns. Source: Great Barrier Reef Marine Park Authority (2024)[1174]

Management | Management of marine tourism in the Region is well established with comprehensive planning, policy and permission systems in place. The Australian *Great Barrier Reef Marine Park Zoning Plan 2003*[1183] and the complementary Queensland Government *Marine Parks (Great Barrier Reef Coast) Zoning Plan 2004* (zoning plans)[1184] list activities that require permission and those that are allowed as of right. Commercial marine tourism requires permission in every case and can be conducted in almost all zones (except the Preservation Zone) of the Marine Park and several other restricted areas.

Applications for permission to conduct tourist programs in the Region are jointly decided and managed by the Reef Authority and Queensland Parks and Wildlife Service. In high-use tourism areas within the Region, an added layer of spatial planning complements the zoning plans, including statutory plans of management for Cairns, Hinchinbrook and the Whitsundays. Other policies, such as site management arrangements, also complement these zoning plans.

In response to the COVID-19 pandemic, government support was provided to the marine tourism industry through the waiving of permit application fees and the environmental management charge . Fee waivers affected permission application volumes during this period.[1185] In the 2019–20 financial year, about 3215 tourism permissions were valid and in 2022–23 about 4675.[1185,1186]

In 2021, the Reef Authority released its *Tourism Management Action Strategy.*[1187] The strategy identifies specific actions to review, simplify and rationalise tourism policies and other management tools under the Reef Authority's *Policy and Planning Strategic Roadmap.*[1188] An established Tourism Reef Advisory Committee continues to inform the development of policy and strategic direction in the management of the Marine Park. Stakeholders from the commercial marine tourism industry also sit on Local Marine Advisory Committees.

The Reef Authority's High Standard Tourism Operator program has been in place since 2004. In 2023, the Reef Authority commenced a review of the program to enhance and modernise tourism management. High Standard Tourism Operators voluntarily operate to a higher standard than other permit holders as part of their commitment to ecologically sustainable use of the Marine Park. The number of operators involved has increased from 19 in 2004 to 72 in 2023 and has increased by 13 per cent since 2019. These operators carry approximately 63 per cent of tourists visiting the Reef.[11] External auditing and reporting are undertaken to make sure High Standard Tourism Operators are meeting certification requirements.

5.2.2 Benefits of commercial marine tourism

The Reef continues to be recognised locally, nationally and internationally as an iconic nature-based tourism experience. The Reef can provide cultural, social or economic benefits to people, which links to personal wellbeing and a sense of identity (Section 4.5.1).[1189] Commercial marine tourism delivers benefits to both tourists and tourism operators.[1190]

The Reef is an internationally recognised nature-based tourism experience

Since 2019, several management programs have identified participation and collaboration between Traditional Owners and the marine tourism industry as key to protecting and conserving the values of the Marine Park. This collaborative approach is consistent with new research into the degree to which visitor education empowers stewardship and engagement and results in environmental protection (Section 8.5.1).[1190] Reef visitation with tourism operations is how people can easily connect with the Reef, and it can inspire visitors to adopt conservation and stewardship behaviours that can help protect the Reef.[1191]



Tourists at Moore Reef. © Matt Curnock 2023

Programs such as the Reef Authority's site stewardship, Master Reef Guides (Box 5.1) and citizen science-focused Eye on the Reef benefit Reef management through visitor and industry contributions. Since 2019, 47 tourism operators have contributed to 19,754 Reef health surveys, compared to 36 operators and 4759 surveys over the preceding 5 years.[1192,1193] Chapter 7 includes an assessment of the management

effectiveness of these programs and other initiatives. The marine tourism industry also promotes education, protection and appreciation of natural and cultural values through ecotourism[1194] and eco-certification.

Many marine tourism operators now undertake stewardship actions, for example, removing coral predators (such as crown-of-thorns starfish and *Drupella* snail culling and interventions), monitoring species diversity, collecting imagery and water quality data. Operators also keep an eye out for other impacts, such as illegal activities, oil spills and injured wildlife. These activities assist Reef managers with day-to-day management. The marine tourism industry is interested in implementing these stewardship approaches and other technologies, such as Reef interventions, to have a positive impact on the environment and local communities. However, how to achieve this and how to engage consumers in supporting sustainable tourism operations are often difficult to ascertain.[1197]

Commercial marine tourism in the Region contributes significantly to the economy. A value analysis of Reef-dependent and Reef-associated industries has not been undertaken since 2017 and remains a knowledge gap. Consequently, the economic value of the Reef is expressed here as a state or national value, rather than Reef-specific. In Australia, the domestic and international marine tourism output was $20 billion in the 2020–21 financial year, making it the second largest subsector in the marine industry.[1198] Within Queensland, the output in the same period was estimated at $7 billion and $29 million for domestic and international, respectively. The domestic marine tourism industry also provides the largest share of employment of all marine industries in Australia. In 2020–21, this industry generated an approximate total of 140,000 direct and indirect jobs nationally.[1198] In Queensland in the financial year 2021–22, the total tourism-filled jobs (both direct and indirect) totalled 206,200 (up 32 per cent on 2020–21 and down 17 per cent on 2018–19).[1199]

BOX 5.1

Master Reef Guides Program

Master Reef Guides are world-leading reef guides, storytellers and interpreters who share the wonders of the Great Barrier Reef World Heritage Area with their guests and the world. The program started in 2018 with 26 guides completing the course by the end of the first intake. The guides are associated with High Standard Tourism Operators and are ambassadors for the Marine Park.

The Master Reef Guide program is globally recognised as a leading platform for professional development within the marine tourism industry. By equipping these individuals with the knowledge, skills and support to deliver accurate, relevant and engaging information to visitors to the Reef and online communities, they are empowered to inspire change with their audience. The guides create connections with the natural ecosystems they share, promote responsible behaviours around these locations and, ultimately, provide exceptional experiences to those who visit the Reef. As of December 2023, more than 120 Master Reef Guides from across the Region have graduated through the program. Master Reef Guides participate in professional development including ongoing training, networking and leadership development through an annual masterclass and induction field school.

The Master Reef Guide program is led by the Reef Authority, in partnership with the Association of Marine Park Tourism Operators and Tourism and Events Queensland.[1195,1196]

5.2.3 Impacts of commercial marine tourism

Commercial marine tourism activities can pose threats to ecosystem and heritage values, mostly at a local scale. The most common of these include: **incompatible uses**, where tourism use may displace or affect another user group, such as Traditional Owners or recreational users; **groundings** of vessels; and, in some locations, **marine debris** and **discharge of sewage**.

Direct impacts from commercial marine tourism can include, for example, localised **damage to reef structure** or coral by snorkelling tourists and the footprint left by concrete mooring blocks associated with tourism pontoons. Site-specific tourism operations mitigate impacts through guided snorkel tours, trails and resting stations that reduce contact with corals. Operators funded under the Tourism Reef Protection Initiative are required to complete site stewardship plans detailing the actions they implement to reduce impacts.[1179] Policies, plans and educational material for permit holders adopted by Reef managers continue to provide guidance to tourism operators about best-practice and preferred mitigation measures.[1200,1201,1202,1203]

Tourism industry emissions (both from air travel and vessel operations) contribute to broader greenhouse gas emissions, but quantitative data are lacking. At a global scale, disruptions to international travel due to the pandemic provided an opportunity to analyse the extent of any associated reductions in environmental impacts of travel and tourism.[1197,1204,1205]



Anchor damage on a reef. © Johnny Gaskell 2024

Physical damage to reefs and shoals can be caused by vessel groundings. Since 2019, the number of groundings of commercial tourism vessels have fluctuated, ranging from 3 to 11 groundings in a year (Section 5.5.3, Figure 5.16). **Sewage discharge** from vessels (both commercial and recreational) can increase nutrients in the water, reduce water quality and damage habitats. There are few land-based sewage pump-out facilities adjacent to the Region, with only five fixed onshore pump out facilities registered.[1206] In 2023, an amendment was made to Annex 1 of the London Protocol to remove disposal of sewage sludge as a permittable activity.[1207] As such, no new permissions have been, or can be, granted for the dumping of sewage sludge. Existing permissions remain until expiry, with no subsequent granting of permission possible.

Since 2019, sea dumping has been granted for the installation of underwater artwork in the Region as a novel aesthetic opportunity for tourists. Policy restrictions were introduced in 2023 around new, or expansion of, artificial reefs in the Marine Park.[1208]

Compliance with regulations or permissions influences the scale of impacts associated with commercial marine tourism. Since 2019, improvements in compliance effort, data capture and education programs by Reef managers have contributed to minimising the impacts (Sections 7.3.1 and 7.3.12).[11]

5.3 Defence activities

The Australian Defence Force, consisting of the Army, Air Force and Navy, has operated and trained in the Region for more than 100 years. Bases in Townsville and Cairns serve as key platforms for defence operations in the Region alongside training sites in Shoalwater Bay, Cowley Beach and other places. Regular training activities, such as Exercise Wallaby, occur in designated areas. These areas cover less than 4 per cent of the Region (Figure 5.3).

Defence activities have occurred in the Region for more than 100 years

5.3.1 Current condition and trends of defence activities

Since 2019, defence activities have used areas outside the regular training sites. For example, as part of Exercise Talisman Sabre 2023, Joint Logistics Over the Shore activity occurred at Kings Beach in Bowen.[1209]

As part of the Australia–Singapore Military Training Initiative, work has commenced on the expansion of Shoalwater Bay Training Area in the areas adjacent to the Region with targeted completion by mid-2024.[1210] The footprint of the training site within the Region is not expected to change, but the frequency and scale of defence activities may increase in the future.[1211]



HMA Ships *Ballarat* and *Melville* conduct manoeuvres off the coast of Queensland during Exercise Talisman Sabre 2021. © Department of Defence 2021

Defence activities may increase with expansion of the Shoalwater Bay Training Area

Management | Defence activities are allowed under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act), *Great Barrier Reef Marine Park Act 1975* (Cth) (Marine Park Act) and zoning plans. The Australian Department of Defence directly manages the environmental impact of operational and training defence activities

including the conduct of activities by visiting international defence forces. This management is primarily through a strategic environmental assessment and environmental management plans. The Department of Defence works in collaboration with the Reef Authority through a Memorandum of Understanding, which strengthens the management system through information sharing and collaboration. Other management agencies, such as the Queensland Department of Environment, Science and Innovation and the Australian Department of Climate Change, Energy, the Environment and Water engage on an *ad hoc* basis in relation to training activities such as Exercise Talisman Sabre.

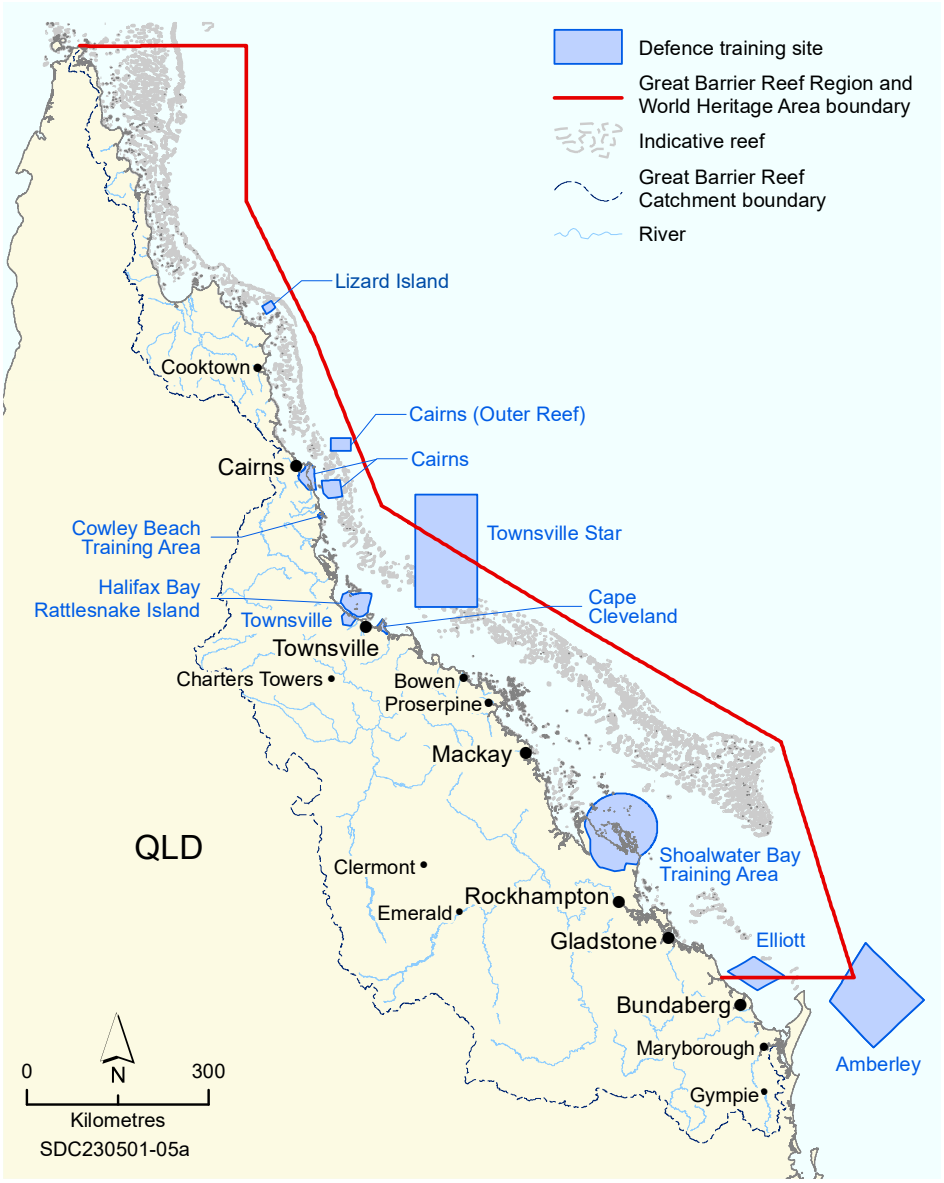


Figure 5.3 **Defence training sites in the Region**

The Australian Defence Force undertakes training in designated areas within the Region, shown in blue. The Townsville Star and Shoalwater Bay Defence training areas are some of Australia's largest.

5.3.2 Benefits of defence activities

Defence activities contribute to the training and operation of Australia's defence forces. In Queensland, financial outputs from defence activities amounted to $573 million for the 2020–21 financial year.[1198] Coastal communities within the Catchment benefit economically from defence activities, primarily through increased employment from infrastructure projects.[1212] Benefits are also seen during training exercises. For example, Exercise Talisman Sabre, which utilises locations both within and outside the Region, welcomed more than 34,000 military personnel from 13 different countries in 2023.[1213] Through historical monitoring, the Australian Department of Defence has contributed to knowledge on the current condition (and trend in condition) of species such as marine turtles, dugongs and seagrass. For example, the Department of Defence contributed to a range of research projects within the Region, including a survey of dugong populations for the southern Reef, including Shoalwater Bay.[522]

5.3.3 Impacts of defence activities

Defence activities are well managed (Section 7.3.2) and impacts are generally limited to within training areas, including from conduct of training operations and using live ammunition. Local-scale impacts include pollution, oil spills and leaks, debris from expendable stores, and disruption, injury or death to marine life.[1214,1215] Incidents involving the wreckage of military assets, for example, could lead to many of the environmental impacts listed.[1216] A series of mitigation measures are in place to minimise the impact defence activities have on the values of the Region and the likelihood of incidents remains rare.

Defence activities are well managed and generally limited to training areas

A range of legacy impacts associated with past defence activities continue in specific areas. Unexploded ordnance (shells, missiles and bombs) and chemical warfare agents that were deliberately dumped at sea at the end of the World War II remain.[1217]

Firefighting foam containing per- and poly-fluoroalkyl substances (PFAS) was historically used across Department of Defence sites adjacent to the Region. PFAS are a group of thousands of manufactured chemicals used in many common household and industrial products to resist heat, oil, stains and water.

The Department of Defence began phasing out the use of PFAS in 2004. However, these chemicals are environmentally persistent, bioaccumulative and, while not yet shown to cause disease, may have some effect on human health (e.g. cholesterol level elevation, effects on kidney function and hormone levels) and can cause liver toxicity, tumours and reproductive effects in animals.

The PFAS constituents in the firefighting foam are very persistent and mobile and can enter into and migrate in soil and groundwater, eventually moving beyond the source of release, in some cases for several kilometres.[1218,1219] Contamination travels in the environment through groundwater. Downstream areas where contamination enters surface water can be widespread, as can the area of impact.[1219] Since 2019, a major focus for Defence has been managing the impact to communities from PFAS contamination: investigating where and at what concentration the PFAS contamination is, developing management measures to prevent spreading, and remediating to clean up the source of contamination. PFAS contamination within the Region has been confirmed at RAAF Base Townsville, Lavarack Barracks and HMAS Cairns naval base.[1220]

5.4 Fishing

Fishing is an important activity in the Region and provides valuable commercial, recreational and cultural benefits for users. It is the largest extractive use of the Region targeting a diversity of species, including fish, sharks, crabs, prawns, rock lobsters, squid, coral and sea cucumbers.

Fishing continues to be an important use of the Region

5.4.1 Current condition and trends of fishing

For the purposes of this report, the term 'fishing' includes recreational, charter and commercial fisheries. Fishing activities associated with traditional use are considered in Section 5.9. Where fishing can occur in the Marine Park is primarily set by the zoning plans and Queensland fisheries legislation. Under the zoning plans, approximately two-thirds of the Marine Park is open to some form of fishing.

Currently, no marine-based aquaculture facilities operate in the Region. Land-based aquaculture is considered in Section 6.4.1.

Recreational fishing is an important pastime for many Australians and is one of the most popular activities on the Great Barrier Reef. During the 2019–20 period, approximately 660,000 Queenslanders participated in 2.8 million days of recreational fishing.[1221] This is a slight increase in effort days from the surveys in 2013–14 and 2010–11, which recorded 2.5 and 2.6 million days, respectively.[1222,1223]

As the Queensland population has grown since 2019, recreational vessel registration has continued to increase to the highest on record (Section 5.5). Within the Region, fishing effort was highest in the Mackay and Cairns regions.[1221] The distance travelled to boat ramps to access the Reef for recreational fishing has decreased since 2019.[1224] Most fishing occurred inshore (less than 5 kilometres from the coastline).[1221]

Queenslanders spent approximately $630 million on recreational fishing items in 2019–20.[1221] Line fishing was the most common method used by fishers, and shore-based fishing was more popular than boat-based fishing.[1225]

Coral trout and mud crab were commonly harvested by recreational fishers

In 2023, coral trout was the most commonly harvested fin fish species from the Region by boat-based anglers. Mud crab is also frequently harvested from the Region. The other types of finfish kept by boat-based anglers vary regionally, but include saddletail snapper, grass emperor, pikey bream and redthroat emperor (Figure 5.4). Diary surveys of both shore-based and boat-based recreational fishers report harvest of similar species. Fishers also commonly harvest mullet, hussar and sand whiting. More than 70 per cent of fish caught recreationally were released in the Region.[1224]

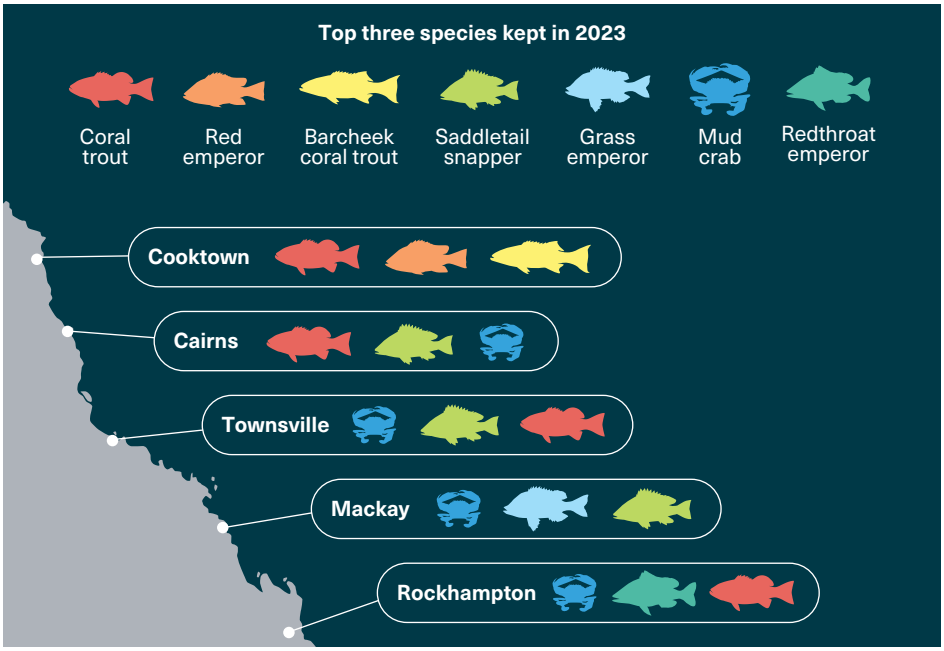


Figure 5.4 **Top three species caught and kept by recreational fishers during 2023**

The ranking is based on number of individuals kept by recreation fishers, using data gathered through recreational fishing surveys at boat ramps. This figure highlights regional variation in the fish species most commonly harvested by recreational fishers. Source: Queensland Department of Agriculture and Fisheries (2023) [1224]



Recreational fishing in the Region. © Darren Cameron 2024

Charter fishing operators take paying customers on boat trips on a tourism vessel for the purpose of recreational fishing. Despite a concerted effort by the Queensland Government to grow the charter fishing industry,[1226] from 2019 to 2020 effort within the Region decreased by 40 per cent and harvest decreased by nearly 50 per cent (Figure 5.5).[1227] These decreases are likely due to national and state border closures implemented in response to the COVID-19 pandemic.[1226] Effort and harvest have increased in recent years but have yet to return to pre-pandemic levels. Participation in the sector (number of active Queensland licences) also declined from 92 in 2019 to 81 in 2022.[1227]

Charter fishing decreased by 40 per cent due to COVID-19

Coral trout and redthroat emperor made up 44 per cent of the total harvest between 2019 and 2022, with saddletail snapper, crimson snapper, Spanish mackerel and red emperor also key target species.[1227] These species are also key targets for recreational fishers and the Reef line fishery and have been subject to fishery stock assessments since 2019.[1228]

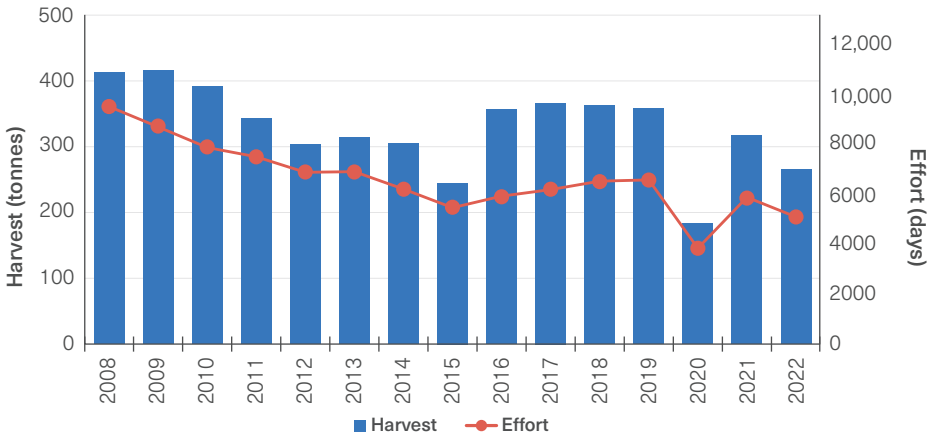


Figure 5.5 **Charter fishing total harvest and effort in the Great Barrier Reef, 2008 to 2022**
Total harvest (tonnes) collected by charter fishing operations in the Great Barrier Reef 2008 to 2022. Effort is expressed in fishing days. Data are accurate at the point of extraction from QFish. Source: Queensland Department of Agriculture and Fisheries (2023)[1227]

Commercial fishing | Trawl, net, line and pot remain the most significant commercial fishing methods in use in the Region (Table 5.1). In 2022, the commercial harvest (retained catch) of fisheries product in the Region was about 5000 tonnes, not including marine aquarium fish or coral.[1227] The management arrangements for all commercial fisheries in the Marine Park have undergone significant reform since 2017, as part of the implementation of the *Queensland Sustainable Fisheries Strategy 2017–2027* (Sustainable Fisheries Strategy) (Box 5.2). This includes setting sustainable catch limits at around 60 per cent pre-fishing biomass by 2027 to achieve maximum economic yield for all Queensland fisheries and setting clear triggers for management action (for example biomass reference points). Compulsory catch-reporting arrangements and vessel tracking systems are in place for the commercial sector. Data validation through independent onboard observers is being implemented across many commercial fisheries (Box 5.3).

The Queensland commercial fisheries industry relies heavily on export, airfreight and visitors, which were affected during the COVID-19 pandemic.[1229] Many commercial fishing businesses stopped fishing and exporting in the 2019–20 financial year because of the loss of international markets and international freight.[1229]

Queensland commercial fisheries were affected during the COVID-19 pandemic

Table 5.1 **Commercial harvest in the Great Barrier Reef by fishery, 2007 to 2022**

Data are accurate at the point of extraction from QFish and other databases. Differences to 2007, 2012 and 2017 figures reported in the Outlook Report 2019 generally result from subsequent database corrections or changes to the spatial boundaries used to extract data from the QFish database. *Although most harvest occurs within the Great Barrier Reef, harvest from the Sea Cucumber Fishery is from the whole fishery extent (that is, not limited to the Reef). ** Sea cucumber harvest data are from the 2016 to 2017 and 2021 to 2022 fishing seasons (not calendar years). Source: Queensland Department of Agriculture and Fisheries (2023)[1227]

Fishing method	Fishery	Commercial harvest (retained catch)				Main target species
		2007 (tonnes)	2012 (tonnes)	2017 (tonnes)	2022 (tonnes)	
Trawl	**Otter Trawl**	3333	3426	3636	2759	Prawns, scallops, bugs and squid
	Beam Trawl	70	33	21	13	Prawns
Net (mainly gillnet)	**East Coast Inshore (principally)**	2341	1697	1015	418	Barramundi, sharks, grey mackerel, threadfin, salmons, sea mullet, whiting
Hook and line	**Coral Reef Finfish and Spanish Mackerel (principally), and hook and line component of East Coast Inshore**	1995	1743	1844	1264	Coral trouts, cods, emperors, tropical snappers, Spanish mackerel, other mackerels, sharks
Pot	**Mud Crab, Blue Swimmer Crab — pot**	602	893	670	362	Mud crab, blue swimmer crab
	Spanner Crab — dillies	526	205	132	61	Spanner crab
Hand-based collection (harvest)	**Coral**	110	87	85	61	'Live rock' and potentially hundreds of species of coral
	Marine Aquarium Fish	68,086 fish	73,578 fish	62,641 fish	67,766 fish	More than 1500 marine fish and invertebrate species could be harvested — only a few hundred are collected regularly — mostly damselfish, anemone fish, wrasses, angel fish
	Tropical Rock Lobster	238	154	185	125	Tropical rock lobster
	Trochus	140	16	0	0	Trochus
	Sea Cucumber*	252	379	338**	342**	White teatfish, black teatfish, curryfish, burrowing blackfish

BOX 5.2

Queensland Sustainable Fisheries Strategy 2017–2027

In June 2017, the Queensland Government released the *Queensland Sustainable Fisheries Strategy 2017–2027* which sets out a 10-year reform agenda, paving the way for a world-class fisheries management system. In the first 5 years of implementation, the strategy delivered 29 out of 33 actions across 10 reform areas. Key achievements include:

- harvest strategies are now in place across all major fisheries
- ecological risk assessments updated for 10 major fisheries that operate in the Region
- stock assessments updated for more than 34 species
- vessel-tracking units installed on all commercial boats
- regional-specific fishing rules introduced for some fisheries
- technologies used more effectively.

This reform is the biggest in Queensland's fisheries history. The strategy aims to ensure fish stocks are healthy, support the social and economic values of the industry and help protect the Great Barrier Reef by ensuring fisheries are managed in a sustainable way within the World Heritage Area.

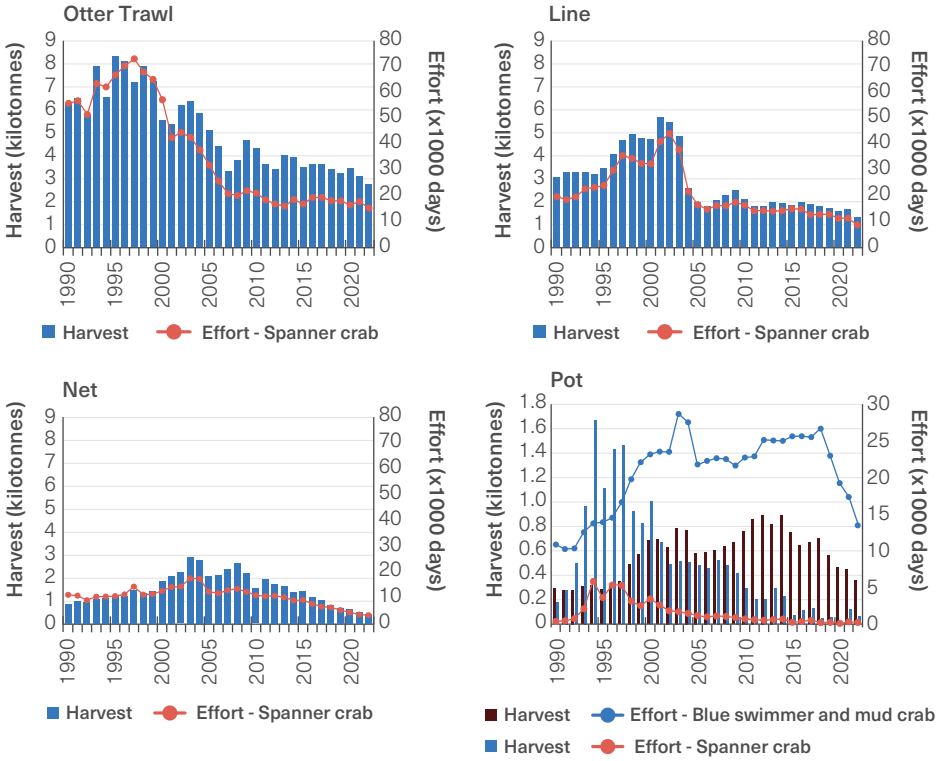


Figure 5.6 **Commercial fisheries harvest and effort in the Great Barrier Reef, 1990 to 2022**
Annual harvest and fishing effort for the four major fisheries (otter trawl, net, line and pot) from 1990 to 2022. Data are sourced from commercial fisher logbook records. Effort is expressed in fishing days. A day of fishing effort has not been standardised over time and does not account for changes in fishing power (such as technology advances and fishing efficiency). Source: Queensland Department of Agriculture and Fisheries (2023)[1227]



Commercial fishing vessel. © Commonwealth of Australia (Reef Authority) 2024

Trawl fisheries are Queensland's largest commercial fisheries with two operating in the Region: the East Coast Otter Trawl Fishery, and the River and Inshore Beam Trawl Fishery. The **East Coast Otter Trawl Fishery**, which operates in more open waters, accounts for approximately 99 per cent of the total harvest taken in trawl fisheries each year (Table 5.1). The number of licences operating in the Region and the effort (in fishing days) has remained relatively stable since 2019, but there is potential for the fishery effort to increase under current management arrangements. While historical catch levels in the Region peaked in 1995 at around 8300 tonnes, long-term (annual) harvests are well below this level (Figure 5.6).[1230] Annual harvest declined from 1997 before stabilising between 3100 and 3600 tonnes in 2015 (Figure 5.6).[1230]

Trawl fishing is allowed in all General Use Zones (with some additional spatial restrictions) of the Marine Park, totalling 34 per cent (118,488 square kilometres) of the World Heritage Area.[1231] Historically, the fishery was managed as a single entity. In 2021, the fishery transitioned to a regional management framework as part of the broader reforms. It is now guided by regional harvest strategies for the following five trawl regions: Northern,[1232] Central,[1233] Southern Inshore,[1234] Southern Offshore,[1235] and Moreton Bay[1236] that does not operate in the Region. Most of the effort is concentrated between Cooktown and Townsville in Far North Queensland, and between Rockhampton and the Gold Coast.[1237] In the outer southern Reef, some areas are particularly deep (down to about 250 metres) and continue to have some of the highest trawl footprints and effort intensity.[1238] Some species, such as the Moreton Bay bug,[1239] have strong genetic connectivity indicating a single biological stock across the whole fishery.

Trawl fishers in the Region target major commercial species, such as prawns, scallops, bugs and squid.[1237] Since 2019, stock assessments have been completed for multiple key target species including tiger prawn,[1240] eastern king prawn,[1241] red spot king prawn,[1242] endeavour prawn,[1243] Moreton Bay bug [1244] and saucer scallops[793] (Table 5.2). For 2020, the stock status of all these species is assessed as sustainable, except for saucer scallops which are depleted.[794,1245,1246,1247,1248,1249] The fishery interacts with a wide array of non-target species which are discarded as bycatch, including invertebrates, fish, sea snakes, marine turtles, seahorses and pipefish, sharks and rays (Section 5.4.3).

Table 5.2 **Stock assessment and stock status results for commonly targeted species in the East Coast Otter Trawl Fishery**

The red spot king prawn is excluded on the basis that stock assessment results were undefined in 2021. Source: Stock assessments, unfished biomass estimates and historical declines are based on models prepared by the Queensland Department of Agriculture and Fisheries. The stock status assessment results are published in the Status of Australian Fish Stock Reports.[793,794,1240,1241,1243,1244,1245,1246,1248,1249]

Fisheries resource	Modelled year of unfished biomass	Historical minimum biomass		Stock assessment		Stock status assessment
		Year	Per cent of unfished biomass	Year	Per cent of unfished biomass	
Tiger prawn	1958	1996	31	2021	79	Sustainable
Eastern king prawn	1950	1985	50	2019	62	Sustainable
Endeavour prawn	1958	1997	34	2021	69	Sustainable
Moreton Bay bug	1968	2000	67	2021	78	Sustainable
Saucer scallop	1956	2016	10	2022	15	Depleted



Management actions have not rebuilt saucer scallop stocks

Saucer scallops are targeted by trawlers using otter trawl nets with large mesh but also appear as incidental catch while other species are targeted.[1237] Fishery-independent surveys of scallops in the trawl fishery have indicated very low scallop densities, including within replenishment areas, and poor recruitment levels.[1250] The 2022 stock assessment estimates the scallop biomass at 15 per cent of unfished biomass[793] and the stock is currently classified as depleted.[794] Management actions have not been successful in rebuilding the stock, and since 2019, it has remained below the 20 per cent limit reference point set out in the *Queensland Sustainable Fishery Strategy 2017–2027*.[1251] In 2021, the *Fisheries (Saucer Scallops) Amendment Declaration 2021* was enacted to prevent the take of saucer scallops in the Southern, Inshore and Central trawl regions. This closure will remain in place until the scallop stocks have rebuilt to a 30 per cent biomass level.

Saucer scallop can still be taken in the Southern Offshore region on the basis that they are assumed to not contribute to the spawning biomass fishery.[1252] Similarly, scallops that spawn east of K'gari (Fraser Island) may not be strongly reproductively connected to those on fishing grounds between Yeppoon and Hervey Bay.[793] However, some uncertainty remains around the accuracy of the assumption that the scallops from the Southern Offshore region are biologically distinct from the two closed fishery regions.[1250]

The **East Coast Inshore Fishery** is a multi-species multi-gear fishery that covers all tidal waters from the tip of Cape York to the New South Wales border. In the Region, the main gear types are mesh, net, bait net and line and the fishery primarily targets barramundi, threadfin, grey mackerel and shark.[1253] Many of the species are also targeted by line fishers, recreational fishers and charter fishers.[1253] Commercial effort in the East Coast Inshore Fishery has been reduced in the past decade with the removal of 120 large mesh net licences.[5] In 2023, the Australian and Queensland governments committed to further action to completely phase out gillnet fishing (specifically N1, N2 and N4 Queensland licences) in the Marine Park. This included a reduction in the number of gillnet licences in the Marine Park before 31 December 2023 (from approximately 240 licences down to 40). The remaining licences will be phased out by 30 June 2027 through the *Fisheries and Other Legislation (Structural Reform) Amendment Regulation 2023*.

Gillnet fishing will be phased out in the Region by 2027

In 2019, there were sustainability concerns for black jewfish.[5] Historically considered a by-product species within the inshore net fishery, black jewfish has become a targeted line-caught species.[1254] Nominal catch rates have been steadily increasing over the past 20 years, with the most notable increases seen in 2018–19.[1255] Over the 5 years from 2017 to 2021, the estimated Queensland east coast total retained catch averaged 82 tonnes per year with 57 tonnes (69.1 per cent) caught by the commercial sector and 24 tonnes (28.8 per cent) by the recreational sector.[1254]

In 2022, the first stock assessment for Queensland east coast black jewfish found that the stock is healthy, being at least 56 per cent of the unfished spawning biomass.[1254] The total allowable catch on the east coast was subsequently set at 54 tonnes for 2023. Recreational fishers are also permitted to target the stock. Increased commercial fishing pressure will continue while there is high demand for swim bladders in overseas markets and while high prices are attainable.

Fishers in the inshore fishery can harvest a variety of shark and ray species, but the extent differs to which each is targeted, retained and discarded. The targeted take of sharks in the fishery is restricted using a total allowable catch limit. The statuses of the northern Australia spot-tail shark stock [422] and the east coast stocks of the Australian blacktip shark[421] and common blacktip shark [420] were assessed as sustainable in 2020. The proposed removal of gillnets from the Region is likely to reduce the ecological risk posed to shark species. Since January 2024, the take of hammerhead sharks from the Region is no longer permitted. Implementation of monitoring, planned as part of the Sustainable Fisheries Strategy, will improve the understanding of retained and discarded shark catch.

In the **Spanish Mackerel Fishery** (a line-only fishery) the majority of commercial catch is taken from north Queensland, off the coast of Townsville.[1256] While Spanish mackerel are widely distributed around the northern Australian coastline, the Queensland fishery targets a single biological (genetic) stock.[1256] During spring, east coast Spanish mackerel form predictable spawning aggregations in waters north of Townsville, in October and November each year.[1256] These spawning aggregations support most commercial fishing effort and catch with estimates of around 40 per cent of the annual Queensland commercial harvest taken from the Region during the spawning season.[1256] The predictable schooling and aggregation behaviour has been associated with vulnerability to overexploitation and rapid stock depletion. Such behaviour can be associated with hyperstability, where catch rates remain generally stable as the fish population declines and fishery performance is overestimated.[1256]

Spanish mackerel stocks remain depleted at 17 per cent

The spawning biomass of Spanish mackerel has declined significantly as a result of historically high harvest levels.[1256,1257] From 2016 to 2020, the total Spanish mackerel annual harvest by all fishing sectors averaged 515 tonnes per year, which is approximately half the annual average harvested between 1973 and 2004. Estimated recreational catch in Queensland declined from 231 tonnes in 2013–14 to 171 tonnes in 2019–20.[1221,1223,1257] In 2021, the east coast Spanish mackerel stock was assessed as depleted, with the spawning biomass at 17 per cent of unfished levels.[1256,1258] In response to this decline, new management arrangements were implemented with the aim of rebuilding the stock while still providing a level of more controlled access for recreational and commercial fishers. The changes include short seasonal closures to reduce the overall targeted

fishing mortality and to improve protection of critical spawning aggregations. Also, the recreational possession limit was reduced to 1 fish per person or 2 fish per boat when 2 or more persons are onboard, and the total allowable commercial catch was reduced to 165 tonnes for the 2023 fishing season.[1258] The effectiveness of these measures in rebuilding the depleted stocks in a timely manner is yet to be determined.

The **Rocky Reef Fishery** is one of the smallest line-only commercial line fisheries operating in Queensland.[1259] It harvests 8 species or species complexes and predominantly targets Australian snapper and pearl perch.[1260,1261] While some take of these species occurs in the Region, most of the catch is from further south.[1262]

In 2020, the status of the Queensland component of Australian snapper was assessed as depleted, and the stock was assessed as recruitment overfished in 2018 with biomass estimated to be between10 and 45 per cent of unfished levels.[1261,1263] The stock assessment has not been updated since 2018. Commercial harvest of snapper in Queensland in 2019 was 25 tonnes, a level approximately 44 per cent lower than 2016 and 63 per cent lower than the previous 10-year average.[1261] Maintaining total harvest at previous levels is unlikely to rebuild stocks in the Queensland component of the stock, given the depleted state of the stock and low estimated spawning ratios.[1261] Similarly, the east coast pearl perch stock was classified as depleted at the beginning of 2020, with declines to around 22 per cent of unfished spawning biomass.[1264,1265]



Snapper and pearl perch stocks remain depleted

In September 2019, urgent management action for the Rocky Reef Fishery was introduced to reduce the impacts of fishing on depleted stocks of snapper and pearl perch while a rebuilding harvest strategy is developed.[1259] These management actions included new seasonal closures, commercial catch limits for snapper and pearl perch, and size restrictions. Modelling of environmental changes and the effects on snapper and pearl perch suggest that historical levels of harvest of these species are unlikely to be achievable in the future.[1266]

The commercial component of the **Reef Line Fishery**, previously named the Coral Reef Fin Fish Fishery, is a line-only fishery that operates predominantly in the Marine Park. It is Queensland's second most valuable fishery after the East Coast Otter Trawl Fishery.[1267] The majority of the catch is commercial harvest of coral trout for the live export market. Other target fish include redthroat emperor, saddletail snapper, red emperor and a range of other tropical snappers and bottom-dwelling reef fish. Charter and recreational fishing sectors also target the same species. The commercial component of the fishery is managed with total allowable commercial catch limits which are adjusted via individual transferable quotas, limited entry, minimum and maximum size limits, short spawning closures, no-take species, gear restrictions and vessel and tender restrictions. The estimated export value of this fishery experienced an increase from $7 million in the 2018–19 financial year to $12 million in 2019–20 but decreased the following year to $10 million after exports were affected by COVID-19.[1268]



Harvest of coral trout is considered sustainable

In 2020, the spawning biomass of coral trout was 59 per cent of unfished biomass and status of the stock was considered sustainable (Table 5.3, Section 8.3.4).[1269,1270] Between 2017 and 2021, the Queensland total retained catch averaged 1002 tonnes per year, including 812 tonnes by the commercial sector (Figure 5.7), 68 tonnes by the charter

sector, 111 tonnes by the recreational sector and 11 tonnes by traditional fishing.[1269] From 1 July 2023, the total allowable commercial catch for coral trout has been set at 912 tonnes which is a 51-tonne reduction from the previous year.[1228] There is uncertainty around whether the current stock assessment adequately reflects increased recreational effort since the COVID-19 pandemic.[1271] Redthroat emperor abundance was at 72 per cent of unfished biomass in 2020 and the status of the stock is sustainable.[1272,1273]



Commercial Reef Line fishery is Queensland's second most valuable fishery. © Commonwealth of Australia (Reef Authority) 2024

The first Queensland east coast stock assessments for three other target species in the Reef Line Fishery, red emperor, saddletail snapper and crimson snapper, were completed in 2021.[1274,1275,1276] The assessments showed small increases in biomass for all three species since historical declines, but all were below the 60 per cent target for biomass (Table 5.3). The saddletail snapper stock level was estimated to be between 13 and 73 per cent of unfished biomass, with the most likely estimate at 23 per cent. This is marginally higher than spawning biomass limit reference point (20 per cent) that is identified in the harvest strategy beyond which management efforts to rebuild stocks will be required.

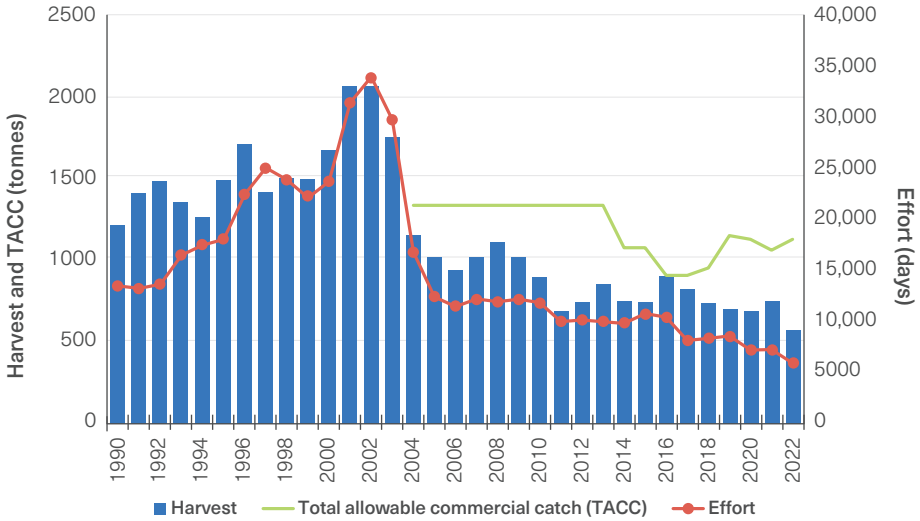


Figure 5.7 **Commercial coral trout line fishing harvest and effort in the Great Barrier Reef, 1990 to 2022**

Effort is expressed in fishing days (primary vessel). Source: Queensland Department of Agriculture and Fisheries (2023)[1227]

Table 5.3 **Stock assessment and stock status results for commonly targeted species in the Reef Line Fishery**

Source: Stock assessments and historical declines are based on models prepared by the Queensland Department of Agriculture and Fisheries. The stock status assessment results are published in the Status of Australian Fish Stock Reports.[1270,1273,1274,1275,1276,1277]

Fisheries resource	Modelled year of unfished biomass	Historical minimum biomass		Stock assessment		Stock status assessment
		Year	Per cent of unfished biomass	Year	Per cent of unfished biomass	
Coral trout	1953	2011	46	2022	60	Sustainable
Redthroat emperor	1945	2012	54	2020	72	Sustainable
Saddletail snapper	1961	2017	19	2020	23	Undefined
Crimson snapper	1958	2019	35	2020	44	Undefined
Red emperor	1953	2005	55	2022	58	Sustainable

Several crab species are commercially and recreationally targeted in the Region. In the Queensland crab fisheries, most of the annual harvest in the Region since 2019 has been mud crab. Spanner crab and blue swimmer crab harvests are mostly south of the Region and are taken in very small numbers from within the Region.[1227] The three species are managed under separate harvest strategies[1278,1279,1280] and the status of each was assessed as sustainable in 2020.[327,328,1281] The protection of female crabs and size limits that protect small males remain important measures for sustainability.[327,328,1281]



Live commercially caught coral trout in holding tanks prior to sale. © Darren Cameron 2019

The harvest of mud crabs in Queensland is higher than all other Australian mud crab fisheries combined (Northern Territory, Western Australian and New South Wales).[1280] However, commercial catch of mud crabs within the Region has declined in recent years, which reflects similar declines across the whole Queensland fishery, including recreational harvest.[1280] The commercial catch from the Region fell from around 703 tonnes in 2018 to 434 tonnes in 2022. Reduced catch rates, reflected in this decline in

total harvest, are reported by commercial fishers as not being economically viable.[1280] A stock assessment for mud crabs has not been completed; however, the stock status for the Queensland East Coast management unit was identified as being sustainable in 2020.[328] The blue swimmer crab stock has been declining since the mid-2000s and was around 33 per cent in 2018–19.[327,1282] Low catch rates continue to affect the profitability of the fishery, and there is competition for access to stock between commercial and recreational sectors. In 2022, the export approval for blue swimmer crab and mud crabs was revoked.[1283]

Queensland crab stocks were assessed as sustainable in 2020

The Australian east coast fishery for spanner crab is shared between Queensland and New South Wales and is the largest in the world.[1284] The Queensland commercial sector accounts for 80 per cent of annual harvests of the single Australian stock.[1284] After 2012, the fishery experienced several years of declining catches (Figure 5.8). In 2019, the total commercial spanner crab harvest in the Region was 54 tonnes, and in 2022, it was 610 tonnes.[1227] The spanner crab fishery relies heavily on export markets. In 2020, the fishery was affected by the COVID-19 pandemic due to instability in market demands and transport, with just 18 tonnes being harvested in the Region.

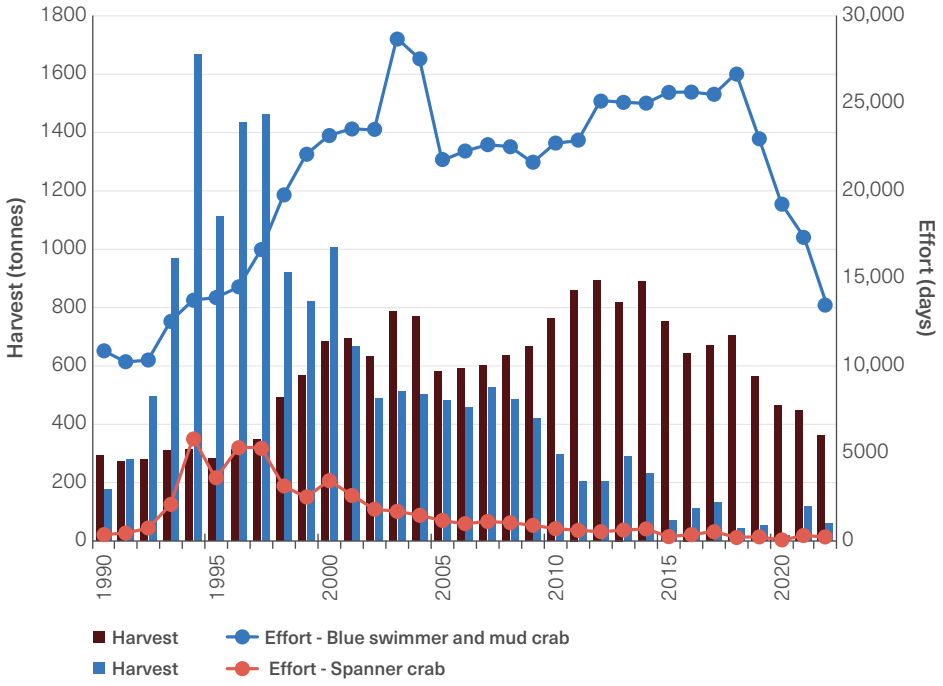


Figure 5.8 **Spanner (via dillies), swimmer and mud crab (via pot) fishing harvests and effort in the Great Barrier Reef, 1990 to 2022**

Effort is expressed in fishing days (primary vessel). Source: Queensland Department of Agriculture and Fisheries (2023)[1227]

Ongoing concerns remain about high latent effort in the crab fisheries, competition between commercial and recreational sectors and black-marketing due to the high value of products from this fishery.[1285,1286] In addition to compulsory vessel tracking in the commercial fishery, a number of new management arrangements came into effect on 1 September 2019. These included introducing individual transferable quota for mud and blue swimmer crabs, managing the recreational take of the two target species, and reducing risks associated with the black-marketing of mud crabs. The measures include

reducing possession limits for both species, imposing a boat limit for mud crabs and improving pot identification measures. Given implementation is only recent, information is limited on how these measures are influencing the impact of the fishery.[1286]

The main commercial **dive-based harvest fisheries** operating within the Region are the Sea Cucumber Fishery, Coral Fishery, Marine Aquarium Fish Fishery and the Tropical Rock Lobster Fishery.

The Queensland **Sea Cucumber Fishery** operates in offshore waters from Cape York to Tin Can Bay. The fishery allows collection by hand only and harvests more than 20 species of sea cucumber. The key target species are the burrowing black fish, white teatfish and black teatfish.[1287] The Queensland *Sea Cucumber Fishery Harvest Strategy: 2021–2026* was implemented in September 2021 to formalise the previously voluntary measures the industry was taking.[1287] The fishery is managed by limited entry (18 licences across 2 operators), transferable quota and a rotational harvest arrangement under which harvest reefs are split into 158 zones and a maximum fishing effort of 18 days per zone per year is allowed. The harvest strategy has species-specific management limits in biomass or catch to trigger specific actions. Species are harvested by hand collection only. There is no minimum size limit.[1287]



Key target species are the burrowing black fish, white teatfish and black teatfish

The total annual quota for the fishery is 391 tonnes, split between 53 tonnes for white teatfish, 30 tonnes for black teatfish and 308 tonnes for other sea cucumbers.[1287] The average annual total harvest for the fishery was 346 tonnes between 2019 and 2023. The annual harvest of white teatfish was around 52 tonnes between 2017 and 2020, while the annual harvest of black teatfish tonnes was around 30 tonnes in 2020 and 2021.[347]

Fishing for black teatfish reopened in 2019 after two decades of closure. The 2020 stock assessment for black teatfish estimated biomass at around 40 per cent of unfished stocks, indicating there is limited evidence of recovery since closure (Section 8.3.3).[347] The 2021 stock assessment of white teatfish estimated the exploitable biomass in 2021 was 76 per cent of unfished levels in 1995[1288] and the 2020 stock status was assessed as sustainable.[1289] However, uncertainty in this assessment remains due to the lack of biomass surveys for the species and assumptions underlying the assessment.[1290] Since 2019, no updated stock assessments for other species targeted by the fishery, including prickly redfish, amberfish and burrowing blackfish, had been completed at time of writing of the Outlook Report 2024. However, several assessments were underway.

The Queensland **Coral Fishery** is a hand-collection harvest fishery operating along the Queensland east coast, from the tip of Cape York to the southern border of the Great Barrier Reef. This fishery supplies live coral to domestic and international markets. Collection can only take place within permitted zones of the Marine Park. Approximately 38 per cent of the Marine Park is closed to commercial coral collection.

The fishery targets a large range of species which are predominantly exported.[1291] The total allowable commercial catch of 200 tonnes is divided into 60 tonnes for 'specialty coral' and 140 tonnes for 'other coral'. Total annual harvest generally fluctuates between 74 and 110 tonnes since 2006 but exceeded 110 tonnes for the first time in 2018–19. The amount of effort, participation rates and the number of pieces of coral collected have increased in recent years (Figure 5.9).[1291] These increases reflect a change in the dynamics of the fishery with larger quantities of smaller corals and coral fragments retained. This change is likely driven by increased market demands, as well as improved collection

techniques, operating procedures for export and advancement in propagation techniques in aquaria.[1291] The combined coral harvest and marine aquarium fisheries have the highest estimated export value of all fisheries in Queensland, which increased from $14 million in the 2018–19 financial year to $19 million in the 2020–21 financial year.[1268]

Effort, participation and the number of pieces of coral collected have increased

The Queensland Coral Fishery is currently undergoing reform driven by the Sustainable Fisheries Strategy and the requirement to address conditions of approval as a wildlife trade operation. Export by the fishery was approved under the EPBC Act in 2021, allowing export to continue for 3 years until October 2024, subject to conditions. A harvest strategy was implemented in 2021 and an ecological risk assessment conducted in 2022.[1291,1292] The harvest strategy, among other provisions, establishes a series of decision rules, trigger limits and reference points to guide the management of key species.[1291] The reforms aim to transition the fishery to a more comprehensive system of output controls specific to individual species and genera. These output controls will be supported by corresponding advancements in the systems used to monitor, report and validate catch data. A mechanism is also under development to distinguish between, and trace, wild-harvest corals and captive-bred corals.

Despite this progress, some uncertainties remain regarding the impacts of the fishery, such as the extent of localised depletion for species of high value and low abundance. There is also significant potential for catch and effort to increase at the species or regional level under current management arrangements.[1292] The effects of disturbances (for example, due to climate change threats) on the viability of the fishery into the future is not well understood.[1292] Available information on non-commercial collection of coral is limited, affecting broader understanding of the overall impact of coral collection from activities such as research, Indigenous take and reef intervention activities.[1291]



Coral harvest. © Commonwealth of Australia (Reef Authority) 2019

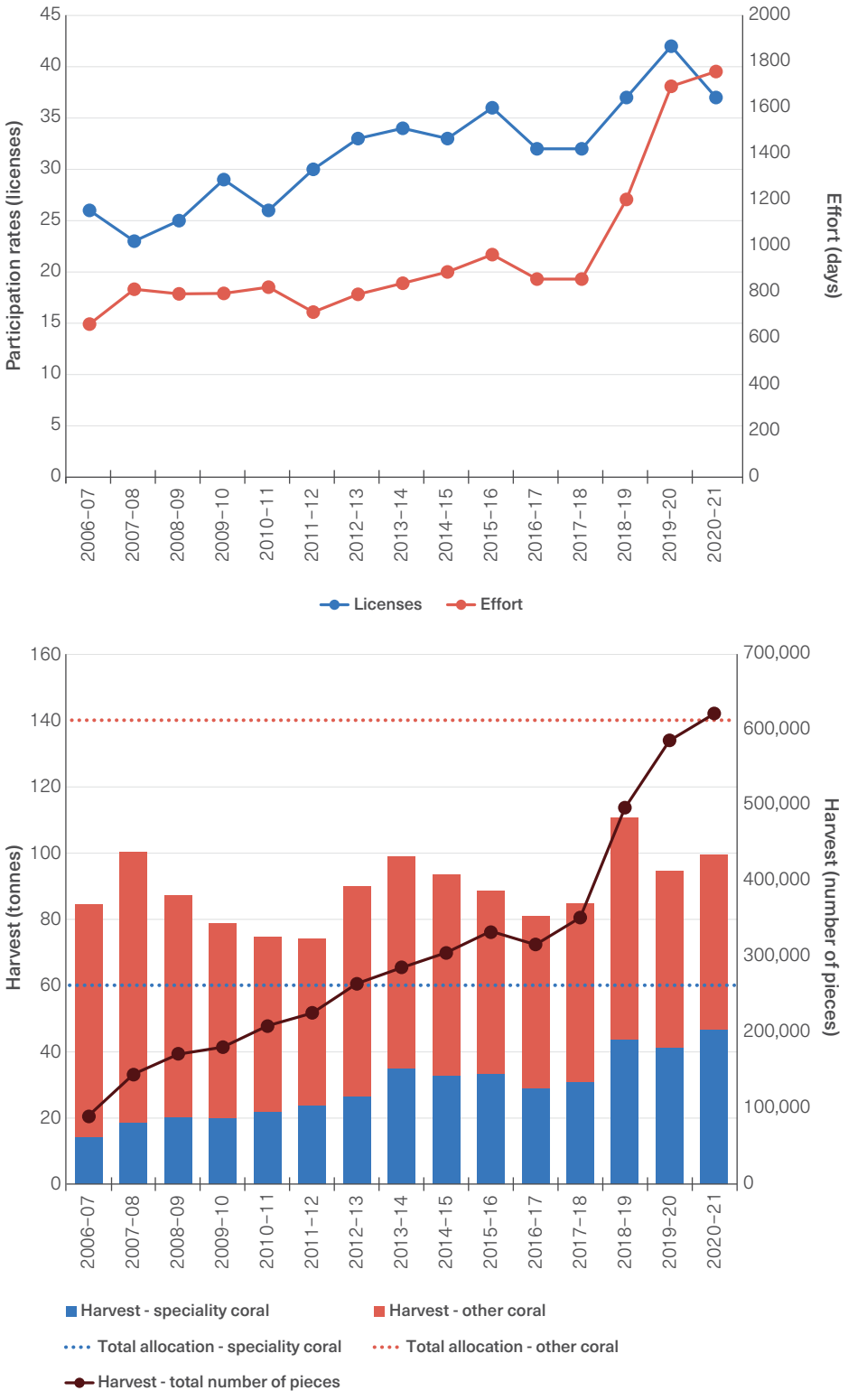


Figure 5.9 **Participation, effort and harvest in the Queensland Coral Fishery 2006 to 2021**

Top: Participation rates (active licences) and effort (days). An active licence means any licence with a 'D' fishery symbol that has reported catch from the fishery during a given season. Bottom: Annual harvest (tonnes and pieces) and total allocation (tonnes). The total allocation means the maximum permitted annual quota for the fishery. Updated harvest information is available on QFish. Source: Queensland Department of Agriculture and Fisheries (2022)[1291]

The **Marine Aquarium Fish Fishery** primarily operates within the Region. It collects a wide variety of fish and invertebrates for the live aquarium trade,[1293] most of which is exported under a wildlife trade operation approval.[1294] While the number of active licences has generally remained stable between 23 and 30 since 2010, there has been a decline both in effort and in the number of operators reporting catch from the fishery each year.[1295] This corresponds to operators prioritising the harvest of corals in the Queensland Coral Fishery, likely due to changes in market demand.

Between 2010 and 2022, at least 20 families of marine fishes, marine invertebrates and elasmobranchs (sharks and rays) were retained in the fishery.[1295] More than 1500 marine species could be harvested from Queensland, but only a few hundred are collected regularly. Approximately 70 per cent were fishes (primarily damselfishes and wrasses).[1295] Stock assessments and stock status reports have not been conducted for most targeted species. A 2020 ecological risk assessment for the fishery found that the ecological impact of the fishery is generally considered to be low. However, there are a number of deficiencies in the data and in the catch reporting.[1296] An updated ecological risk assessment for target species is being prepared, and improvements to data collection are planned under the Queensland *Marine Aquarium Fish Fishery Data Improvement Plan.*

Ecological impact of marine aquarium fish fishery is generally low

The **Tropical Rock Lobster Fishery** operates almost exclusively in Reef waters on the east coast between Cape York and Cape Melville. The fishery predominantly supplies a live export market. The season is closed from 1 October to 31 December in the regulated fishery area.[1297] The fishery consists of approximately 8 active licence holders and collection is by hand, to a depth of 25 metres. The ornate rock lobster is the key target species with other species only contributing marginally to the harvest.[1297] From 2019 to 2022, the total harvest remained relative stable between 54 and 76 per cent of the total allowable catch. However, international trade disruptions and trade tensions with China have affected export demand and sales over the past few years.[1298] In 2019, harvest decreased to near historical lows (Figure 5.10). The tropical rock lobster population in north Queensland is considered to be connected to the Torres Strait and Coral Sea populations. The status of this north-eastern Australian stock is classified as sustainable.[1297] A stock assessment has not been updated for Queensland ornate rock lobster since 2011.

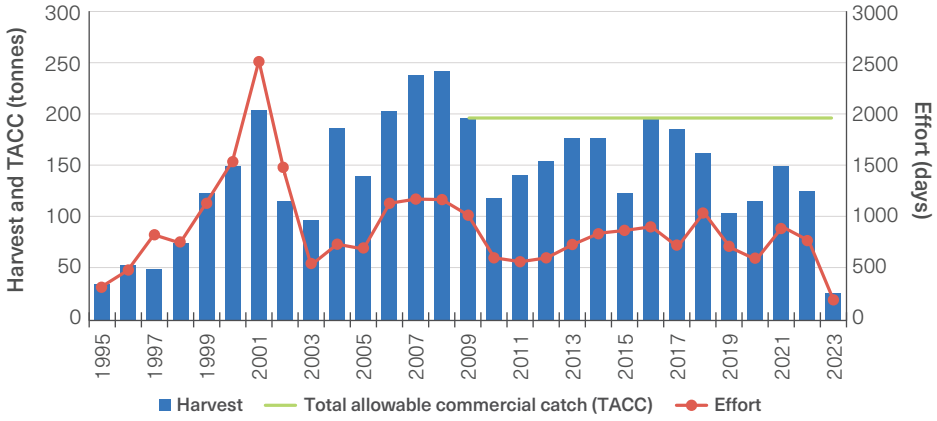


Figure 5.10 **Tropical Rock Lobster Fishery harvest and effort in the Great Barrier Reef, 1995 to 2023**
Harvest and total allowable commercial catch are expressed in tonnes; effort is expressed in fishing days. 2023 data until October only. Source: Queensland Department of Agriculture and Fisheries (2023)[1227]

This fishing assessment considers the capture and extraction of sharks from the Region that occurs under the **Queensland Shark Control Program**. This program has been implemented under fisheries legislation since 1962 and aims to reduce risk of shark interactions with swimmers in Queensland waters at popular swimming locations. Currently no shark nets are deployed in the Marine Park and a total of 131 drumlines are allowed under a Marine Parks permission.

The current program is enacted through the *Queensland Shark Management Plan 2021–2025* and includes the operation and maintenance of shark nets and drumlines, research to understand the risk of shark bites, trials of alternative mitigation strategies, and educational programs. From July 2019 to June 2023, approximately 1415 sharks were caught within the Marine Park under the program with around 50 per cent of these being target species (tiger shark and bull shark).[1299] Most target species were found deceased or euthanised. Thirty-one per cent of all non-target captures were released alive. In total, 708 non-target sharks and 49 other non-target animals were caught, including fish, rays and turtles, of which 31 per cent were released alive. By comparison, there were 1251 target sharks taken and 232 non-target sharks caught between 2014 and 2017, with 36 per cent of non-target sharks released alive. The first phase of the trials of alternative mitigation strategies is underway to compare interactions and survival of marine fauna caught with 11 catch alert drumlines and 11 modified traditional drumlines.

Management | The offshore constitutional Settlement arrangements and the *Great Barrier Reef Intergovernmental Agreement 2015* identify that the Australian and Queensland governments have interrelated roles and responsibilities related to fishing.[1300] Subject to meeting the overarching objective of the Marine Park Act, namely long-term protection and conservation, the Offshore Constitutional Settlement provides for the Queensland Government to have lead responsibility for fisheries management within the Region.

Management of fisheries (for the purposes of commercial and recreational take) occurs under the *Fisheries Act 1994* (Qld) and supporting regulations. Management of fishing activities and impacts on the species and habitats of the Reef occurs through the Marine Park Act and the EPBC Act. The zoning plans, which apply to all fishing activities in the Marine Park, specify areas that can be fished and the type of fishing that can be undertaken. Provisions related to fishing also apply under Plans of Management. Operationally, the Australian and Queensland governments work cooperatively through the Reef Joint Field Management Program to conduct fisheries-related surveillance and other compliance and enforcement activities.

Recreational fishers in Queensland do not require a fishing licence. Recreational fish size, take, possession and gear limits apply, and the sale of any fish caught recreationally is prohibited.[1301] Seasonal closures also apply for some species. Guidance on release techniques for line-caught fish is available.[1302] There remain limited data to allow a comprehensive assessment of recreational fishing take and associated impacts.

For commercial fishing activities, management arrangements include licences for all operators, total allowable commercial catches for some species, fish size and possession limits, restrictions on fishing apparatus, closed areas and seasonal closures. In addition to the controls on recreational and commercial fishing under the under the *Fisheries Act 1994* (Qld), commercial harvest fisheries and all developmental fisheries also require Marine Parks permissions under the zoning plans.

For commercial fisheries that export produce overseas, management arrangements must be accredited as a wildlife trade operation under the under the EPBC Act. The accreditation process includes assessment against guidelines for the ecologically

sustainable management of fisheries.[1303] Since 2019, all species of hammerhead sharks, guitarfish and requiem sharks have been listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). This means they are identified as at risk of being threatened with extinction if trade is not closely controlled and require a wildlife trade operation accreditation. Sea cucumbers, including white teatfish, black teatfish, prickly redfish and amberfish, have also been listed in Appendix II since 2019.



Queensland Sustainable Fisheries Strategy continues to drive important reforms

Fisheries have been subject to reforms through the Queensland Government's Sustainable Fisheries Strategy (Box 5.2).[1251] The strategy sets out a reform agenda across 10 major areas, including improved monitoring and research, setting sustainable catch limits, improved stakeholder engagement, environmental risk assessments, resource allocation, harvest strategies, fishing rules and access, responsive decision-making, compliance and resourcing. All major fisheries are now managed under harvest strategies, which specify overall fishery objectives, fishery performance indicators, pre-determined triggers for management action and appropriate management decision rules (Box 5.2).

Under the strategy, new Queensland Government regulations commenced in 2019 with the aim of protecting the long-term sustainability of fisheries; rebuilding depleted snapper, pearl perch and scallop stocks; combatting black-marketing of priority species; and standardising fishing rules and supporting compliance.[1304,1305,1306] Further regulatory changes primarily affecting commercial operations took effect in 2020.[1307] The changes standardised reporting requirements for all commercial fisheries[1308] and modified the quota allocations for the crab[1309] and east coast inshore[1310] fisheries, and the effort unit allocation for trawl fisheries.[1311] Additional changes in 2022 included modified effort cap and closure arrangements for the East Coast Otter Trawl Fishery,[1312] as well as closure arrangements, limits for recreational and charter take, and total allowable commercial catch of Spanish mackerel.[1313] The latter coincided with the publishing of a new harvest strategy for the east coast Spanish Mackerel Fishery that aims to rebuild the stock following the 2021 stock assessment.[1256,1258]

In June 2023, Australian and Queensland governments announced several reforms to address risks to the Reef from fishing and transition the industry to more sustainable fishing practices. The reforms include a reduction in the number of gillnet licences in the Marine Park before 31 December 2023 (approximately 240 down to 40 licences), phasing out the use of gillnets by June 2027, making hammerhead sharks no-take species for commercial fishers in all Queensland waters, and introducing legislation to mandate independent data validation on commercial fishing vessels. The *Fisheries and Other Legislation (Structural Reform) Amendment Regulation 2023* has been implemented to enact these commercial fishing regulation changes. A Fisheries Structural Adjustment Scheme has been implemented to support eligible industry members affected by these changes.

The Reef 2050 Traditional Owner Implementation Plan (Box 10.2) published in 2023 includes actions that relate to implementation of the fishing reforms. The actions aim to ensure First Nations peoples' rights, interests and obligations in the conservation, customary use and management of fisheries resources are appropriately considered and cultural risk assessments and Indigenous sector allocations are included in harvest strategies.[1120]

Concerns remain regarding some aspects of current fisheries management, particularly in relation to depleted stocks and information gaps. For some key target species, such as mangrove jack, no stock assessment has been undertaken or planned, and the stock status is undefined. Independent validation of fishers' logbook reporting is limited following cessation of the independent fishery observer program (for all fisheries) in 2012. However, there have been recent commitments to improve independent data validation in fisheries (Box 5.3).[1314,1315] Reporting of interactions with **species of conservation concern** is limited, as is monitoring of fishery discards.

5.4.2 Benefits of fishing

Commercial fishing is an important source of income for Queensland coastal communities and plays a vital role in Australia's seafood industry. In the 2020–21 financial year, the Queensland commercial fishing industry supported an estimated 3484 jobs and 1031 businesses and contributed $279.3 million in gross production value to the economy.[1268] The majority of this production value (86 per cent) was sold to the domestic market. In the same period, commercial fishing in Queensland generated an estimated $397.3 million in total gross state product throughout the Queensland's state economy (that is, including direct and flow-on contributions). While estimates vary across studies, the average annual value of commercial fishing in the Region is approximately $200 million.[1316] Globally, in the past 5 years, aquatic foods have become a growing subject of research and policy interest, with studies highlighting the important contribution of fish and other marine foods towards human health and nutrition.[1317]



Commercial fishing generated $397.3 million for Queensland's economy

In 2020–21, Queensland's commercial fishing output (wild-capture fisheries) was $157 million.[1198] Over the past 5 years, domestic and international factors have constrained growth in the Australian commercial fishing industry, including additional costs to fishers from government-imposed catch limits and competition from low-cost imports from Asia.

In 2019–20, the economic output of Australian aquaculture surpassed commercial fishing for the first time, driven primarily by Tasmania. In Queensland, growth in the aquaculture industry since 2019[1318] has led to government investment in the development of the industry and the implementation of aquaculture development areas within the Catchment (Section 6.4.1). However, assessments of projected growth in aquaculture within the Catchment remain limited.

Commercial fishers also derive non-financial benefits from fishing. These include a high personal connection to the Reef and a strong appreciation for the Region's natural beauty, aesthetics and lifestyle benefits.[1319] In 2020–21, about half of the commercial fishers felt they understood the fishery management arrangements for the fisheries they are involved in, but most felt that the management changes in the past few years had made it more difficult to operate their business.[1268] Many surveyed were concerned about their future security.

The COVID-19 pandemic and associated government health directives affected fishing in Queensland. It is difficult to attribute changes in economic return directly to COVID-19 pandemic management, given the many factors that contribute to Queensland's economic and market activity,[1268] and the significant reform program progressing under the Sustainable Fisheries Strategy.[1320] However, the loss of international markets and international freight caused many commercial fishing businesses to stop exporting. The domestic market for seafood was also affected by COVID-19 pandemic management. The

loss of the visitor economy in Queensland led to a significant fall in the amount of seafood purchased by local businesses, and this was exacerbated by local market oversupply from almost all Queensland fisheries.[1229]



Recreational fishing provides personal connection, enjoyment and wellbeing for communities.
© Dieter Tracey 2024

The 2020–21 forecast for gross value product from Queensland commercial fisheries was $170 million. This forecast is 12 per cent lower than the estimate for 2019–20 and 16 per cent lower than the 4-year average.[1229] It is estimated that the economic contribution of Queensland's commercial fisheries to gross state product was reduced by approximately $105 million and the employment supported by the fisheries dropped by approximately 188 full-time jobs. Fisheries — including coral trout and spanner crab — which relied on high-value live export markets were affected by the COVID-19 disruptions through international border closures.[1320] The largest negative impact of COVID-19 identified by fishers was in the East Coast Otter Trawl Fishery (loss of $39.2 million gross state product and 80 full-time jobs).[1229] While the export value and gross value product for combined coral harvest and marine aquarium fisheries increased between 2019–20 and 2020–21, the net economic return was not as high as forecast.[1268]

In 2020–21, the charter fishing sector in Queensland supported an estimated 325 jobs and 139 businesses and contributed $30.9 million in gross production value to the economy.[1321] In the same period, charter fishing generated an estimated $40.0 million in total gross state product (that is, including direct and flow-on contributions). However, during this period, the charter fishing sector was affected by border closures due to the COVID-19 pandemic. The border closures resulted in an estimated loss of 18 full-time jobs and $9.8 million in gross state product.[1321] In a 2020–21 survey, more charter fishers felt that management changes made it more difficult to operate their business than in the preceding year.

In 2019–2020, recreational fishing in Queensland by residents generated an estimated $333.7 million in total gross state product throughout Queensland's state economy (that is, including direct and flow-on contributions), $209.5 million in total household income and 3136 jobs.[1322] Within the Region, the highest estimated total expenditure on recreational

fishing was in the Dry Tropics region (approximately from Bowen to Ingham) at $81.54 million in 2019–20.[1322] Estimates suggest that, on average, Queensland recreational fishers expend $295 on each recreational fishing trip.[1316] During the COVID-19 pandemic, the economic contribution of recreational fishing was estimated to be $1.5 million total gross state product, an increase of 0.4 per cent.[1322] Recreational fishers also derive non-monetary benefits from recreational fishing, such as personal connection, enjoyment and wellbeing.[1323,1324]

An annual time-series capturing economic and social indicators of the Queensland commercial, charter and recreational fishing industries has advanced the availability of relevant data since 2019. Improvement in participation of active commercial fishing businesses in the survey is needed to provide a more comprehensive analysis.[1268]

5.4.3 Impacts of fishing

Fishing removes biomass from the Region and, when harvest is not conducted in an ecologically sustainable way, it can affect the abundance of targeted species locally and at a population level. Declines in populations of culturally significant species affected by fishing can have flow-on implications for the Region's Indigenous heritage values (Section 4.3), such as cultural practices, observances, lore, stories, songlines and sites.

BOX 5.3

Validating commercial fishing data

The Queensland Department of Agriculture and Fisheries currently collects commercial fishing data from a wide range of sources, including commercial logbooks, catch disposal records, quota notices and vessel tracking systems. Independent validation of catch, effort and protected species interactions will ensure accurate information is used to inform best-practice management decisions that support the sustainable management of fisheries resources.

As part of the Sustainable Fisheries Strategy,[1251] a key action was the creation of a fisheries data validation plan in 2018.[1327] The plan provides a framework for the validation and collection of more accurate fisheries information with priority actions, including range checks, cross checks, forensic auditing, improved data systems, education, electronic logbooks and electronic monitoring.[1327]

Major reforms to Queensland fisheries legislation through the Sustainable Fisheries Strategy has changed reporting requirements. In 2023, the data validation plan was updated [1328] and future work will focus on further developing the Qld eFisher app, progressing the electronic monitoring project with a field trial, reviewing and updating range and cross checks, and improving data systems.[1328] In 2024, independent data validation was mandated in some Queensland fisheries, including gillnet and trawl fisheries. Evaluation trials for onboard cameras have commenced with new net licence symbols being released with mandated onboard cameras.

Improved data collection and independent data validation is a critical step toward improving our understanding of impacts from fishing, particularly in relation to interactions with species of conservation concern.

Since 2019, the Sustainable Fisheries Strategy has guided a range of key efforts by the Queensland Government to better understand the impacts of fishing, including through updated stock assessments, stock status reports, ecological risk assessments and a data validation plan (Box 5.3). Approximately 42 per cent of more than 60 Queensland east coast fisheries resources that are fished within the Reef have been assessed as sustainable.[1325,1326] However, 32 per cent have not been assessed or are undefined and the status of some targeted species remain cause for community and scientific concerns.[793,1256,1261,1265,1276]

Predators, such as coral trout, emperors, mackerel and sharks, make up nearly 40 per cent of the total commercial harvest (Figure 5.11) and the majority of the recreational fishing catch.[1225] Reductions in predator populations can have long-term effects on marine systems, including direct and indirect effects on the food chain (Section 3.4.5). For example, predator abundance and behaviour changes can alter food webs and result in flow-on effects for herbivore populations that moderate algal cover on coral reefs.[1329,1330,1331]

Some predatory species are subject to considerable fishing effort, as demonstrated by stock assessment and stock status findings described earlier in this section for Australian snapper, pearl perch, Spanish mackerel, saddletail snapper and black jewfish.[1261,1265,1257 1276 1254] In some cases, assessments are hindered by data limitations, and no stock assessment has been completed for some key target species.

Some sharks and rays are at higher risk from fishing than others.[817,1332,1333,1334,1335,1336] The stock statuses of three common species of reef shark have been assessed as sustainable. However, current assessments of other shark species are lacking, including hammerhead sharks and bronze whaler. Sharks and rays are discarded in the trawl fishery, but mortality and health impacts are still a concern.[1337,1338,1339,1340] The equipment used in the Queensland Shark Control Program extracts targeted sharks and also interacts with other species, including some species of conservation concern (Section 5.4.1).

Particle feeders (such as prawns and scallops) account for more than half of the weight of the total retained commercial catch across the Region's four main fishery types (Figure 5.1).[1227] Overharvesting will cause population declines. Saucer scallops were identified as depleted in 2022 with limited evidence of recovery since 2016.[793] Potential flow-on effects of extraction include damage to other particle feeders, such as sponges, and changes to other ecosystem processes (for example, to predation through changed feeding opportunities).[9] Uncertainties around the impact of coral harvest remain and existing efforts to improve data collection and reporting in the harvest fishery are expected to enhance this understanding.

In addition to extracting retained catch, fishing can cause death, or injury and stress, to the **discarded species**. For example, post-trawl survival analysis for two small elasmobranch (shark and ray) species caught incidentally in the Region's prawn fisheries found lowered survival with increased time on deck and differences in capture and release resilience.[1338]

Preliminary analysis for the Region in the Outlook Report 2009 suggested non-retained catch (discards and bycatch) by commercial fisheries is likely to be significantly higher than the retained catch, with the trawl fishery responsible for most of the non-retained catch.[3] Discards from the Queensland East Coast Otter Trawl Fishery declined by around one third between 1988 and 2014 primarily due to concurrent reductions in fishing effort over this period.[1341] Due to an increase in fishing effort, discards from the deepwater eastern king prawn component of the trawl fishery approximately doubled from 1988 to 2014, which contrasts markedly with the other components of the fishery and the overall fishery trend. Discard rates in the shallow eastern king prawn component of the trawl

fishery were 3 to 6 times higher than the deepwater fishery.[1341] Commercial fisheries are not required to report discards so discard rates in the trawl fishery since 2014, and from other fisheries, remain poorly quantified.

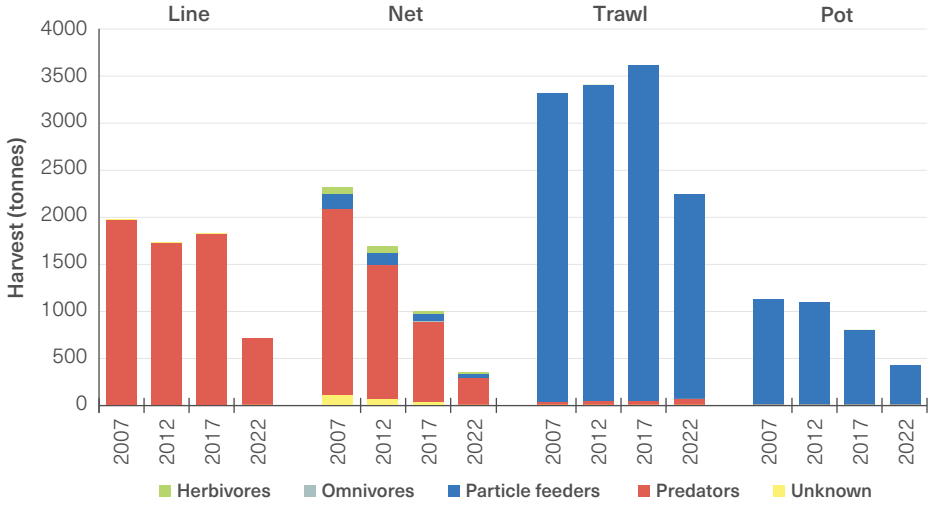


Figure 5.11 **Ecological groups retained by major commercial fisheries in the Great Barrier Reef in 2007, 2012, 2017 and 2022**

Predators and particle feeders make up the majority of the harvest retained by commercial fishing in the Region. Particle feeders include species that are primarily filter feeders, detritivores and scavengers. Data are for commercial retained catch only. Discarded catch and bycatch are not included. Source: Queensland Department of Agriculture and Fisheries 2023[1230]

Recreational fishers generally release more than 70 per cent of animals caught due to catch-and-release practices or due to the catch being undesirable, too small or outside the legal size limit.[1224] Sharks and rays are not generally targeted by recreational fishers; an estimated 95 per cent of these catches are released because they are unwanted.[1224] Catch-and-release practices presume the fish is likely to resume normal behaviour and survive.[1342] However, stress or injury from fishing interactions can lead to post-release mortality. Behavioural impairments can increase a released fish's susceptibility to predation.[1343] Recreational fishing can be a significant pressure on coastal fish stocks, with recreational harvest exceeding commercial harvest for some species.[1223,1225,1344]

Recreational fishing take and associated impacts is a not well understood

Information from voluntary recreational fisher boat ramp and diary surveys are highly valuable but are limited in their ability to allow a comprehensive assessment of recreational fishing take and associated impacts. Recreational fishers typically harvest a wider range of species and size classes than those targeted and taken by commercial fishers. The increase in efficiency of recreational fishers through new technologies, such as GPS, side-scan and three-dimensional sonar, and changes to fisher behaviour, such as rapid information transfer via social media, may alter the harvest profile of the fishery in the Region.[1345,1346] Impacts to particular species or stocks from recreational fishing are difficult to quantify due to the high number of fishers and different techniques used. New research methods are being trialled under the Sustainable Fisheries Strategy to improve estimates of recreational harvest and effort.

Understanding depredation of catch, which occurs when a fish caught in fishing apparatus is completely or partially consumed by other marine animals before it can be landed, is coming under increasing focus.[839,842,844,1347,1348] Depredation can lead to

economic (lost fishing gear and catch), social (reduced quality of fishing experience and conflict between stakeholders) and ecological (increased mortality of target species, injury and bycatch of sharks) impacts.[1347] Depredation is likely to lead to underestimates of fish mortality in both commercial and recreational fisheries and may affect stock assessments. However, the nature and scale of depredation impacts on biodiversity, social and economic values remain a knowledge gap.[407,839]

Incidental capture, entanglement and death of **species of conservation concern** as a result of commercial fishing continue to affect the Region's ecological values.[1349,461] The 2021 Queensland ecological risk assessment for the East Coast Inshore Fishery identified that gillnets present a high risk to the majority of species of conservation concern.[1349] These species, such as inshore dolphins, dugongs, sawfishes and some marine turtles, are particularly vulnerable.[1350,1351,1352,1353,1354] Loss of even small numbers of individuals may have a substantial effect on population status, resilience and rate of recovery from past impacts. The 2023 Queensland ecological risk assessment for the East Coast Otter Trawl Fishery identified several species at high risk from trawling activities based on these vulnerabilities, and further management action was required to reduce risks to one species, green sawfish, in the Region.[437]

Between 2003 and 2017, the East Coast Inshore Fishery reported around 2000 green turtle interactions from large mesh net operations, followed by loggerhead turtles and hawksbill turtles with 124 and 41 interactions, respectively.[1349] In the same period, 37 dugong and 6 dolphin interactions were reported. Interactions are also reported through the Queensland StrandNet marine wildlife stranding and deaths database,[461] though not all incidents can be directly attributed to *in situ* fishing activities (as opposed to marine debris and ghost nets).

Between 2019 and 2021, in the East Coast Otter Trawl Fishery, approximately 2400 interactions were reported with threatened, endangered and protected animals of which more than 99 per cent were sea snakes. Despite mandatory reporting of these incidents, many interactions are not reported, and reporting of the survival of released animals may be inaccurate.[1349] Therefore, the magnitude of the impact is likely to be underestimated and concerns remain about the reliability and accuracy of report interactions. It is also important to consider the cumulative impact of interactions across multiple fisheries.[1355] The removal of gillnets from the Marine Park by 2027 is expected to reduce the likelihood of interactions. Work is progressing under a *Queensland Data Validation Plan*, with a key focus on field trials of onboard cameras, control systems and software to detect and provide validated reporting of interactions during commercial trawl fishing activities (Box 5.3).[1327]



Discarded crab pot at low tide. © Connie Rowe 2023

Fish **spawning aggregations** are recognised as a natural phenomenon that contributes to the Reef's outstanding universal value.[1356] They are protected to some extent by the current zoning arrangements. Seasonal fishing closures have been introduced since 2019 for Spanish mackerel, snapper and pearl perch. Other than for barramundi, spawning aggregations of inshore species — including golden snapper, barred javelin and black jewfish — are not protected by seasonal fishing closures. The Coral Reef Fin Fish Fishery is subject to short seasonal closures during spring based on the expected seasonal and lunar spawning of the common coral trout. However, new research has indicated that this species spawns year-round with little to no alignment with existing closures.[1357] The spatial and temporal distribution of spawning aggregations of Spanish mackerel has contracted over time, with one aggregation near Cairns now commercially extirpated.[1358,1359] The loss of spawning aggregations has important ramifications for fish population dynamics and can lead to localised stock collapse with negative ecological, social, cultural and economic consequences.[1360]

Physical damage to the seabed and reef habitats occurs as a result of some fishing activities. Line fishing gear can cause direct physical damage to live coral tissue and coral colonies and can contribute to increased coral disease.[1361] Physical damage to reefs and shoals can be caused by poor anchoring and retrieval practices, and is of concern, but the extent to which this occurs across the Region is poorly quantified. Damage to benthic habitats is also caused by grounding (and in some cases sinking) of commercial and recreational fishing vessels in the Region (Figure 5.16). Trawling has physical impacts on habitats in the Region and can remove or damage seabed plants and animals. While risk for seabed biodiversity has been reduced by trawl management actions, some concerns remain. For example, an area in the southern Reef has been identified as being among the national hotspots for risk from trawling and is the area at highest potential risk within the Region.[1237,1238] High trawling effort levels and a poor understanding of the habitat in this area contribute to the risk. At-risk, long-lived, deep-water elasmobranch species occur in this area and are taken and killed in trawl bycatch.[1332] Further information on the risk from fishing to these species is needed. The impacts of trawling on upper continental slope habitats must also be better understood. Physical damage can also affect underwater historic heritage sites. Discarded fishing line and loss of fishing gear contribute to **marine debris** (Section 6.5.1), causing entanglement and ingestion by marine species.

Illegal recreational fishing in the Region continues to be of concern. The number of reported offences has averaged around 670 each year since 2018–19 (a 35 per cent increase since the preceding 5 years).[1362] During the COVID-19 pandemic, the number of reported offences peaked at 814 which likely correlates to an increased number of people accessing the Reef for recreational purposes. Illegal recreational fishing accounts for approximately 50 per cent of the 1266 fishing and non-fishing possible offences reported in 2022–23. The increasing trend in non-compliance reports may reflect improved surveillance efforts and technologies, such as new high-speed patrol vessels armed with technology for detection at night. Rate of change in recreational fishing effort (and therefore, likelihood of offences) is not well known, but is generally expected to correlate with population growth in the Catchment and long-term increases in recreational vessel registrations (Section 5.5.1).

Understanding of the spatial and behavioural patterns of fishers remains a focus and indicates illegal extraction from no-take zones is more likely to occur at some locations than others.[1363,1364,1365 1366] Between 2019 and 2023, 37 per cent of all reported poaching occurred in only 10 no-take zones.[1362] By contrast, in 2017 this was higher with 50 per cent of all reported offences occurring in 10 no-take zones.[1362] Reported offences tend to occur in no-take zones that also attracted high levels of legal non-fishing activity, a finding that provides insight into the opportunity factors that increase the risk of poaching.[1363] While the majority of recreational fishers consider this type of illegal poaching to be

personally and socially unacceptable, the use of different social survey techniques has found that between 3 and 18 per cent of recreational fishers will admit to having fished in no-take Marine Park zones during the past year.[1364] Even low levels of poaching can have substantial impacts on fish populations and ecosystem health.[1367]

The number of **commercial fishing offences** in the Region increased from 66 in 2017–18 to around 230 in the 2019–20 and 2020–21 financial years.[1362] During this period, the industry was transitioning to compulsory vessel tracking, with all commercial fishing boats required to have tracking capability by 2020. Since implementation, the number of reported offences has steadily declined to 133 in 2022–23. The majority of offences involved Coral Reef Fin Fish Fishery dories transiting no-fishing zones while not attached to a primary fishing vessel. Fishing offences in other commercial fisheries are generally less frequent.

Some commercial and recreational fishers employ counter-surveillance tactics to avoid detection of their illegal activity. Therefore, the actual extent of illegal fishing by both sectors is considered to be greater than the number of detected offences suggest. The expansion of commercial fishing vessel tracking has substantially improved commercial fishing compliance rates and the efficiency and efficacy of the multi-agency surveillance program.[1362]

5.5 Recreation (not including fishing)

Recreation is defined as an independent visit to the Region for enjoyment that is not part of a commercial operation. It is distinct from tourism, where a visitor pays to use a commercial operation.[1098,1368]

5.5.1 Current condition and trends of recreation

The Reef is enjoyed recreationally by Queensland's coastal communities,[1369] by other Australians[1370] and by the broader international community. Aside from commercial operations and tourism, people use the Region for a wide range of recreational activities, including relaxation, stress reduction through access to natural settings, and enjoyment through snorkelling, boating and diving. Recreational fishing, a major part of recreational activities, is considered in Section 5.4.

Quantifying and monitoring recreational use of the Reef in terms of numbers of people and locations is difficult and gaps remain in our understanding of trends. It is especially hard to distinguish recreation other than fishing from reported statistics that often include recreational fishing and sometimes tourism.

In a 2021 survey, 82 per cent of Region residents had visited the Reef at least once in their lifetime and 50 per cent had visited the Reef once in the previous 12 months for recreation.[1075] Most residents (35.5 per cent) visit only once, twice or every few months. A smaller proportion (14 per cent) make more regular visits, either monthly, fortnightly, weekly or more than once a week (Figure 5.12).[1075] Slightly more than 50 per cent of the residents who had already visited the Reef once in their lifetime reported that they would choose to visit the Reef over other places in their recreational time.[1075] Residents place a high value on the socialising and lifestyle benefits provided by the Reef.[1075] The most popular recreation activities in and around regional waterways include swimming, picnics and barbecues, wildlife watching and nature appreciation, exercising and fishing (recreational fishing is addressed in Section 5.4).[1159]

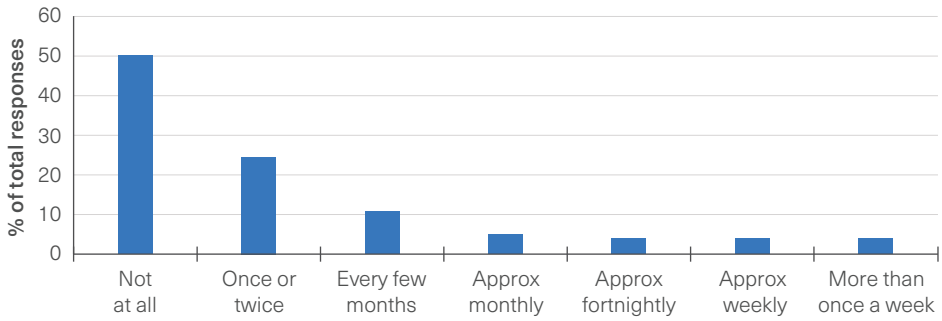


Figure 5.12 **Residents' frequency of visitation of the Reef for recreation in a 12-month period (2021)**
Responses from 2488 residents. Source: Hobman *et al.* (2022)[1075]

The number of recreational vessel registrations in 2018 to 2022 is the highest recorded and has increased in proportion to population growth in the Catchment (Figure 5.13). The impact of COVID-19 lockdowns and border restrictions on recreational use varied throughout the pandemic. Nationally, the ability to access to Reef depended on the proximity of residents to the Reef and different state health policies. Initially restrictions were placed on recreational boats accessing waters.[1371] In Queensland, restrictions initially did not allow travel further than 50 kilometres from a person's primary residence or fishing and boating except for obtaining food. As restrictions relaxed and travel resumed across the entire state, recreational boating provided an outlet for families and friends to connect with the Region. Border restrictions mostly stopped interstate and international boats and yachts from accessing the Region. From 2020 to 2021, people also diverged away from centralised workplaces and large population centres to regional areas, with the largest internal migration being to Queensland.[1372,1373]

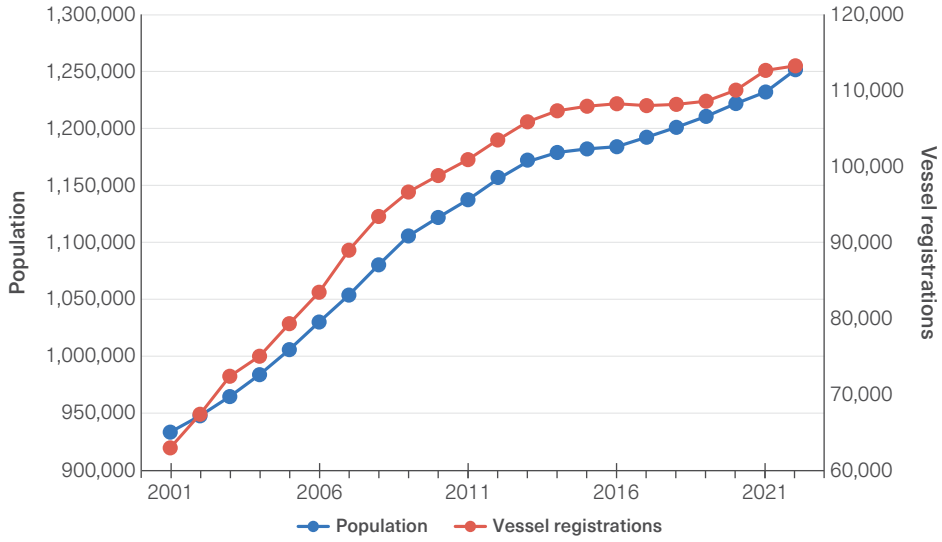


Figure 5.13 **Number of recreational vessels registered and population in the Catchment, 2001 to 2022**
Source: Queensland Department of Transport and Main Roads (2023),[228] Australian Bureau of Statistics (2022)[229]

The Reef is accessed by large number and wide range of recreational users. Most recreational vessels registered in the Catchment are less than 5 metres in length, so recreational use is generally concentrated in inshore areas close to urban centres. The Cairns, Townsville, Mackay, Bundaberg and Fraser Coast (including Maryborough) local government areas have the highest numbers of boat registrations in the Catchment (Figure 5.14). Local residents spend a significant portion of their leisure time along the Reef coastline in coastal and inshore waterways, freshwater systems and estuaries.[1075]

However, 48 per cent of local residents surveyed also reported accessing offshore marine areas.[1075] Marked increases in registrations of both small personal watercraft, such as jet skis, and larger vessels that can access mid- and outer-shelf reefs, indicate that local residents are accessing the Reef in different ways. The proportion of dinghies under 4 metres in length, however, has decreased (Figure 5.15). Population growth and economic development will continue to increase the demand for recreational activities within the Region (Section 6.2).

Recreational use continues to grow in the Region

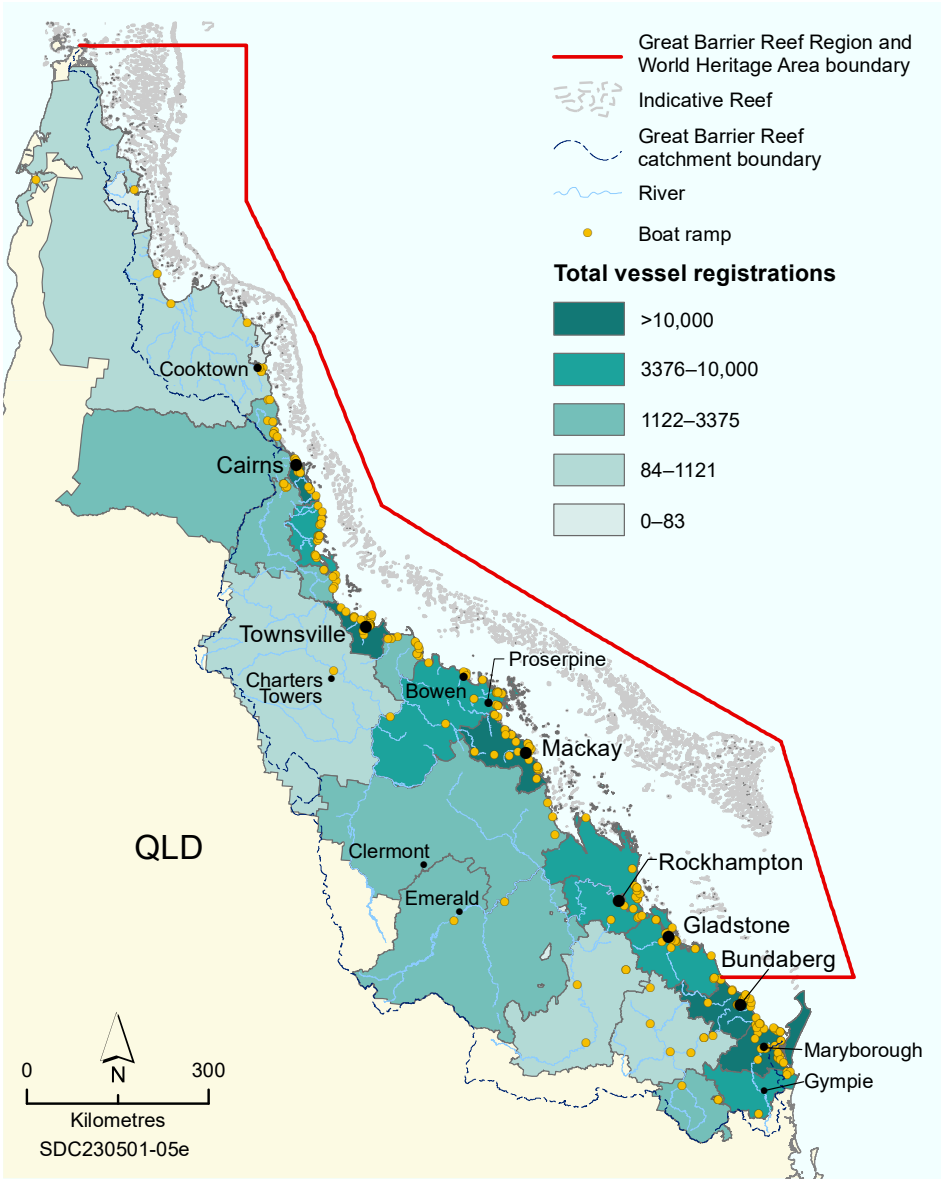


Figure 5.14 **Recreational vessel registration per local government area and recreational boating facilities in the Catchment**

Data as of June 2023. Source: Queensland Department of Transport and Main Roads (2023)[1374,1376]

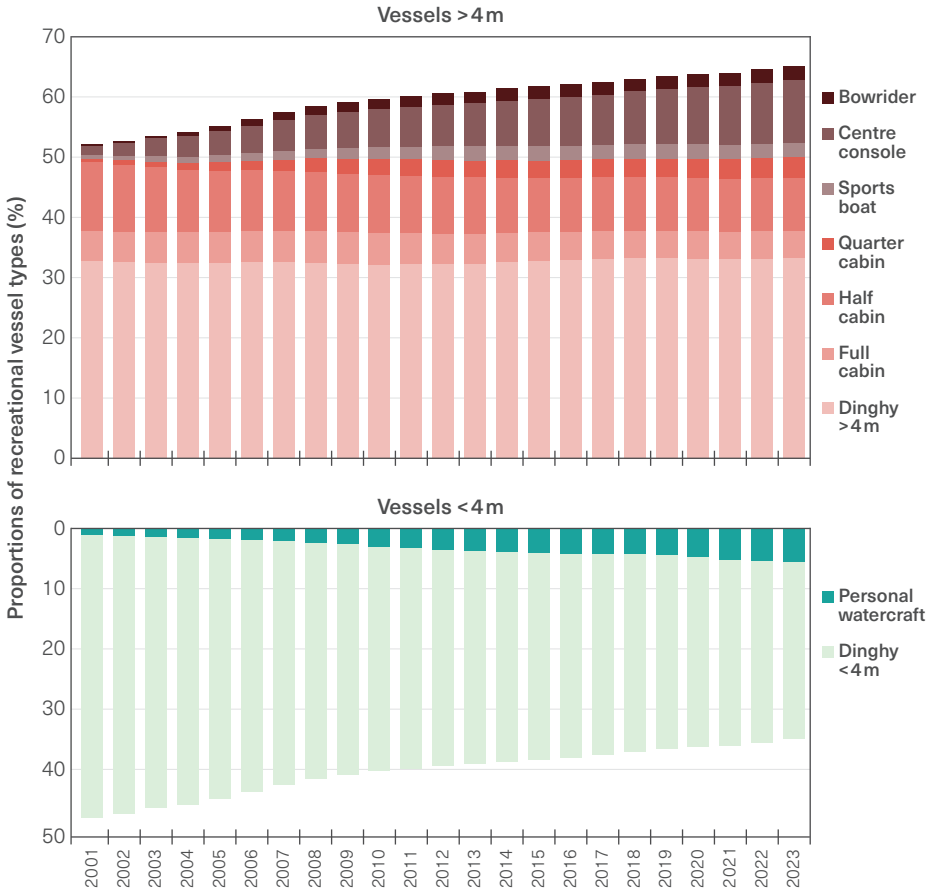


Figure 5.15 **Proportions of recreational vessel types registered, 2001 to 2023**
Source: Queensland Department of Transport and Main Roads (2023)[1374]

Management | A number of Australian and Queensland government agencies and local government authorities are responsible for managing recreational use and/or the infrastructure that supports recreational use. Recreational use (not including fishing) is one of the major direct uses in the Region.[1368] Recreational activities can be undertaken in almost all parts of the Region; exceptions are the Preservation Zones (which cover less than 2 per cent of the Marine Park) and Restricted Access Areas.

The zoning plans and plans of management for the Cairns, Hinchinbrook and Whitsundays areas protect the environment while providing for a range of uses. The plans of management cap the number of tourism operations, define maximum group and vessel sizes at specific locations, and define where motorised watersports can take place. These strategies were developed to protect the values of the Marine Park in high-use areas and to manage multiple uses, including recreational use. The *Recreation Management Strategy for the Great Barrier Reef Marine Park* (2012) provides an overarching framework for the management of recreation in the Marine Park.[1368]

A suite of responsible reef practices cover: anchoring and mooring (including use of public moorings); operating in the Region around turtles, whales and dolphins; bird watching; boating and yachting; collecting; diving and snorkelling; motorised watersports; outboard engines; visiting islands and cays; waste (including sewage); chemicals and litter; and accessing maritime heritage sites.[1377]



Enjoying the scenery at Fitzroy Island. © Nick O'Carroll 2021

The Reef Joint Field Management Program provides and maintains infrastructure that supports recreational visitors, minimising the impacts to ecosystem values. Since 2019, for example, management initiatives have increased the number of reef protection markers, which show no-anchoring areas, and increased public moorings to a total of 1234 in the Region. Since 2019, an additional 60 moorings and 13 reef protection markers have been installed in the Whitsundays region, and 13 moorings and 4 reef protection markers within the North Tropical Coast region (from around Mission Beach to Cape Upstart). These management initiatives protect coral communities that are under threat from recreational boating damage, by raising awareness and influencing the distribution of recreational activities within the Region.[1378] Campgrounds, boardwalks and walking tracks also provide for visitor experiences, improving community understanding of responsible reef practices and of the Region's values and threats.

This program also improves community understanding of responsible reef practices and of the Region's values and threats. For example, visitor experiences provided by campgrounds, boardwalks and walking tracks can improve community understanding. Other management initiatives under the Reef Joint Field Management Program to minimise impacts from recreational use include weed and pest management on islands.

Most vessel access to the Region is via public launch facilities (such as boat ramps) maintained by local and state governments. Existing infrastructure continues to be upgraded, and new infrastructure is being built, to keep up with demand for this ongoing direct use of the Region (Section 6.4.1). Recreational users have better access to learn about permitted activities in the Region via programs such as Reef Guardians and Eye on the Reef.

5.5.2 Benefits of recreation

The Reef's outstanding universal value, underpinned by its biophysical and natural heritage values, is one of the primary reasons why people visit the Reef for recreational purposes. In 2021, 90 per cent of the Region's residents felt proud that the Reef is a World Heritage Area, which was slightly less than in 2017.[1075] The Reef provides constantly evolving recreational and lifestyle opportunities for people to engage with it. These opportunities allow people to develop a sense of identity based on living within the Region and to develop an attachment to the Region (78 per cent feel a strong sense of belonging

to where they live).[1075] However, feelings of attachment due to specific reasons, such as one's lifestyle or family and friends, and a sense that the Reef is 'part of their identity', were not quite as strongly or commonly experienced by people. Some 53 per cent of respondents agreed that the Reef is part of their identity, a level that has been maintained since 2017.[1075]

The Reef contributes to the wellbeing of people by providing physical and psychological benefits. In 2021, 83 per cent of residents stated that living in the Region contributed to their overall wellbeing.[1075] Two-thirds to three-quarters of recreational users agree that they experienced physical and psychological benefits when interacting with the Reef — helping to feel better physically, de-stress, relax, and improve their capacity to concentrate and clear their thoughts.[1075] However, declines in Reef condition are interlinked with human wellbeing.

Half of the residents felt that their lifestyle would be negatively affected by a decline in the health of the Reef.[1075] Ecological grief is experienced by residents of the Region[1158] with 59 per cent of respondents feeling sad and disappointed when hearing about damage to the Reef.[1075]



Stand-up paddleboarding at Scawfell Island. © Mark Fitz 2023

As well as being a key part of people's identity and wellbeing, recreational use of the Reef is woven into the social fabric of coastal communities and generates significant regional economic value. In the 2015–16 financial year, recreational activities (including recreational fishing) were one of the prominent direct uses of the Region, generating $346 million (value-added) to the Australian economy.[1324] In Queensland, non-fishing marine recreational activities generated $4.5 billion in output [1198] mostly attributed to expenditure on equipment, including the purchase of boats and repair of recreational equipment. Recreational users contribute to the long-term protection and management of the Region's values by adopting best practices and being engaged in stewardship programs. Recreational users of the Reef are highly engaged in low-cost simple actions such as disposing of food scraps and rubbish appropriately, avoiding touching corals and marine life, and responsible anchoring.[1075] These users are moderately engaged in more effortful actions such as reporting suspicious activity to the authorities, using the Eye on the Reef app and participating in Reef-related community activities.

Residents' attitudes and beliefs towards Reef stewardship are positive, with more than 80 per cent agreeing that it is the responsibility of everyone and that they are morally obligated to reduce their impacts on the Reef.[1075] Recreational users collect valuable information on Reef condition, marine animals and incidents through programs such

as Eye on the Reef, Reef Guardians, Citizens of the Great Barrier Reef[1379,1380] and the Strandings Hotline. These community-based programs are built to empower people to understand trends in condition and reduce threats to the Region. For example, in 2022–23, more than 300 people submitted more than 4000 interesting or unusual sightings in the Region through the Eye on the Reef mobile app.[1186]

5.5.3 Impacts of recreation

How people use the Region for recreation varies. Recreational use (excluding fishing) is not regulated by the Marine Parks permission system, and few studies have investigated its impact. Recreational uses can affect the Reef through direct localised impacts, such as **anchor damage**, litter, vessel groundings, handling marine organisms (such as sea stars), **boat strikes** on marine organisms, disturbance of shipwrecks and other heritage sites, disturbance by personal drones of wildlife and human enjoyment, **damage to corals** from snorkelling and diving fins, and negative **interactions between different users** especially in relation to vessel, speed and noise (for example, jet skis).[1368,1381] Indirect impacts include encroachment of structures on the Region, such as those that provide access and facilities for recreational users (for example, boat ramps, moorings and underwater structures). Most impacts are minimal and concentrated around major population centres. However, given the large number of recreational users in the Region, the cumulative effect of many small impacts concentrated in certain areas can be significant.

Recreational users may interrupt the connection Traditional Owners have to their Sea Country by **removing or damaging significant artefacts** or sites of cultural significance (whether intentional or unintentional).[1368] High recreational use in culturally significant areas can also displace Traditional Owners by preventing them from accessing these sites and practising their culture (Chapter 9).

Damage to the environment from tourism, commercial fishing and recreational vessels occurs in the Region due to accidental **groundings**, human error and severe weather. The number of such incidents from tourism and recreational vessels is likely to rise with increasing visitation. From 2019 to 2022, recreational vessel groundings were more common than either tourism or commercial fishing vessel groundings (Figure 5.16). It is assumed that the number of incidents occurring in the Region is higher than what is reported to managing agencies.

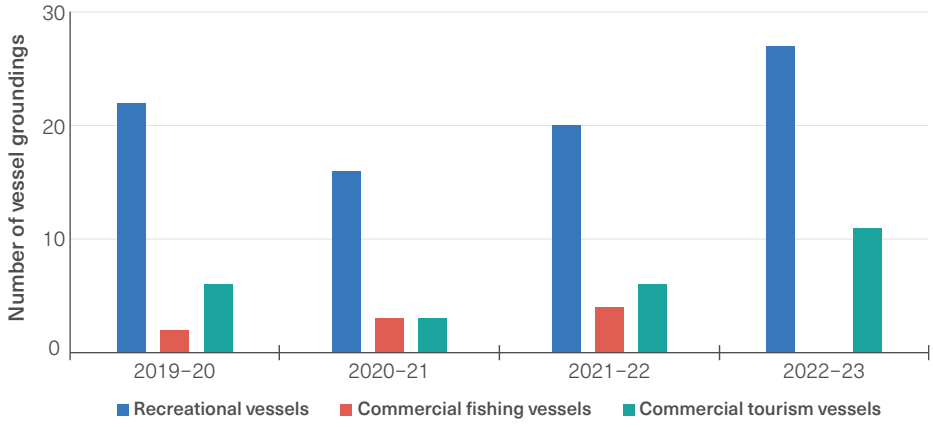


Figure 5.16 **Number of groundings of recreational, commercial fishing and commercial tourism vessels in the Marine Park, 2019 to 2022**

Recreational vessels include recreational yacht, sail and powerboats. Commercial fishing vessels include foreign fishing vessels. Commercial tourism vessels include tourist and charter vessels. It is unknown how many recreational vessels are active in the Region per day or year. These groundings are only a small proportion of the total vessels that operate in the Marine Park in any given day. Total vessel registration numbers for Queensland are shown in Figure 5.13. Source: Great Barrier Reef Marine Park Authority (2023)[1382]

Construction and maintenance of launch facilities can directly affect the Region through clearing of coastal habitats, dredging and **disposal** (capital and maintenance). Encroachment of permanent human-made structures in the marine environment can also affect the aesthetic value of the area. Up-to-date data are lacking on the extent of this infrastructure (within or adjacent to the Region) and its impact on the Region.

Introduced species, including weeds, marine pests or feral animals brought into the Region by recreational users, pose a threat to the Region (Section 3.6.3). For example, international yachts entering the Region are a high-risk vector. Other disturbances from recreational use include oil and chemical spills, waste discharge and disturbance of wildlife, particularly on beaches and islands.[1368]

Recreational activity in the Region can be influenced by the state of the ecosystem, weather, water quality, access, socio-demographic factors, visual amenity, social interaction, and health and wellbeing of individuals.[1383,1384] The current and future implications of climate change, poor water quality and coastal development on the values of the Reef and adjacent areas are key sources of community concern.[1385]

Impacts from recreational users are predominantly managed by legislation, enforcement, public education and public infrastructure, such as signage. Due to the Region's size, management focuses heavily on ensuring users are aware of the impacts of their activities, thereby fostering self-management. For example, the Eye on the Reef mobile app allows users to use their GPS position to determine what activities can be conducted in the Marine Park. Providing information about threats caused by recreational activities, and how they can be managed, plays a major part in managing recreational use and encouraging stewardship through responsible reef practices.



Vessel grounding on a reef. © Commonwealth of Australia (Reef Authority) 2019

5.6 Research and educational activities

The Reef is of strong scientific interest due to its high biological and ecological diversity, geomorphology, and broad heritage values (natural, Indigenous, historic and heritage values). Scientific research has made, and continues to make, a critical contribution to the way the Region is understood, managed and used.[1254,1386,1387] Research on the Great Barrier Reef also has global significance and is of value to the understanding and management of coral reefs beyond Australia.[1388,1389]

The Reef is of strong scientific interest and research is globally significant

This section considers research and educational activities as a direct use of the Region. This includes activities that occur within the Region boundaries under Marine Parks permissions, and limited impact research and limited impact education programs conducted by accredited institutions (as defined in the zoning plans). Educational programs are those that access the Marine Parks and involve the systematic education of participants in a particular skill or topic, where none of the participants are tourists. Education, stewardship and management of tourists are discussed in Section 5.2. Reef research that does not involve direct use of the Region is considered in a general way.

5.6.1 Current condition and trends of research and educational activities

The response of Reef organisms, particularly reef building corals, to climate change has continued to be an important area of active research. Its pertinence is highlighted by two mass coral bleaching events since 2019 that did not result in significant coral mortality.[161] A key focus has been on identifying processes that support coral and coral reef habitat resilience. However, the effects of climate change and marine heatwaves on other organisms that maintain Reef resilience remain a key knowledge gap.

Since 2019, there has been an increased focus on developing methods that use artificial intelligence, environmental DNA (eDNA) and autonomous vessels to complement current monitoring programs (Section 6.2.3). Contributions to research by non-research institutions, including through citizen science, are also increasing, as are collaborations between research institutions, tourism operators, Reef managers, local community groups and Traditional Owners.[1078,1390,1391]

From 2018 to 2020, the annual number of research permits operating in the Region increased from 219 to 335. This number has remained generally stable in 2021 and 2022.[1392] In particular, research focusing on potential interventions that may support the ecosystem resilience of the Reef has increased rapidly since 2019.[6,7] Largely driven by the implementation of the Reef Restoration and Adaptation Program (RRAP), this program is one of the largest coral reef restoration research initiatives globally (Box 5.4).[32] The program has led to an accelerated research and development program that aims to develop, test and assess the risk of a suite of novel interventions that may contribute to the resilience of coral reefs. A number of coral intervention projects are underway across the Reef which are independent to the Reef Restoration and Adaptation Program.[32] This research includes testing intervention approaches, which are novel to the Reef, at a local scale based on techniques initially developed and tested in the laboratory or in other marine environments overseas.[32,1078]

The primary focus of developing intervention methods has been on building the functional resilience of reef-building corals, but there is an emerging focus on other species or habitats, such as marine turtles, seagrasses and coastal ecosystems, particularly in relation to blue carbon opportunities.[924,1393,1394]

Research on interventions to support resilience has increased rapidly since 2019

A network of four island research stations continues to operate at Lizard Island, Orpheus Island, Heron Island and One Tree Island. This network continues to be integral to the

conduct of research activities at these locations. Scientific Research Zones around these stations are intended to provide opportunities for scientific research to be undertaken in relatively undisturbed areas. In 2024, eight research institutions are accredited to undertake limited impact research without a permit.

The majority of permitted educational activities are focused on learning about the natural and cultural values within the Marine Park and associated field research methodologies. Approximately 66 permits were granted for education programs between July 2019 and September 2023. These educational programs are generally based at the island research stations. More than 60 per cent of these permits were for education classes visiting the Heron Island Research Station. Permitted educational activities also include courses for recreation or professional activities, such as sail training or occupational dive certification.[1395]

Management | The zoning plans and Marine Park regulations set out how research and educational activities are managed. Limited impact research and limited education programs may be conducted by accredited research institutions in accordance with the zoning plans and the Marine Park regulations. All other research and educational activities are managed through permits granted by the Reef Authority and the Queensland Parks and Wildlife Service.[1395] The guidelines for *Managing Research in the Great Barrier Reef Marine Park* [1396] complement the statutory framework by providing further definitions, examples and best environmental practice guidance for researchers, particularly when conducting extractive research.

The *Policy on Great Barrier Reef Interventions*,[1397] adopted in 2020, guides decisions on matters related to restoration and/or adaptation interventions that are designed to support and build ecosystem resilience and provide conservation benefits within the Marine Parks, including research into interventions. This policy is complemented by the *Guidelines: Applications for restoration/adaptation projects to improve resilience of habitats in the Great Barrier Reef Marine Park.*[1398]



Students learning how to conduct seagrass surveys. © Commonwealth of Australia (Reef Authority) 2022

Implementation of the Reef 2050 Integrated Monitoring and Reporting Program (RIMReP)[1399] is designed to provide Reef managers with evidence-based information on condition (and trends in condition) of reef organisms and habitats, and to track progress against the objectives of the *Reef 2050 Long-Term Sustainability Plan* (Reef 2050 Plan) to protect the Reef. The managing agencies also publish science strategies to communicate priority research and information needs as well as drive outcomes that can inform evidence-based decision-making.[1386] For example, the Reef Authority's *Science and Knowledge Needs for Management* details priority information needs for Reef management under four overarching themes. Since 2019, science strategies to inform management are increasingly embedding the importance of First Nations peoples' research priorities, incorporating traditional knowledge and adopting a social–ecological systems approach to addressing priority information needs.[1120,1386,1400]

Citizen science is community participation and collaboration in scientific research. The Queensland Government published the *Engaging Queenslanders in Science Strategy 2021–24* to foster science engagement, participation and innovation.[1401] This includes increasing community participation in citizen science to grow scientific literacy and contribute to scientific discovery. Ten key principles guide best-practice citizen science contributions.[1402] The Eye on the Reef program is the Reef Authority's citizen science platform, enabling Reef visitors to be citizen scientists by contributing valuable information to management about reef health, wildlife and incidents. Other programs, such as the Great Reef Census, have directly contributed to management — for example, aiding in the selection of sites for crown-of-thorns starfish control.[1380]

5.6.2 Benefits of research and educational activities

Research is indispensable to the protection and management of the Region's values. Natural and environmental sciences improve our understanding of the biology and function of organisms, and the physical, chemical and ecological processes that affect the Reef ecosystem. Research on the Great Barrier Reef has economic, social and cultural benefits and contributes to global knowledge about individual species, coral reef systems and tropical marine ecology.



Research and education are indispensable to the protection of the Region's values

Long-term monitoring of the Reef includes biological variables, such as species abundance and demographic rates, community composition, functional diversity, taxonomic diversity, and chemical and physical environmental variables. Such programs allow the detection of trends in, and changes to, populations or environmental variables. These programs also inform management decisions by identifying drivers of change and assist with prioritising actions.

Much of the Region's research extends beyond natural and environmental science, with interdisciplinary approaches essential to gain a holistic understanding of the Region's values. For example, natural, environmental, social and economic sciences overlap when estimating the economic value of services that are provided by, and that affect, the Region's ecosystems and human communities.[1323] Targeted and applied research can help managers assess the outcomes of management actions and can, in conjunction with a deep understanding of natural and environmental components, lead to the development of improved operational methods and strategies (Box 10.1). Scientific monitoring of and question-driven research on key processes, habitats, species and use patterns, particularly when maintained long term, enable early detection of trends and changes in a range of the Reef's values and factors affecting them.

More holistically, the research into the Region's values contributes greatly to global knowledge and to the Australian economy, with an estimated combined economic value of $182 million for research and management in 2016.[1324] Importantly, substantial contributions to climate change science have improved global understanding of the resilience and adaptation potential of species,[920,1403] habitats[150,1404,1405] and human communities.[933,1158,1406] Scientists are also investigating and field-testing a suite of interventions to support coral reefs more proactively, including both engineering and biological approaches (Box 5.4).

BOX 5.4

The Reef Restoration and Adaptation Program

In 2018, the Australian Government funded the Reef Restoration and Adaptation Program consortium to determine the feasibility of intervening at scale on the Great Barrier Reef to help it adapt to, and recover from, the effects of climate change. The program scoped existing and novel approaches that could help support the resilience of the Reef. The feasibility study found no single silver bullet solution and delivered an investment case for further research and development of reef interventions. A range of methods are needed to work together to provide compounding benefits, along with ongoing best-practice Reef management and reducing carbon emissions.

The second phase of the Reef Restoration and Adaptation Program (2020 to 2024) is an accelerated research and development program into the prospective techniques. Since 2019, investigations have progressively developed and field-tested different technologies, including cooling and shading methods, assisted adaptation of Reef species, and supporting natural rehabilitation of damaged and degraded reefs. The program also includes complementary research across a range of subprograms, including assessing the feasibility of implementation at scale, modelling and decision support, and stakeholder engagement and regulation. The program has led to changes in the nature and scale of research conducted on the Reef.

The goal of the Reef Restoration and Adaptation Program is to provide reef managers and decision-makers with an innovative suite of safe, acceptable and cost-effective interventions. The next phase is envisaged to be an implementation phase that will overlap with the research and development phase as early as 2025, depending on the specific intervention. This implementation phase may include commercial transfer of some of the intervention measures, including the construction, operation and deployment of full-scale systems. In 2024, some uncertainty remains about the pathway to implementation. However, it should be underpinned by sound science, calibrated against a range of risk factors (including inaction), consider ethics and the social and cultural acceptability, and be cost effective.

While knowledge advancement is critical, educational outreach activities can showcase how we are all connected through oceans by emphasising the importance of the Reef to human health. In-park edu-tourism involving secondary or tertiary groups provide an opportunity for students to actively learn through immersion; by experiencing the Great Barrier Reef and its surrounds. Direct use of the Region that is enriched with an educational component can influence behavioural change and inspire participants to care, learn and take actions that will help the Reef. Reef managers embed educational outreach in a wide range of management initiatives and programs (Chapter 7). Educational programs empower stewardship over the Region's values for present and future generations.



Research vessel. © Commonwealth of Australia (Reef Authority). Photographer: Rohana Rogan-Darvill 2021

5.6.3 Impacts of research and educational activities

Research and educational activities can affect the natural, social and heritage values of the Region. However, most research impacts are considered minor under the existing well-established regulatory and policy framework.

Research and education activities are generally spatially constrained to Scientific Research Zones, which are dispersed throughout the Region. These zones represent 0.04 per cent of the Marine Park and range in size between 3 and 52 square kilometres. However, there is some evidence that permitted research has become more common in other zones and locations since 2019. In the period from July 2014 to January 2018, the porportion of granted research permits that included access to at least one of the Scientific Research Zones was more than 70 per cent. A total of 549 scientific research permits were active between January 2018 and December 2022, of which only 43 per cent were permitted to operate in at least one of the Region's 10 Scientific Research Zones.[1392]

Research and educational activities have the potential to locally deplete certain species or damage habitats, or to disturb wildlife when concentrated spatially, such as around research stations. However, in Scientific Research Zones, impacts are generally locally managed by the directors of the research stations. These directors have discretion to influence the spread of activities in time and space to reduce conflicts and minimise impacts. Where research is conducted outside Scientific Research Zones, localised impacts are often unquantified. Information about cumulative impacts of research and educational activities remains a knowledge gap. Negative impacts of certain novel interactions are also not well understood, but this is likely to improve through the ongoing research and development program.

5.7 Ports

Ports have existed in the Region for over a century. Twelve ports are located in the Region, four of which are designated as priority ports under the *Sustainable Ports Development Act 2015* (Qld) (the Sustainable Ports Act) — Gladstone, Hay Point/Mackay, Abbot Point and Townsville. Specific management applies to priority ports. The major trading ports in the Region are located at Gladstone, Hay Point, Mackay, Abbot Point, Townsville and Cairns. Smaller trading ports are community or minor ports (Figure 5.18).

Ports have existed in the Region for over a century



Storage silos at the Port of Gladstone. © Matt Curnock 2022

5.7.1 Current condition and trends of ports

The current condition of ports is assessed by the trend in port-related activities that influence the values of the Region (such as dredging, sea disposal and land-based disposal of dredge material, and land reclamation) and the level of port activity generated (trade throughput). Dredging activities remain an essential operational requirement of operating a safe and efficient port.[1407] Dredging and disposal (or placement) at ports is undertaken in two forms: capital and maintenance. Capital dredging creates new, or improves existing, channels and berths to accommodate increased traffic and larger ships (Section 5.8).[1408] In contrast, maintenance dredging removes the build-up of mainly fine sediments that accumulate in existing channels and berths.[1409]

Since late 2015, the disposal of capital dredge material in the World Heritage Area has been prohibited (for volumes greater than 15,000 cubic metres) and capital dredging is limited to priority ports and the port of Cairns. Figure 5.17 highlights the change in annual volumes of sea disposal of capital dredge material across the ports in the World Heritage Area before and after the 2015 regulatory change. Since 2019, three key capital dredging campaigns have progressed as part of expansion projects at the ports of Cairns, Townsville and Gladstone. A total of 4.99 million cubic metres of capital dredge material was removed from the World Heritage Area, and all material from these campaigns was disposed of on land.[1410]

Capital dredging occurred as part of three port expansion projects

The average annual total of dredge material disposed in the World Heritage Area was approximately 1.2 million cubic metres between 2019 and 2023,[1410] compared to 1.5 million cubic metres for the period between 2013 and 2016.[5] Between 2019 and 2023, approximately 53 per cent of the total dredge material removed from the World Heritage Area was disposed of at sea, all of which was maintenance dredge material.

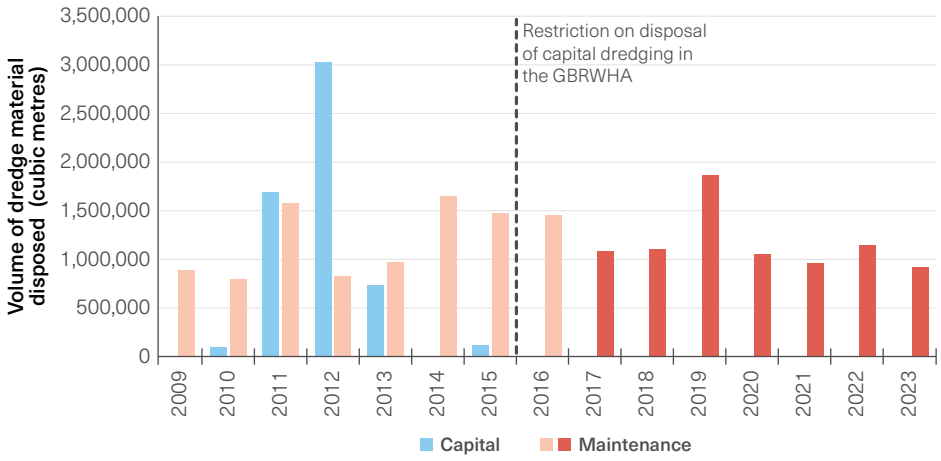
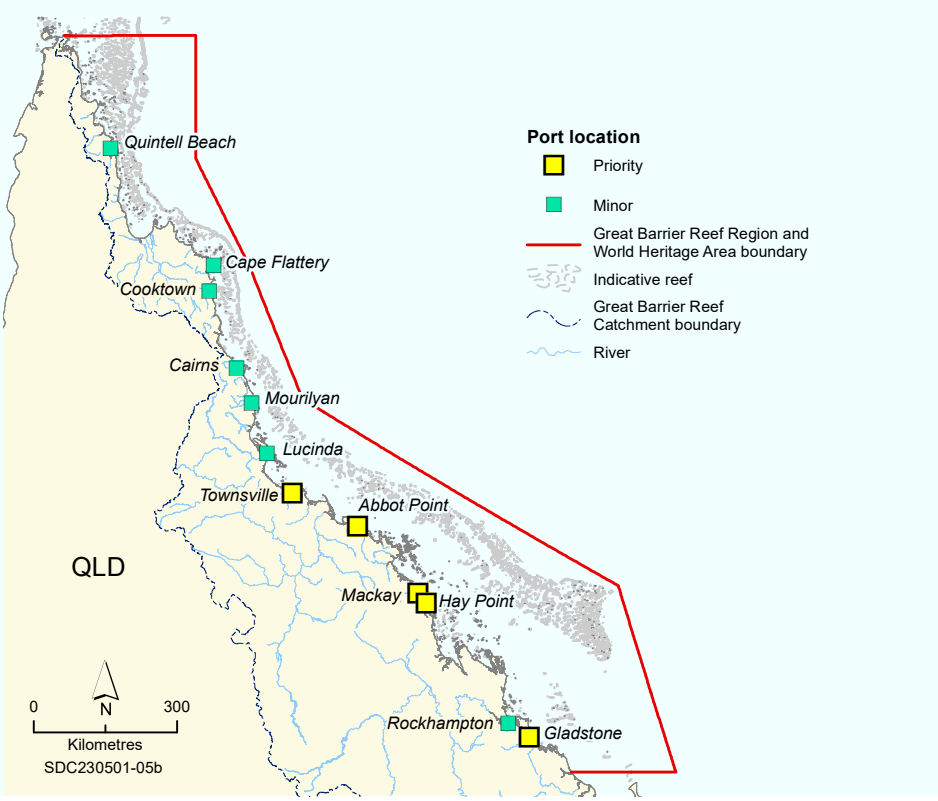


Figure 5.17 **Dredge material disposal (capital and maintenance) in the Great Barrier Reef World Heritage Area, 2009 to 2023**

2009 to 2016 (blue and pink): Data shown include permitted works issued under the *Environment Protection (Sea Dumping) Act 1981* (Cth) and do not include dredge campaigns in internal Queensland waters. Disposal within port limits (including port exclusion areas; or operational areas) is included. The data informed annual reports to the International Maritime Organization.[1207]
2017 to 2023 (red): Data shown include actual volumes reported to the Queensland Department of Transport and Main Roads by individual port authorities. It includes disposal within port limits (including port exclusion areas) and excludes dredge campaigns in internal Queensland waters.
Sources: Far North Queensland Ports Corporation Limited (trading as Ports North), Port of Townsville Limited, Gladstone Port Corporation Limited and North Queensland Bulk Port Corporation Limited (2023)[1410] and Australian Department of Environment and Energy (2018)[1411]

The total amount of reported maintenance dredge material removed from the World Heritage Area between 2019 and 2023 was approximately 1.5 times that for the preceding 5 years. Compared to the preceding 5 years (Figure 5.18).[1410] Maintenance dredging requirements can be driven by local port characteristics. The ports of Cairns and Townsville are both shallow harbours and have higher levels of sedimentation due to natural sediment transportation and coastal storm events. Acute weather events, such as significant rainfall, can also influence maintenance dredging requirements. In 2019 and 2020, the relatively large maintenance dredging campaigns at the port of Townsville related to the 2019 flood event in this area, in which approximately 1.8 metres of rain fell in 10 days [771]. In the period between 2019 and 2023, approximately 6.2 million cubic metres of maintenance dredge material was removed from the World Heritage Area. The majority of this (92 per cent) was from Cairns, Townsville and Gladstone, with the remaining volumes from Hay Point and Mackay. No maintenance dredging was reported for the same period at minor ports.[1410]



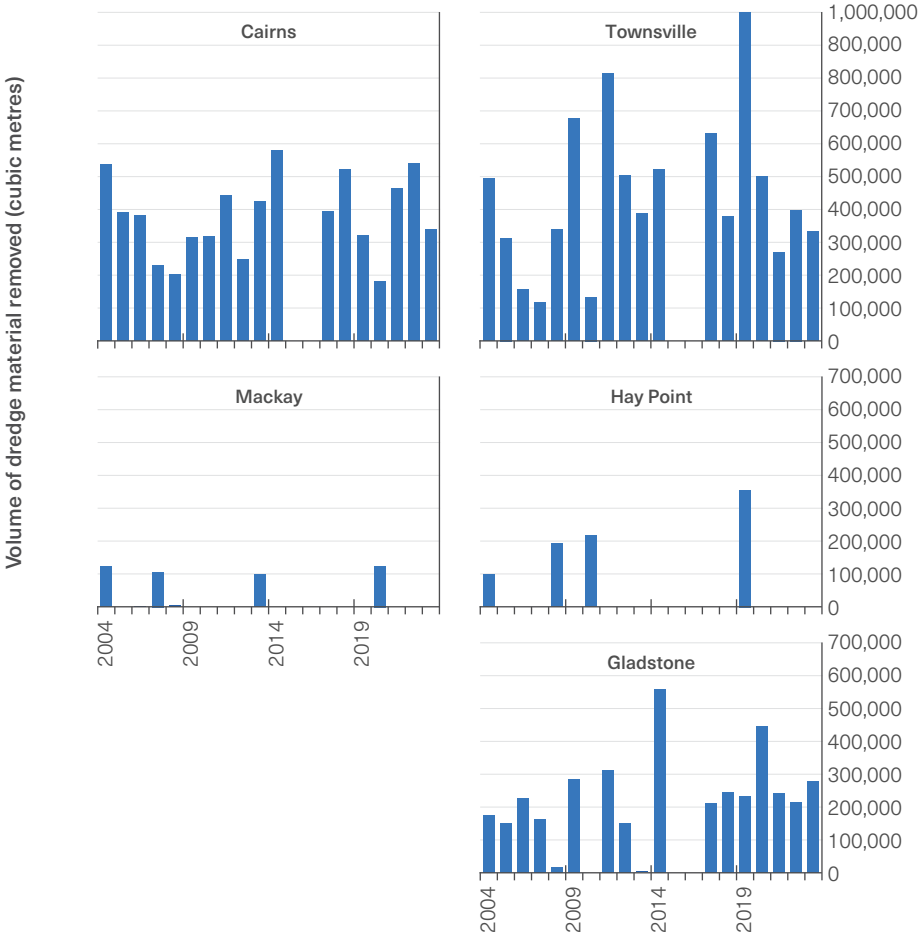


Figure 5.18 **Maintenance dredging volumes in the Great Barrier Reef World Heritage Area, 2004 to 2023**

The map shows the 12 ports in the Region. The graphs show volumes of material dredged for maintenance purposes. Source: Far North Queensland Ports Corporation Limited (trading as Ports North), Port of Townsville Limited, Gladstone Port Corporation Limited and North Queensland Bulk Port Corporation Limited (2023)[1410]

Land reclamation occurs when an area is restricted from tidal influence and converted into land above the high water mark. Since 2019, approximately 30 hectares (0.3 square kilometres) of new land has been created at the Port of Townsville from the adjacent seabed.[1410] This land reclamation represents the only known spatial extent of new land created across the Region's 12 ports. While capturing and reporting on this land extension represents an improvement since 2019, a historical baseline of land reclaimed in the Region since European settlement for port and other purposes (such as other coastal development; Section 6.4) remains a knowledge gap.

30 hectares of new land has been created at the Port of Townsville



Port of Townsville Channel Upgrade project. © Port of Townsville 2023

Management | Port authorities and managing agencies continue to implement the significant reforms introduced in 2014 under the *Sustainable Ports Development Act 2015* (Qld) (the Sustainable Ports Act),[1412] the *Maintenance Dredging Strategy for the Great Barrier Reef World Heritage Area Ports* (the Maintenance Dredging Strategy)[1408] and the *Dredging and Dredge Spoil Material Disposal Policy* (the Dredge Policy)[1413]. These reforms reflect actions under the Reef 2050 Plan.[1414] The reforms seek to balance the economic growth of ports with environmentally sustainable use through systematic planning, policy, monitoring and reporting of maritime port infrastructure. Key actions from these reforms are now embedded in the planning and development processes for ports. The effectiveness of these changes is addressed in Chapter 7.

The Sustainable Ports Act applies to all 12 ports in the Region with an objective to provide for the protection of the World Heritage Area through managing port-related development in and adjacent to the area. Since 2019, all four priority ports have made master plans, as have some minor ports, as required under the Sustainable Ports Act.[1415,1416,1417,1418,1419] Each priority port must also adopt a port overlay, which is a statutory planning layer that fosters and implements ecological sustainable development principles and guides port development. Port overlays have been adopted for the ports of Townsville and Gladstone.[1420,1421]

All dredging and material disposal activities in the Region's ports are managed under both Queensland and Commonwealth legislation (Chapter 7).[11] Australia is a signatory to the *1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972* (the London Protocol).[1207] The *Environment Protection (Sea Dumping) Act 1981* (Cth) implements Australia's obligations under the London Protocol to prevent marine pollution by dumping of wastes and other matter.

5.7.2 Benefits of ports

Ports form an integral part of the supply chain supporting industries, trade, defence and local communities.[1422] Ports enable the export of agricultural and mineral commodities, enable the import of goods (such as fuel, cars and household items that support regional communities) and support commercial tourism by provision of deep channels and berths. Ports provide a vital link between Queensland, the rest of Australia and the world, and have significant economic and social value. Maritime port infrastructure, including shipping lanes, channels and berths, is critical to the ongoing operation of many trade industries. In the same way that roads and rail must be maintained, maritime port infrastructure must be maintained for the efficient flow of trade.[1423]



Ports provide critical support services and contribute significantly to the economy

Management of the COVID-19 pandemic affected trade through the Region's ports. The combined trade throughput at the priority ports in the Region varied in the period between 2016–17 and 2021–22 financial years, seeing an overall loss during the COVID-19 management period. The average annual trade throughput from all priority ports was about 268 million tonnes.[1424] In the same period, the Port of Townsville saw the highest growth of about 12 per cent, peaking just before the COVID-19 pandemic. The Port of Gladstone was the highest performer continuing at a steady 120 million tonnes annual throughput during this period. Hay Point saw a steady decline from a peak of 120 million tonnes in 2017–18 to 97 million tonnes in 2021–22. Among the minor ports, Cape Flattery was the highest performer during this period, with an average 2.7 million tonnes annual throughput.[1424] For the coal terminals, Hay Point had a steady decline of about 12 per cent in coal throughput since 2017–18. The Dalrymple Bay terminal, which is part of the Abbot Point priority port, had an approximate 18 per cent decline in coal throughput in the same period.[1425] The Port of Mackay continues to be a key commodity hub for petroleum, raw and refined sugar.[1425] Comprehensive data on direct and indirect employment across all ports in the Region are lacking.

The scale of capital works is a further indicator of the economic stimulus generated by ports.[1426] Across the major trading ports since 2019, such works include:

- Townsville — The $1.6 billion port expansion project commenced in 2019. It is predicted to provide 354 additional jobs and includes capital dredging, a new outer harbour, wharves and associated infrastructure. Stage one of the project is a $251 million Channel Upgrade project to deliver a wider shipping channel and 62-hectare (0.62 square kilometre) port reclamation area. The wider shipping channel will allow vessels up to 300 metres in length to safely access the port instead of bypassing Townsville.[1427]

- Cairns — The $127 million shipping development project was completed in 2020. The project included the widening and deepening of the existing Trinity Inlet shipping channel. Cruise ships up to 300 metres can now be accommodated at the Port of Cairns. One of the first ships to berth in the new Cairns development was the Queen Elizabeth cruise ship (294 metres) in February 2020.

The Region's ports continue to conduct long-term environmental monitoring programs and be innovative in data capture approaches and ways to minimise harm (Section 5.7.3). These local port data are integrated into regional report cards. However, the availability of the data to integrate into Reef management more broadly is limited. Port authorities also undertake a range of ambient and project-specific monitoring, sediment sampling analysis as well as engage with and contribute to local communities, including with Traditional Owners. The existing port network provides opportunity to capitalise on emerging industries, for example, green hydrogen export.[1428] Dredge material is also a reusable resource; however, its beneficial reuse within ports is often associated with increased costs and emissions.[1429]

5.7.3 Impacts of ports

The impacts from port activities range from direct removal of habitat, for example, by capital and maintenance dredging of the seafloor, through to indirect environmental impacts, such as intermittent noise pollution (Section 5.8.3), dust, spills (cargo and pollutants) and light pollution from port infrastructure. The range of pressures on the environment are well documented.[1430,1431] Weighing up the degree of impacts from each type of port-related activity requires a site-specific assessment taking into consideration characteristics such as the local environmental conditions, volume of material dredged or dumped at sea, the type of dredging undertaken (capital or maintenance) and the configuration of port infrastructure.[1432]

Since 2019, port-related research has focused on expanding our understanding of how local environmental conditions, including resuspension of sediments, prevailing winds, tides and currents affect sediment loads and availability of benthic light. Understanding the spatial and temporal scale of the impacts from dredging activities (**dredging** and **disposal of dredge material**), and how these factors interact, is key to managing some of the impacts of maritime port development. In the Region, the major port dredging campaigns are generally restricted to the major trading ports. The local sediment and benthic characteristics of the 12 ports in the Region vary.

The impact of increased sediment due to dredging and disposal, and the extent to which sediment is resuspended by wind and waves, continues to be a focus of research and monitoring. New evidence continues to strengthen the hypothesis that port activities have adverse impacts on the marine environment at a local scale, but broader effects are more limited. In one 2019 study conducted outside the Region, the silt and clay content of the seabed was found to be 5-times higher after dredging, and it remained up to 2.5-times higher than the pre-dredging levels for up to 3 years after the dredging activities were completed.[1433] The *in situ* observations were used to analyse sedimentation and deposition rates at various distances from the dredging site. The majority (90 per cent) of the turbidity and light effects dissipated at around 20 kilometres from dredging site. The biological effects, including smothering of corals, were generally restricted closer to the dredging site (approximately 3 kilometres).[1433] However, more sensitive species may still be affected at further distances. A 2020 finding suggests that even in the presence of dredging activity, wind and waves can be the dominant drivers of turbidity and are often localised.[1434]

Reef organisms are affected differently by changes in environmental conditions. The frequency and intensity at which they are exposed to these changes will also affect an organisms' response. Acute and chronic exposure to reduced water quality caused by suspended dredging material will yield different physiological responses in benthic organisms that rely on photosynthesis for growth and survival.[1434] For example, the hard coral *Pocillopora damicornis* is sensitive to reduced light and may be a useful indicator of low light stress in coral communities during dredging.[679,1435] Port development rather than flooding may explain demographic variation in Australian humpback dolphins.[515]

Management measures, such as environmental windows (periods of go-slow or, in some cases, no dredging), can minimise impacts to the values of the Region during periods of coral spawning, seagrass recruitment[1436] and turtle breeding, and immediately following severe weather events.[1408,1437,1438]

Other impacts, such as **marine debris**, **artificial light** and impacts on the Region's aesthetic values can also result from port operations. Although the impacts of artificial light on some marine organisms are generally understood, light impacts from ports remains a knowledge gap. A report published in 2020 suggests that direct measurements of benthic light availability during dredging activities provide more ecologically relevant measurements than assessment of the water clarity.[1434] Measurements of particle size distribution and volume concentration profiles have become more common during dredge campaigns.[1439,1440] Budget and time constraints continue to be barriers to comprehensive data collection and analysis.[1441]



Impacts from ports are generally localised

Since 2019, the port-led long-term monitoring programs have become more systematic and the data are publicly available, mainly due to the requirements of the statutory approvals process and actions driven by the Reef 2050 Plan. For example, *in situ* monitoring of light availability to benthic photosynthetic organisms[1442] and *in situ* dredge-induced sediment suspension information are collected in some port areas.[1443] Access to near real-time data to aid managing agencies in responsiveness is currently not available for dredging activities.[39] Long-term monitoring of seagrass at Port Curtis found that both area and biomass of the seagrass meadows had decreased since the previous survey in 2019 but remained greater than the long-term average.[1444] Monitoring at the port area in Cairns has showed a continued increase in seagrass biomass and a stabilisation of meadow area since 2019 against a historical low in the period from 2009 to 2011.[1445]



Monitoring information is more systematic and publically available

Innovation and technological advances in modelling and *in situ* data capture during a capital dredge campaign in Cairns supported systematic, rapid and reproducible approaches to land disposal of the capital dredge material.[1446] A novel, beneficial reuse solution combining ecological and engineering goals to create 'living seawalls' may minimise connectivity impacts of intertidal port development.[1447,1448] The first empirical estimates during dredging of sediment accumulation were collected by deposition sensors in the port area in Townsville,[1434] and other studies are developing innovative methods and instruments to collect data.[1435]

Ports are an established use of the Region and, as with any other use, their presence and ongoing operation continue to pose a range of threats to habitats and species at a local scale. Some impacts associated with the operation of the 12 ports in the Region have been reduced since 2019, while others persist. Of the impacts that remain, some could not be mitigated even with significant additional intervention, for example, the effects on aesthetic values or permanent removal of intertidal and inshore marine habitats.

5.8 Shipping

Shipping includes vessels greater than 50 metres or those carrying specialised product

In this report, shipping includes vessels greater than 50 metres in overall length, including large recreational or commercial superyachts and cruise ships. Shipping also includes vessels carrying specialised products regardless of length, such as chemical or liquified gas carriers and oil tankers. While cruise ships are used in commercial marine tourism (Section 5.2), their size and management are more aligned to shipping in this chapter. Shipping outside the Region does not form part of this assessment unless relevant, such as where ships enter the northern part of the Region.

5.8.1 Current condition and trends of shipping

More than 99 per cent of Australia's international trade occurs via sea.[1449] Shipping provides a critical servicing role and supports the economy through both imports and exports. Nationally, the total volume of cargo moving across Australian wharves in the 2020–21 financial year decreased by 1.2 per cent, which contrasted with the average annual trend growth of 1.4 per cent in the preceding 5 years to 2020–21. In 2020–21, the number of port calls by all cargo ships at Australian ports dropped by 1.2 per cent compared to 2019–20. This continued the 9.3 per cent drop seen in 2019–20.[1450]

Each year from 2019 to 2022, approximately 3000 ships transited through the Region and approximately 11,000 voyages were made (Figure 5.19). Since 2019, the number of ships processed through most major ports declined (Figure 5.20), and the throughput (amount of imported and exported) tonnage has reduced by more than 9 per cent within Queensland ports within the Region (Section 5.7.2).[1424] This is likely due to impacts from the COVID-19 pandemic on global maritime mobility.

Approximately 3000 ships transited through the Region between 2019 and 2022

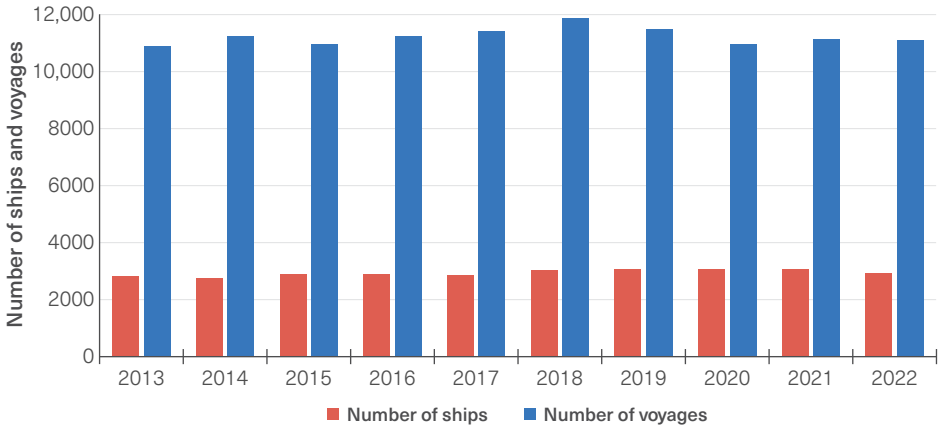


Figure 5.19 Ships visiting the Region, 2013 to 2022

Total number of ships visiting the Region per calendar year and the total number of voyages made by those ships within the calendar years between 2013 and 2017. The ships include coal carriers, bulk carriers, container carriers, vehicle carriers, general cargo ships, tankers and cruise ships (fishing, other tourism and recreational vessels are not included). A voyage is a movement within the Reef and Torres Strait Vessel Traffic Service (Reef VTS). For example, a ship transiting from Palm Passage to Townsville is one voyage; another voyage is logged when the same ship departs Townsville and exits at Palm Passage. Source: Reef VTS (2023)[1451]

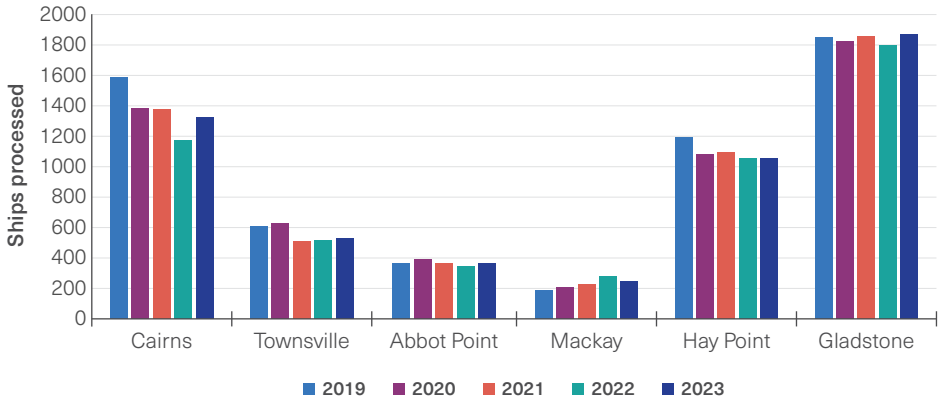


Figure 5.20 **Ships processed by major trading ports in the Region, 2019 to 2022**

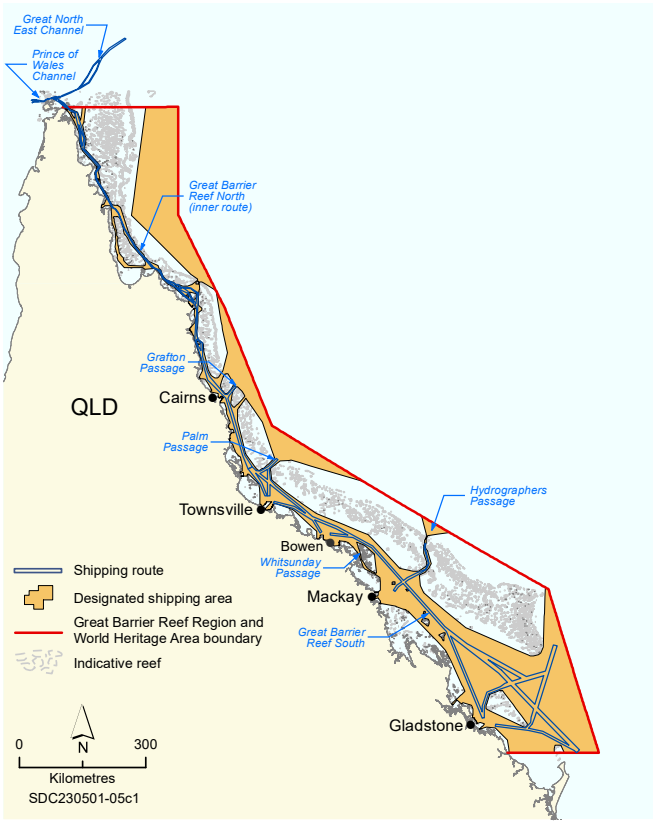
Ships include trade (bulk carriers, gas, tankers, general cargo) and non-trade vessels (passenger, tug and tows, naval). Processed means a ship loads, unloads or does both. Source: Far North Queensland Ports Corporation Limited (trading as Ports North), Port of Townsville Limited, Gladstone Port Corporation Limited and North Queensland Bulk Port Corporation Limited (2023)[1410]



Ship docked at the Port of Gladstone. © Matt Curnock 2022

Ships are required to navigate through the Region within the designated shipping area (Figure 5.21) or the General Use Zones of the Marine Park. Navigation outside these areas in the Marine Park requires permission from the Reef Authority.[1452] A formalised two-way shipping route in the Great Barrier Reef and Torres Strait encourages shipping traffic to use established lanes that separate northbound and southbound traffic. Vessels that transit the Reef enter using one of six major shipping channels (or passages) (Figure 5.22). The busiest shipping passage in the Region is the Inner Route — Cape York to Cairns.[1451] Since 2019, there has been a decrease in the use of Hydrographers Passage, Palm Passage and the Whitsunday Area, while all other main passages have seen an increase in the number of voyages.

The Region is home to four active cruise ship berths, in Bundaberg, Gladstone, Townsville and Cairns, and many cruise ship anchorages.[1454] In the 2022–23 financial year, Cairns and Whitsundays were the most visited areas. The Funnel Bay anchorage in the Whitsundays was the most used in the Region.[1455] In 2020, the Cairns Shipping Development Project was completed.[1456] The project, which widened and deepened the existing Trinity Inlet shipping channel, facilitates cruise ships up to 300 metres in length to enter. Forecasted annual demand of up to 150 cruise ships through the Port of Cairns is expected by 2031 (in total). A similar project is underway in Townsville and due for completion in 2024.[1457]



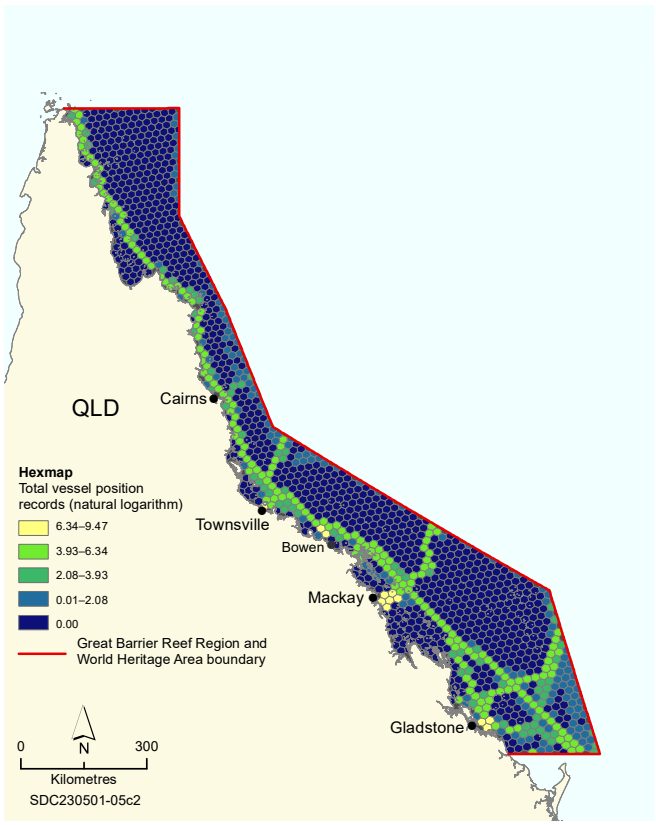


Figure 5.21 **Major shipping channels and shipping density**

Top: Map of shipping routes and designated shipping area in the Region. Bottom: A 'hexmap' representing the total number of detections of vessels in each hexagon for June 2023. Data have been transformed using a natural logarithm for vessel counts. June 2023 data used in the Outlook Report 2024 with the permission of Marine Traffic. However, Marine Traffic has not evaluated the data as altered and incorporated within the Outlook Report 2024, and, therefore, gives no warranty regarding its accuracy, completeness, currency or suitability for any particular purpose. Source: Marine Traffic (2023)[1453]

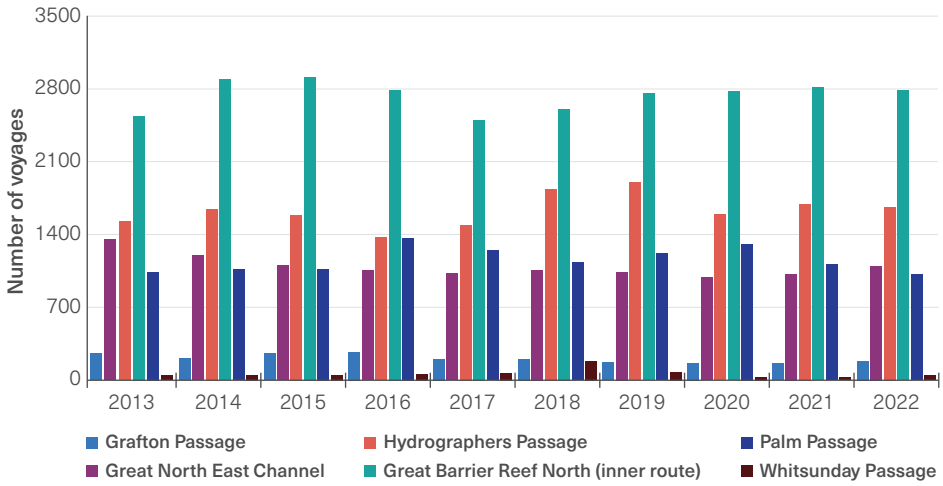


Figure 5.22 **Total number of voyages through the six main passages that enable ships to enter the Reef via the designated shipping channel, 2013 to 2022**

The vessels making these voyages include coal carriers, bulk carriers, container carriers, vehicle carriers, general cargo ships, tankers and cruise ships. Fishing, other tourism and recreational vessels are not included. Source: Reef VTS (2023).[1451]

Management of the COVID-19 pandemic affected global maritime mobility, especially during March to June 2020 when the most severe restrictions were in force.[1458] Reductions in several commodity carriers were documented. For example, internationally, container ships experienced between 6 and 14 per cent reduction; however, the impacts of the COVID-19 pandemic management measures on container ships in Queensland were limited.[1459] Internationally, passenger ships were down between 19 and 43 per cent during March to June 2020.[1458] In Australia, cruise ship activity was halted between March 2020 and April 2022, resulting in significant economic impacts. Since resuming, the Australian cruise ship industry has shown strong recovery and contributed $5.6 billion in direct and indirect output to the Australian economy in the financial year 2022–23 (up from $4.6 billion in 2018–19).[1460]

Globally, the market for superyachts has increased in recent years, from 755 global orders in 2016 to 1024 in 2022.[1461] More than 6600 superyachts are expected to exist worldwide by 2025.[1461] In Australian waters, around 364 superyachts were operating during the 2019–20 superyacht season (September to March). Approximately 25 per cent of these were greater than 25 metres in length. Around 40 to 60 per cent of superyachts operating in Australia are used for recreational purposes.[1461] Global mobility, because of COVID-19 restrictions, significantly affected the superyacht chartering sector, but there is an average expected increase in superyacht activity of 7.5 per cent in Queensland.[1461] The *Queensland Superyacht Strategy (2018–2028)* aims to grow Queensland's share of the Australian superyacht sector to 90 per cent by 2028.

Management | The Reef is designated as a Particularly Sensitive Sea Area by the International Maritime Organization. Shipping activities are managed by multiple government agencies. The Australian Maritime Safety Authority, along with Maritime Safety Queensland and the Reef Authority, administer special measures under international and domestic law to regulate ship activities. Shipping management is coordinated through the *North-East Shipping Management Plan,* which sets out preventative measures to reduce environmental impacts from shipping activities (Section 5.8.3).

Ships transiting through the Region must comply with the zoning plans and designated shipping areas, unless provided with a permission. Pilotage of ships greater than

70 metres in length (and oil tankers, chemical carriers and liquified gas carriers (irrespective of length)) is compulsory within the inner shipping route, Hydrographers Passage and within the Whitsundays. Pilots are licensed by the Australian Maritime Safety Authority to assist ships to safely navigate through the Region.

The Queensland Government is responsible for vessel tracking services and operates five tracking centres for ports and surrounding waterways. The operation of the Great Barrier Reef and Torres Strait Vessel Traffic Service (Reef VTS) provides 24-hour monitoring and tracking of all shipping traffic within the Region. This service can divert ships in the event of a possible traffic conflict, intervene to prevent a maritime incident, monitor maritime incidents, support investigations of potential breaches of legislation, and support effective response to incidents. Since 2019, this service has been divided into Reef VTS north (based in Townsville) and south (based in Gladstone) to provide greater oversight and redundancy (for example, in case of shutdowns due to cyclones).

Regular inspections by the Australian Maritime Safety Authority at ports aims to ensure all ships (including foreign vessels) are in working order, compliant with relevant legislation and safe. Ships can be detained if they are noncompliant and deemed to pose a risk to human safety or the environment (for example, ships carrying introduced pests). The *Guideline for Vetting Bulk Carriers Intended for Travel Through the Great Barrier Reef (2020)*[1462] provides guidance to the maritime industry for adopting of ship vetting processes and managing risk associated with travel through the Great Barrier Reef. This guideline includes consideration of the quality of the ship, competence of the crew, ship emissions and general protection of the marine environment.



Ships at anchor in the Region. © Matt Curnock 2022

Ships visiting ports to load and unload cargo may need to anchor near a port to wait for a scheduled berth. Established anchorages are designated adjacent to Cairns, Townsville, Hay Point, Abbot Point and Gladstone ports. Some anchorage areas do not have designated anchorage points, and there is no single state regulator for designating and approving anchorages; nor are there standard processes to follow.

Commercial superyachts greater than 50 metres in length that visit the Region comply with the same management rules as other similar-sized vessels, as they pose a similar threat. These yachts participate in the Reef VTS, and superyachts greater than 70 metres in length require a ship pilot to be onboard within compulsory pilotage areas. Recreational superyachts must also comply with these requirements but do not need to remain within the General Use Zone or Designated Shipping Areas. In the frequently visited areas, Cairns, Hinchinbrook and Whitsundays, special management strategies are in place to

manage use, and they apply to vessel length, group size and ancillary craft (jet skis and helicopters).

Bookings to use designated cruise ship anchorages aim to provide an uncongested safe anchorage in places where the seafloor is mostly non-coral with limited habitat structure and to allow the values of desirable locations to be presented to tourists (for example, around the Whitsunday and Hinchinbrook islands). Access to locations by the support tender vessels that service cruise ships are also managed closely, restricting the number of visits by group size and vessel size in high-use locations. Superyachts greater than 50 metres are also required to book to use these designated anchorages.

Ships (including cruise ships) accumulate waste during transit in the form of wastewater (oily water, sewage, grey water and wastewater associated with onboard equipment) and garbage (for example, food waste and plastics). Australia is party to all six annexes of the International Convention for the Prevention of Pollution from Ships (MARPOL). These include Annex I,[1463] which regulates for the prevention of pollution by oil, and Annex V,[1464] which regulates garbage pollution from ships. Discharge of plastic into the sea has been prohibited under Annex V since 1988, and discharge of all types of garbage into the sea, with very limited exceptions (not related to plastics), has been prohibited since 2013. These limited exceptions are permitted to be discharged at a distance away from land.

In Australia, the obligations under MARPOL are given effect under *Protection of the Sea (Prevention of Pollution from Ships) 1983* (Cth). MARPOL defines nearest land for north-east Australia by coordinates which are generally the boundary of the Reef. Sewage discharges in the Region need to be in accordance with Annex IV of MARPOL [1465] or, for domestic voyages, in accordance with requirements of Marine Park regulations for both treated and untreated sewage. Grey water may be discharged within the Marine Park as far as practicable from reefs and islands. Roll back provisions are in place for states and territories to give effect to MARPOL in their coastal waters. Queensland gives effect to Annexes I to V in the *Transport Operations (Marine Pollution) Act 1995* (Qld) and *Transport Operations (Marine Pollution) Regulation 2018* but not Annex VI (air pollution).

In 2020, the International Maritime Organization (IMO) introduced the 'IMO 2020' rule which limits the sulfur in fuel oil used on ships operating outside designated emission control areas.[1466] This new limit was made compulsory following an amendment to Annex VI of the MARPOL, which is the main international convention for addressing ship-sourced pollution.

The International Maritime Organization adopted an updated strategy on the reduction of greenhouse gas emissions from ships in 2023 which aims to reach net-zero greenhouse gas emissions from international shipping around 2050. Efforts to reduce emissions within the shipping industry have resulted in a transition from heavy fuel oil to alternative fuel sources such as hydrogen.[1467] Burning hydrogen fuels has zero carbon emission and, when produced using a renewable energy-based approach, has lower emissions than fossil-based hydrogen generation.[1467,1468]

During 2019 to 2020, the Queensland Department of Agriculture and Fisheries, in partnership with port authorities, implemented the Q-SEAS pilot program.[1469] The Q-SEAS program aims to enhance early detection of the presence of invasive marine species in potentially high-risk areas within berthing areas at the ports of Gladstone, Mackay, Townsville and Cairns.

5.8.2 Benefits of shipping

Vessels that visit ports within the Region provide important services to adjacent communities, such as economic benefit. Between 2021 and 2022, exports of Queensland goods overseas increased $56.7 billion to $137.2 billion.[1470] In 2022, mineral fuels and lubricants, such as coal, was the largest export commodity with a value of $82.9 billion. This commodity also experienced the largest annual increase in value, increasing by 136.7 per cent or $48 billion when compared to 2021.

Export value of mineral fuels and lubricants increased by 137 per cent in 2022

Cruise ships and superyachts bring economic benefits to townships throughout Australia as the respective tourism and recreational industries benefit from visitors to their region.[1456] In the 2022–23 financial year, cruise ships spent a total of 491 days along Queensland shores, bringing 1,130,422 passengers.[1471] During this period, Queensland generated the second-largest economic impact from the cruise ship industry in Australia, with a total economic output of $1.69 billion. This was a 10 per cent increase in Queensland's share of the total economic output for the Australian cruise industry since the 2018–19 financial year.

In addition to the direct economic benefit that shipping provides, these industries employ staff from coastal communities. Cruise tourism also employs 2658 full-time staff in Queensland, paying $248 million in wages.[1456] At a local scale, cruise ships contributed approximately $2.3 million into business across Townsville and the surrounding regions in the 2022–23 financial year.[1457] The Australian Maritime Safety Authority employs 14 marine surveyors at five ports in the north-east who carry out port State control inspections in addition to marine surveys.[1469]

5.8.3 Impacts of shipping

A number of impacts result from shipping activities in the Region. These include acute and chronic effects from **ship groundings**, operational and accidental discharges of ballast and bilge water, **damage to reef structure**, **damage to seafloor**,[1472] **vessel strikes** with marine megafauna[1473] and **noise pollution**.[325,1474]

Physical disturbance and damage from shipping can be caused by ship **groundings**, anchor damage and propellor wash. Deployment of a ship's anchor resuspends sediments and can damage the seabed as changing tides and shifting winds cause vessels to swing and drag chains across the substratum.[1475] Ship groundings provide both an immediate and long-term impact on benthos and can potentially damage Indigenous and historic heritage sites. The initial grounding causes loss in the biota of the benthic area and can create fields of unconsolidated substrate (such as coral rubble).
Since 2019, there has been one grounding, one collision (Figure 5.23) and 16 near misses in the Region.[1382] Near misses can be useful in understanding when and where there is an increased potential for environmental damage from groundings and spills. A near miss may occur when a vessel becomes disabled, almost runs aground, and requires assistance as a result of weather, mechanical breakdown or negligence.

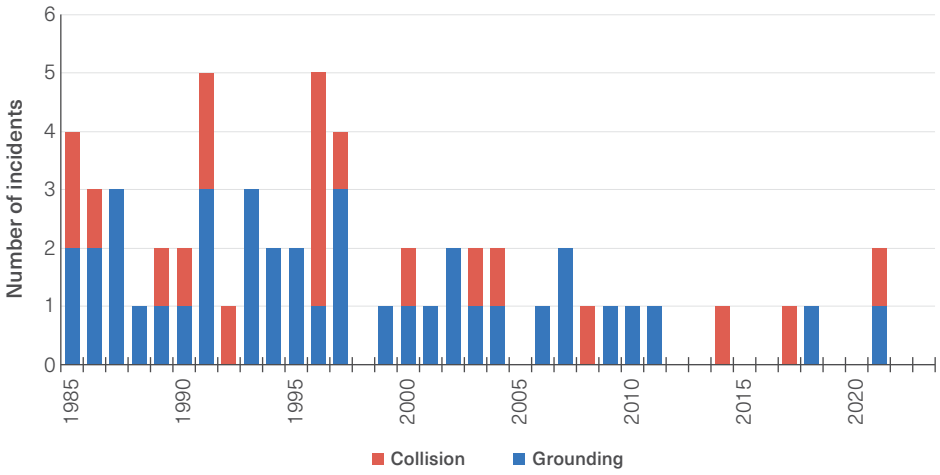


Figure 5.23 **Ship groundings and collisions, 1985 to 2023**

Bars represent groundings and collisions reported to the Reef Authority, Maritime Safety Queensland and the Australian Maritime Safety Authority involving ships within the World Heritage Area. All collisions were between ships and smaller vessels rather than between two ships. Groundings include those within designated port areas. Source: Reef Authority (2023)[1382]

1 grounding and 1 collision occurred in the Region since 2019

Antifouling paint, which is applied to ships to control or prevent attachment of unwanted organisms,[1476] can cause long-term damage by inhibiting future recruitment of benthic organisms. These impacts were observed at the grounding site of the *Shen Neng 1* on Douglas Shoal in 2010 (Box 5.5).

Shipping is the main source of antifoulant paint in the Region. Leaching and release of antifouling components from vessels occur while moving along shipping lanes, anchored in anchorage areas and at berth in port.[1477] In 2020, a study found tributyltin, a chemical in antifouling paint, present in the water column and/or in the sediment in the five main ports in the Region.[1477]

The likelihood of **vessel strike** increases during whale migration season and may rise further if growth in shipping is coupled with increasing whale populations, such as the humpback whale.[1473] The Inner Shipping Route overlaps with migration routes for humpback whales, including a key breeding aggregation in the Capricorn Bunker Group. In one study, the areas of highest relative risk in the Reef were found to be between the Whitsunday Islands and offshore Mackay. Understanding the risk of vessel strike affecting cetaceans in some other areas, such as the Capricorn Bunker Group, remains a knowledge gap.[1478]

Noise pollution has been found to disrupt breeding, migration and settlement behaviours of fish and crustaceans. It also causes stress and disorientation in cetaceans.[1479] However, these impacts are poorly understood in the Region.

Pollution, such as **oil spills** and **marine debris** as a result of shipping activities, reduces water quality and presents a hazard for marine organisms. Four oil spill incidents have been reported since 2019.[1382] Plastics, which are the most common item in marine debris, have known impacts (that is, ingestion and entanglement) on marine organisms in the Region.[1480] One incident was reported of a vessel discharging ballast water within the Region, which represents a risk as marine pests and diseases could be introduced. The potential impact of introduced marine species being transported by ships is discussed in Section 3.6.3.

BOX 5.5

Douglas Shoal Environmental Remediation Project

The Douglas Shoal Environmental Remediation Project is one of the most innovative and large-scale coral reef restoration efforts ever undertaken. The project was initiated after a financial settlement with the ship's owners and insurers in 2016, in response to the grounding of the *Shen Neng 1* in 2010. The project identified that bulk removal of ship-grounding-generated rubble and antifouling paint contamination was likely the best solution to promote natural recovery of the shoal.

Douglas Shoal and its surrounding waters are part of the Sea Country of the Bailai, Gurang, Gooreng Gooreng and Taribelang Bunda peoples. A key project objective was to ensure partnerships with Traditional Owners to deliver critical project activities and support First Nations people's capacity building (see Caring for Sea Country story in Chapter 9). In addition to delivery of cultural awareness training for non-Indigenous project staff, Gidarjil Development Corporation Rangers delivered crucial support, including underwater remotely operated vehicle (ROV) services, marine fauna observation, and offshore logistical support via their Guardian Warrior vessel.

The Reef Authority conducted surveys and logistical planning with Advisian and pre-remediation monitoring and turbidity plume modelling with BMT Australia in the lead-up to remediation activities on Douglas Shoal. In early September 2023, the Reef Authority's primary remediation contractor, Boskalis, undertook targeted remediation of Douglas Shoal using a specialised trailing suction hopper dredge vessel. Subsequent underwater sonar and ROV surveys indicate successful removal of ship-grounding-generated rubble, with minimal impact to adjacent high-value marine benthic habitats. Further extensive post-remediation surveys on the shoal are expected to support initial positive remediation outputs.

All rubble and associated antifouling paint contamination removed from Douglas Shoal were deposited into specially designed and constructed ponds on land leased from the Gladstone Ports Corporation. All dewatering and onshore project activities and subsequent preparation of technical papers are expected to be completed in 2024.

Shipping also contributes to broader greenhouse gas emissions,[1481] but quantitative data for the Region are a gap. In 2021–22, the national domestic maritime sector emitted around 2 million tonnes of greenhouse gas emissions, or 2.2 per cent of Australia's transport emissions and 0.4 per cent of total national emissions.[1482,1483] The *2023 IMO Strategy on Reduction of GHG Emissions from Ships*, adopted by Australia and other member states, includes a target to reach net-zero greenhouse gas emissions from international shipping by or around 2050.[1484]

Since 2019, an emerging impact associated with shipping activities has been the use of sulfur scrubbers for vessel exhaust gas cleaning.[1485] The scrubbers have been implemented internationally as best practice as part of a transition towards lower emissions. The scrubbers discharge sulfur compounds directly into the marine environment. The discharged water is considered to have minimal effect on the marine environments because it is estimated to be buffered and diluted to almost undetectable levels within seconds to minutes of discharge.[1486] While the location of shipping routes, for the most part, are not in proximity to coral reef habitats, assessments of this hazard have not been specific to the context of the Reef and sensitive habitats.[1485]

5.9 Traditional use of marine resources

Traditional use of marine resources is part of First Nations peoples' traditions. It is undertaken by more than 70 Traditional Owner clan groups who maintain connection to the Sea Country within the Region. Traditional use by these groups includes undertaking lawful activities as part of First Nation peoples' customs or traditions for the purposes of personal, domestic or communal needs. Activities such as fishing, collecting, hunting and harvesting, and caring for Indigenous heritage places are considered to be traditional use. Many First Nations people undertake traditional use to practise 'living maritime culture', provide traditional food for families and educate younger generations about traditional rules and protocols.



Traditional use of marine resources is part of First Nations peoples' traditions

5.9.1 Current condition and trends of traditional use of marine resources

First Nations peoples have cared for their Sea Country and heritage for tens of thousands of years.[1104] Since 2019, improvements have been made in Traditional Owner-led and -partnered monitoring and management programs relevant to traditional use within the Region (Section 7.3.8). These include Indigenous Ranger programs, scientific research and the Traditional Use of Marine Resources Agreements program.



First Nation peoples have cared for Sea Country for tens of thousands of years

Sea Country values mapping projects, enabled by Traditional Use of Marine Resource Agreements, are improving our understanding of traditional use and Indigenous heritage values (Section 4.3). In 2020, the Mandubarra Aboriginal Land and Sea Inc. published its first mapping project highlighting places, animal species and plants of cultural significance. More Sea Country values mapping exercises are underway with other Traditional Use of Marine Resources Agreement groups. However, information on trends in traditional use remains a data gap.

Management | The *Native Title Act 1993* (Cth) recognises the pre-existing rights of Aboriginal and Torres Strait Islander peoples in relation to traditional use of marine resources within their Land and Sea Country. Most Traditional Owner groups along the mainland coast continue to exercise their native title rights. Traditional use within the Region is managed collaboratively with Traditional Owners. Indigenous Protected Areas are areas of Land and Sea Country managed by First Nations groups, through voluntary agreements with the Australian Government, in accordance with Traditional Owner objectives. There are seven Indigenous Protected Areas within the Region and neighbouring Catchment,[1487] with two added since 2019 in Wuthathi and Olkola country.

The Marine Park legislation provides for the cooperative involvement of First Nations communities and partnerships with Traditional Owners in the sustainable management of marine resources through Traditional Use of Marine Resources Agreements. Through the marine resource agreements process, Traditional Owners agree on complex matters, such as maritime estate (where lore governs boundaries), Sea Country planning, harvest areas, community permits, protocols and Indigenous heritage management. These agreements

may include voluntary moratoriums on the take of some species, such as dugongs and turtles. These moratoriums can be applied or removed in accordance with changing environmental circumstances and other factors.

Traditional use of marine resources continues to provide for and benefit Traditional Owners through environmental, social and cultural factors. Since 2019, one new Traditional Use of Marine Resources Agreement has been accredited (Darumbal), bringing the total number of groups within the program to 10 (Figure 5.24). These 10 groups and the coastal of the 2 Indigenous Land Use Agreements cover around 46 per cent of the Marine Park coastline (an increase of 18 per cent).[1488]

Around 46 per cent of the Region's coastline is covered by Traditional Owner agreements

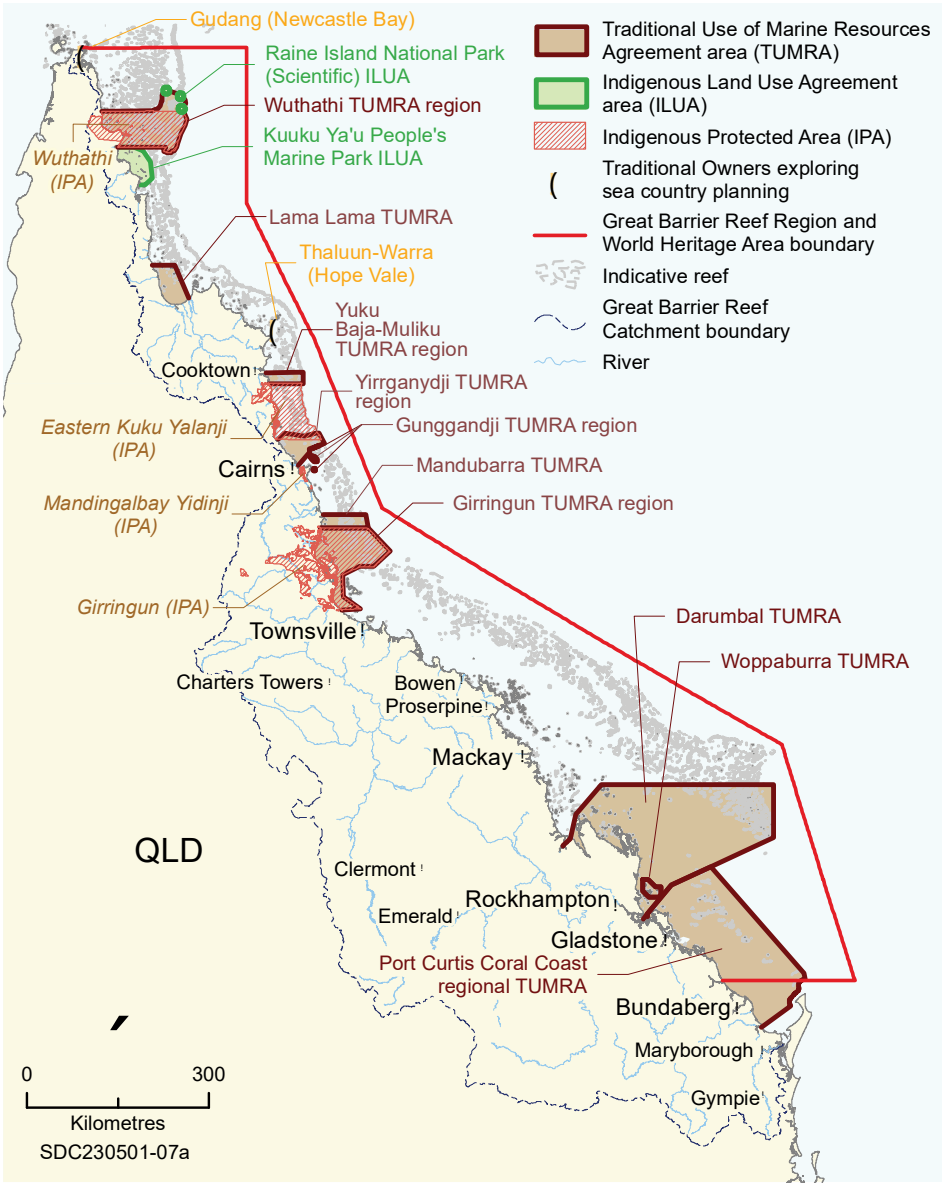


Figure 5.24 **Traditional Use of Marine Resource Agreements, Indigenous Land Use Agreement groups and Indigenous Protected Areas within the Region in 2023**

The Indigenous Ranger program, which is operated by the Australian and state governments, enables Indigenous rangers to uphold compliance on their Sea Country, assess conditions and trends and provide on-Country guidance to management. Since 2019, training opportunities have expanded with rangers completing diver training. Upskilling activities such as these increase the capacity of Indigenous rangers to care for Country. For example, in 2022, Indigenous rangers from Dawul Wuru Aboriginal Corporation partnered with scientists as part of a reef conservation collective that collected coral spawn, and incubated the larvae until they were ready to settle near Hastings Reef, on Yirrgnydji Sea Country.[1489]



Scientists working with Traditional Owners of Jiigurru (Lizard Island). © Sean Ulm 2021

The Reef Authority engages with Traditional Owners through an Indigenous Reef Advisory Committee that provides objective advice as well as insights and recommendations on matters relating to the management of the Marine Park and on the implementation of actions by the Reef Authority to assist Aboriginal and Torres Strait Islander aspirations. Indigenous representation is also within the Marine Park Authority Board, Tourism Reef Advisory Committee and Local Marine Advisory Committee. Since 2019, there has been an increase in the commitments towards co-management of Sea Country and partnerships with Traditional Owners, including through the Reef 2050 Plan, Reef 2050 Traditional Owner Implementation Plan and the Reef Authority's *Great Barrier Reef Blueprint for Climate Resilience and Adaptation* (Reef Blueprint 2030) (Section 7.3.13 and Box 10.2).

The *Reef 2050 Traditional Owner Implementation Plan* (2023) outlines actions to achieve the Traditional Owners' aspirations and priorities for the Great Barrier Reef as part of the Reef 2050 Plan.[1120] One of its aims is to empower Traditional Owners and strengthen their involvement in the management of Sea Country so that Indigenous heritage is kept strong, safe and healthy. The plan also aims to strengthen Traditional Owner connections with Country through cultural heritage mapping, planning and improved protection of sensitive sites.

5.9.2 Benefits of traditional use of marine resources

Sea Country management and custodianship by Traditional Owners, as practised for thousands of years, are important components of the natural and Indigenous values of the Region. Supportive partnerships between Traditional Owners and management are beneficial to biocultural island conservation and monitoring.[1114]



Sea Country management by Traditional Owners is important for all Reef values

An example of this type of partnership and the benefits traditional use brings is evident in the management of Woppa (Great Keppel Island). In order to protect a culturally significant site, Woppaburra people worked with the Queensland Government to design and install a boardwalk to restrict foot traffic over the site. This access, combined with interpretive cultural information signs, not only protected the site but also raised community awareness and cultural understanding of Woppaburra people and cultural sites. Woppaburra people also partnered with a local island resident and the Queensland Government to establish Balban Dara Guya (Leekes Creek) Fish Habitat Area at Woppa in 2017. This fish habitat area protects both a significant ecosystem and a significant cultural heritage site for Woppaburra, making it the first of its kind off the Queensland coast.

Traditional use also has benefits to management. Trends in catch per unit effort of traditional hunting by communities could be used as a potential indicator to assess the status of certain species, such as dugongs.[1490]

5.9.3 Impacts of traditional use of marine resources

Traditional use includes hunting and harvesting a wide range of flora and fauna within the Region. Data are lacking regarding the status, significance, values, trends and practices in Indigenous fisheries across the Region.[1491] However, recent research of historical harvesting practices, undertaken by Traditional Owners over thousands of years, has shown sustainable populations of some target species.[1492,1493]

To ensure traditional use remains a low risk, well-designed monitoring partnerships with Traditional Owners are required. Traditional Owner groups that are a part of the Traditional Use of Marine Resources Agreements program ensure harvest limits are sustainable through nominating levels of traditional harvest which are assessed against scientific research by managing agencies.



Traditional Use of Marine Resources Agreements ensure harvest limits are sustainable

Illegal fishing and extraction from populations of species such as turtles and dugongs are not considered legal traditional use. Illegal fishing and extraction involve people hunting outside their traditional Sea Country and without customary permission from the relevant Traditional Owner. In this context, illegal fishing and extraction represent an impact on traditional use of the marine resources within the Region.

5.10 Assessment summary — Commercial and non-commercial use

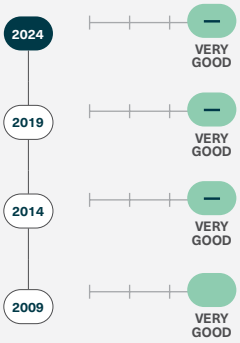
Paragraph 54(3)(c) of the *Great Barrier Reef Marine Park Act 1975* (Cth) requires '... an assessment of the commercial and non-commercial use...' of the Region.

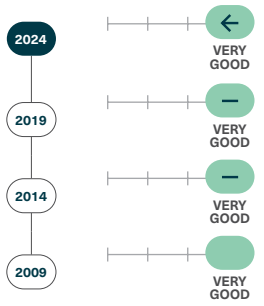
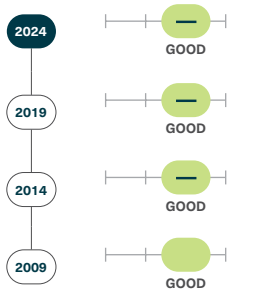
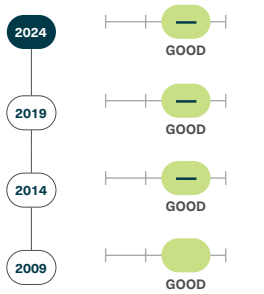
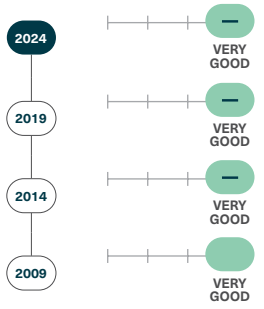
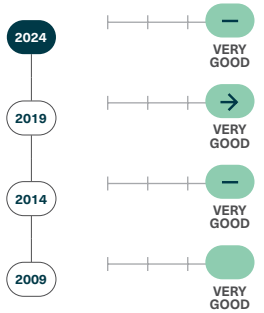
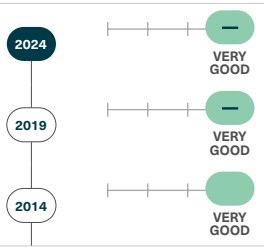
The assessment is based on two assessment criteria:

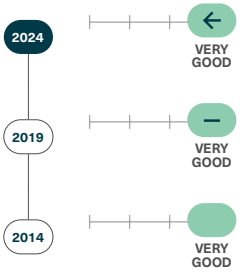
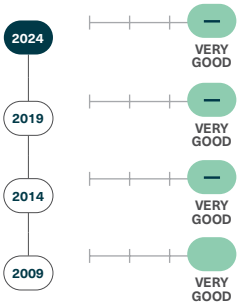
- economic and social benefits of use
- impacts of use on the Region's values.

5.10.1 Economic and social benefits of use

Grading statements — Economic and social benefits of use		Trend since previous report	Confidence
	**Very Good:** Use of the Region provides significant economic and social benefit, in ways that sustain the fundamental value of the natural resource. The Region is strongly recognised, valued and enjoyed by Catchment residents, the nation and the world community.	Improved Stable Deteriorated No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
	**Good:** Use of the Region provides valuable economic and social benefit. The Region is valued by Catchment residents, the nation and the world community.		
	**Poor:** There are few and declining economic and social benefits derived from use of the Region. Many do not recognise the value of the Region and do not enjoy their visit to the Region.		
	**Very Poor:** Use of the Region holds little value for Catchment residents, the nation or the world community.		
	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

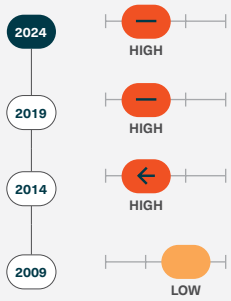
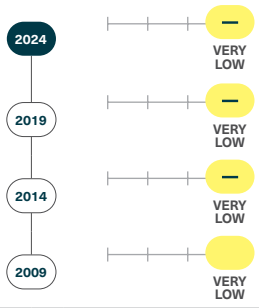
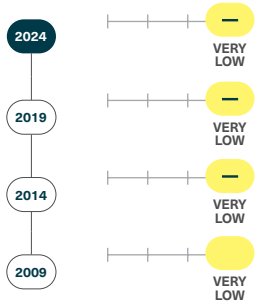
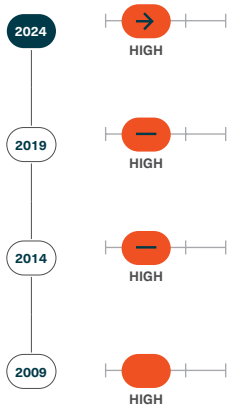
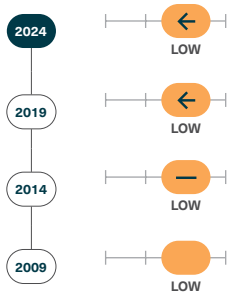
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Economic and social benefits of use: Economic and social benefits to the Region continue to be in very good condition. Despite the COVID-19 pandemic, commercial and non-commercial use contributes significantly to the Region's economy. The Region continues to be critical for the wellbeing of Traditional Owners. Uses such as fishing and recreation contribute to health and wellbeing of people using the Region.			

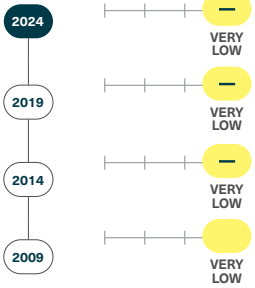
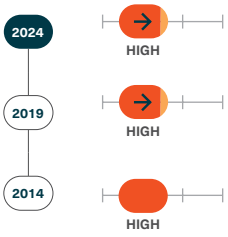
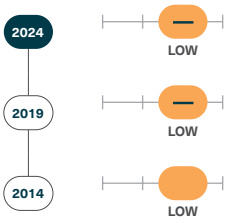
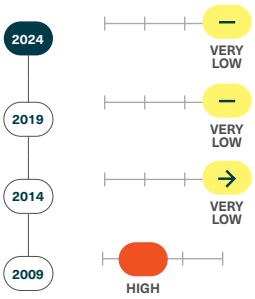
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Commercial marine tourism: Tourism continues to make significant contributions to the social and economic value of the Reef. COVID-19 management restrictions affected the economy of the industry, especially during lockdown, when tourism visitation numbers declined. Visitation increased after travel restrictions lifted and is anticipated to return to pre-pandemic levels.		ADEQUATE	ADEQUATE
Defence activities: Training exercises involving Australian and international defence forces generate economic benefits to the Region. Areas affected by PFAS contamination are being remediated to improve health and wellbeing of communities affected.		ADEQUATE	ADEQUATE
Fishing: The economic contribution of commercial and charter fishing activities has reduced in the Region due to the COVID-19 pandemic but increased for recreational fishing. Commercial and recreational fishers have a high personal connection to the Reef and a strong appreciation for the Region's natural beauty, aesthetic and lifestyle benefits. Changes to management regimes can affect fishers' economic and social benefits.		ADEQUATE	ADEQUATE
Recreation (not including fishing): Recreational use of the Region is important to people's identity. Continued population growth has increased recreational activities within the Region.		INFERRED	INFERRED
Research and educational activities: Research and monitoring activities provide vital support for management of the Region (including research into intervention and restoration activities). The economic contribution of research and education in the Region since 2019 is a knowledge gap.		LIMITED	LIMITED
Ports: The Region's ports provide significant economic and social benefit to the Queensland and national economies. Combined trade throughput had an overall decrease, reflecting the COVID-19 pandemic period, but is expected to return to pre-pandemic levels. Since 2019, two large capital work projects have progressed.		ADEQUATE	ADEQUATE

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Shipping: The number of ships processed through most major ports has declined since 2019 and there has been a reduction in throughput (amount imported and exported) in Queensland. The cruise ship industry was greatly affected by the COVID-19 pandemic but this industry is recovering. The level of economic contribution (both direct and value-added) from shipping in the Region remains a knowledge gap.			
Traditional use of marine resources: Traditional Owners continue to receive environmental, social and cultural benefits from traditional use of Sea Country. Since 2019, the proportion of the Region's coastline under Traditional Use of Marine Resource Agreements has increased to more than 43 per cent.			

5.10.2 Impacts of use on the Region's values

Grading statements – impacts of use		Trend since previous report	Confidence
	**Very low impact:** Any impacts attributable to use of the Region are minor and localised, with no observable effects on overall ecosystem function or heritage values.	Increased Stable Decreased No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
	**Low impact:** The impacts of use are observable in some locations or on some values but only to the extent that limited additional intervention would be required for the use to be sustainable.		
	**High impact:** The impacts of use are obvious in many locations or to many values to the extent that significant additional intervention would be required for the use to be sustainable.		
	**Very high impact:** The impacts of use are widespread to the extent that ecosystem function and heritage values are severely compromised.		
	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Impacts of use on the Region's values: The observed impacts from direct use in the Region are predominantly localised, but collectively, impacts of use are obvious in many locations. Fishing is a high-impact use occurring throughout the Region. However, reforms are continuing to reduce this impact. COVID-19 saw the reduction of use in many industries but there was an increase in recreational use.			
Commercial marine tourism: Although tourism operates through the Region, its impacts are localised to a few well-managed areas. Impacts from cumulative use at heavily used sites will amplify as natural values deteriorate. During the COVID-19 pandemic, the industry increased its stewardship to contribute to resilience of their tourism sites.			
Defence activities: Impacts are localised in the Region. Expansion of training areas may lead to larger impacts with increased activity. Balancing training requirements and conservation of critical environmental values remains a challenge.			
Fishing: Commercial and recreational fishing occurs throughout the Region. The extraction of biomass, interaction of animals with fishing equipment, and discarded catch are ongoing pressures from fishing. Illegal fishing and extraction remain a concern. Management of fisheries has undergone significant reform, with harvest strategies now in place for key fisheries. Understanding of fishing impacts has improved since 2019 through increased and improved stock assessments, risk assessments and stock status assessments. Some stocks remain depleted despite ongoing fisheries management interventions and outcomes from implemented reforms are yet to be fully realised. Some knowledge gaps remain.			
Recreation (not including fishing): The impacts of recreational use (excluding fishing) have not been widely studied in the Region. Impacts are associated with inshore areas around major coastal communities. Vessel registration numbers are increasing, as are the number of incidents involving small vessels. Localised damage to habitats by small vessels is likely to be underreported. The impact of COVID-19 lockdowns and border restrictions on recreational access and use differed throughout the pandemic.			

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Research and educational activities: Research in the Region is generally spatially restricted (around research stations), but other locations are being increasingly accessed. Knowledge on the cumulative effects of impacts associated with research is a gap. The risks of impacts from research into novel interventions are generally poorly understood.			
Ports: Ports are an established use of the Region. Their presence and ongoing operation continue to pose a range of threats to habitats and species, at a local scale, in areas adjacent to the 12 ports. Some impacts have reduced since 2019, while others persist. New technologies and research are improving understanding of the impacts from dredging and other port-related activities.			
Shipping: COVID-19 management restrictions temporarily reduced shipping activity, with cruise ships the most affected. The number of incidents has remained stable. The current implementation of programs to allow for early detection of marine pests, along with plans to transition to fuel sources with lower emissions, may reduce impacts in the future.			
Traditional use of marine resources: Impacts from traditional use, including traditional harvesting, are low compared with other threats. Traditional Use of Marine Resource Agreement groups are known to manage traditional harvesting sustainably. However, the Region-wide traditional harvest remains a knowledge gap.			

5.11 Overall summary of commercial and non-commercial use

The Reef contributes significantly to the Australian economy, to First Nations peoples who depend on it for traditional use, social and cultural purposes, and to the livelihoods, wellbeing and lifestyles of local communities. Despite the effects on commercial and non-commercial use from management of the COVID-19 pandemic, the economic and social benefits are rated as very good.



The Reef continues to provide significant economic and social benefits

The COVID-19 pandemic affected most direct use due to national and international border closures and disruptions to market chains. Tourism visitation was greatly reduced during this time but is starting to recover. Reductions in international trade and exports affected commercial fishing, shipping and port industries. Border closures also led to a reduction in charter fishing. In contrast, the COVID-19 pandemic is understood to have led to an increase in recreational use of the Region.



The COVID-19 pandemic affected most direct use

Most direct use of the Region is localised and rated as high impact. As the population grows, use of the Region and associated impacts are also likely to increase. Marine incidents involving small vessels have continued to rise. The cumulative effects of direct use, coupled with a deterioration of various natural and heritage values, amplifies the identified impacts.



Impacts of most direct use are localised, but add up across the Region

Commercial marine tourism fishing, ports and shipping are economically significant uses of the Region. The impacts of tourism and ports are localised to a few well-managed areas. By contrast, fishing occurs throughout the Region. Fishing is a high-impact activity, and while there have been improvements through ongoing reforms under the Sustainable Fisheries Strategy, some aspects remain a concern, particularly in relation to depleted stocks and information gaps. Fishing reforms and future shifts to low emissions fuel sources in the shipping industry may lead to reduced impacts from direct use.

Defence activities in the Region contribute to Australia's national security capability while generating economic benefits. While defence use is localised, expansion of the Shoalwater Bay Training Area will see increased economic benefits and potentially greater impact in the training areas.

People undertake recreation in many ways throughout the Region. The impacts of recreational activities (excluding fishing) are low and generally associated with inshore areas around major coastal communities. Vessel registration has continued to increase with a growing Queensland population. The cumulative impacts of recreational use remain largely unknown.

Research and educational activities are continuing to provide vital contributions to management of the Reef. A growing research and development program into potential Reef interventions is driving changes in research activities on the Reef, including novel approaches not yet trialled in the Region. Contemporary information on the contributions of research and educational activities to the Region's economy is lacking.

Managing agencies continue partnering with Traditional Owners through Traditional Use of Marine Resource Agreements and Indigenous Land Use Agreements to protect Indigenous heritage values, conserve biodiversity and enhance Reef resilience. These programs help Traditional Owners maintain connection with Land and Sea Country. There are 10 Traditional Use of Marine Resource Agreements and 2 Indigenous Land Use Agreements in place which cover around 46 per cent of the Region's coastline.



Flooding of the Barron River caused by heavy rains following cyclone Jasper in December 2023. © Brent Paterson 2023



Chapter 6

Factors influencing the Region's values

Factors influencing the Region's values

'an assessment of the factors influencing the current and projected future environmental, economic and social values...' of the Great Barrier Reef Region, s 54(3)(g) of the *Great Barrier Reef Marine Park Act 1975* (Cth).

'an assessment of the factors influencing the current and projected heritage values...' of the Great Barrier Reef Region, s 176 (3)(e) of the *Great Barrier Reef Marine Regulations 2019* (Cth).



Agricultural landscape at Halifax in the Wet Tropics. © Nick O'Carroll 2024

"We have an obligation to preserve and protect Country and Sea Country. If Country is sick, our people are sick. Having people work on Country heals them."

"The wet season is changing. We need the rains to flush out the creeks and to keep them running. The colour of the water has changed over time. It doesn't run clear anymore, it runs a dirty red, and it's getting worse every year."

"Our food sources are being affected. Creeks are drying up, as sediment and sand is washing into the creeks and building up along the river and creek banks. Invasive weeds like Guinea grass and Singapore daisy, with shallow root systems that don't hold the ground together, are taking over. Elders are noticing a decline in our food sources like bream, mud cod, yabbies, and river mussels, just to name a few."

"Runoff, water quality and physical barriers affects all species that are meant to thrive there, whether they filter the water or use the area for breeding. Aquatic weeds are also choking our waterways in several places."

"We can restore and heal Country along with our old native species that used to be there, as our seed banks can still be in the ground after all this time."

— Francis Joyce, Mamu Traditional Owner

Mamu Traditional Owner and Senior Ranger, Francis Joyce, leads the first Mamu Healthy Waterways Project for the Mamu Aboriginal Corporation Registered Native Title Body Corporate. Mamu's waterways are facing several challenges. Francis is combining traditional knowledge systems with western scientific knowledge that is proving to be an effective management strategy for land-based runoff.

As part of the Healthy Waterways project, water sampling and monitoring work — along with accompanying surveys of the immediate surrounds — has given the Mamu Community the opportunity to collect important data that feeds into their management plans. Cultural values are also being captured. Elders who are less able to access Country anymore can connect to their place and contribute to management.

Source: Caring for Sea Country — Traditional Owner Stories from the Great Barrier Reef [1]



Millaa Millaa Falls in the upper Johnstone River catchment — water that flows through Mamu Country to the Reef. © Dieter Tracey 2021

6.1 Background

The Region consists of a diverse range of natural values (ecosystems, habitats, species and processes) and Indigenous, historic and other heritage values that are described in Chapters 2 to 4. The condition of these values determines the health of the Region and the quality of the social and economic benefits, such as income, appreciation and enjoyment, that the community derives from the Region.

Several major factors influence the Reef's values. As in previous Outlook Reports, the 4 primary factors influencing the Region are:

- climate change
- coastal development
- land-based runoff
- and direct use.

All are affected by broader drivers of change (economic growth, population growth, technological development and societal attitudes) that affect how society functions, matures and interacts with the environment (Figure 6.1).

This chapter's assessment examines the current and projected impacts of the 4 primary influencing factors on the following Reef values:

- ecological values
- heritage values (natural, Indigenous, historic and other)
- economic values
- social values.

In doing so, it considers the trend in each of these influencing factors, the vulnerability of the Region's ecosystems to them, and the implications for regional communities. Any impacts the factors have on the Region's values, and the benefits derived from those values, provide a basis for predicting future risks to the Region and its long-term outlook (Chapters 9 and 10).

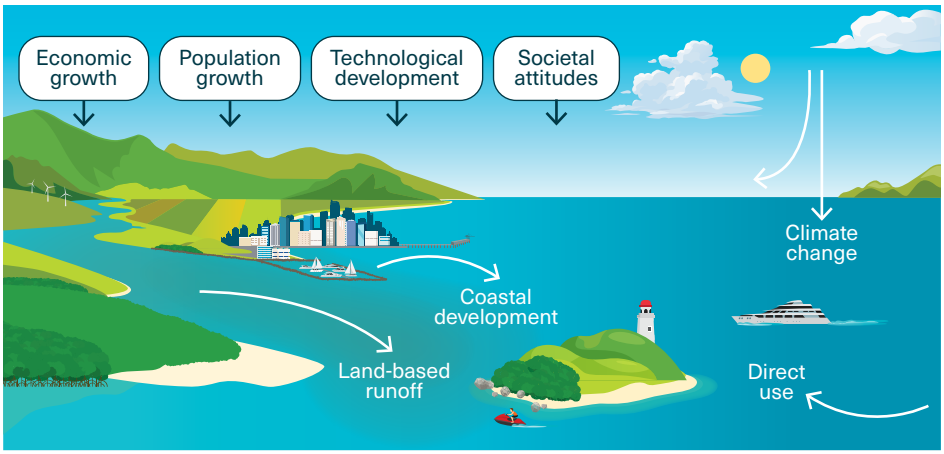


Figure 6.1 **Drivers of change and factors influencing the Region's values**
The Region's values are influenced by 4 main factors: climate change, coastal development, land-based runoff and direct use. These are, in turn, affected by broader drivers of change, including economic and population growth, technological development and societal attitudes.

While direct uses occur in the Region, the other 3 main influencing factors are largely external to the Region. Naturally occurring threats, such as outbreaks of crown-of-thorns starfish, are both influenced by and can contribute to the impact of the influencing factors.

6.2 Drivers of change

Drivers are underlying causes of change in society and ecosystems. The Reef is currently undergoing social, economic and environmental change. Drivers affect how society functions and interacts with the built and natural environment and can act independently or in combination. Economic and population growth, technological developments and societal attitudes are key drivers and affect the nature and intensity of the 4 primary factors influencing the Region (climate change, coastal development, land-based runoff and direct use) (Figure 6.1). Policy and institutions can also be drivers of change. The effectiveness of existing protection and management measures, including governance, is assessed in Chapter 7. Drivers lead to challenges for the natural environment but also benefits, particularly through technological development and societal changes.

6.2.1 Economic growth

Queensland's economy is driven primarily by tourism, agriculture, mining, construction, manufacturing and services.[1494] It has maintained an average annual growth rate of 2.2 per cent over the past decade.[1494]

In the 2019–20 financial year, Australian gross domestic product and Queensland gross state product fell by 0.3 and 1.1 per cent, respectively (Figure 6.2).[1494] This was Queensland's first fall in recorded history and it was due to adverse impacts from the COVID-19 pandemic and related containment measures.[1494,1495] In 2022–23, Australian gross domestic product increased by 3 per cent, following growth of 2.1 and 4.3 per cent in the 2020–21 and 2021–22 financial years, respectively. Similarly, Queensland gross state product increased by 2.3 per cent, following growth of 2.8 and 5.5 per cent in the 2020–21 and 2021–22 financial years, respectively. In 2022–23, Queensland had a gross state product of $464 billion (Figure 6.3), the third highest in the nation after New South Wales and Victoria.[1494] Queensland had less disruption from the COVID-19 pandemic than other eastern states, experiencing no major lockdowns. This provided additional stimulus to many industries. In the 3 years following the COVID-19 crisis, the contributors to Queensland economic growth, as measured using an economic productivity metric called 'gross value added', were: agriculture, forestry and fishing; professional, scientific and technical services; and, health care and social assistance.[1494]

A significant proportion of Queensland's economic activity takes place within the Region and its Catchment, particularly agriculture, forestry and fishing, mining and tourism.[1494] As measured by the gross value added metric in each financial year, agriculture, forestry and fishing rose by 21.9 per cent in 2020–21, by 20.8 per cent in 2021–22 and by 8.9 per cent in 2022–23.[1494] Strong agricultural production across livestock products, cotton and grains was helped by favourable weather conditions. The impacts from floods in February and March 2022 were localised and did not significantly affect overall production.[1494]

Mining activity made up 11.7 per cent of the Queensland economy in 2019–20.[1496] Queensland's coal and bauxite reserves are among the largest in the world and are high grade, making them a sought-after product overseas. Also measured by the gross value added metric by financial year, mining fell by 8.1 per cent in 2020–21, by one per cent in 2021–22 and by 4 per cent in 2022–23.[1494] The global recession caused by the COVID-19 pandemic has lowered demand for Queensland's key exports, particularly coal and liquified natural gas and, as a result, prices have fallen significantly.

Tourism is the Reef's largest economic activity (Section 5.2). In the 2018–19 financial year, the tourism market across Queensland as a whole contributed $12.7 billion to the state economy and was the second largest in Australia, accounting for 22.7 per cent of national

tourism output.[1496,1497] The COVID-19 pandemic and its associated travel restrictions had a devastating impact on Queensland's international tourism.[1496] International tourism expenditure dropped from its height of $6.1 billion in December 2019 to an all-time low of $89 million in January 2021. The international border reopened in early 2022, bringing a steady increase in international visitor arrivals;[1498] however international tourism expenditure has not fully recovered to 2019 levels, reaching $3.6 billion in January 2023.[1499] Forecasts predict the international spend in Australia will exceed pre-pandemic levels in 2024.[1177]

Domestic tourism expenditure dropped from $19.4 billion in December 2019 to $12.1 billion in January 2021.[1499] However, Australians responded by travelling more in Australia.[1498] In January 2023, domestic tourism expenditure reached $29.3 billion, surpassing 2019 levels.[1499] Within the tourism regions adjacent to the Reef, the Tropical North Queensland region had a very significant increase in domestic tourism expenditure, primarily due to Cairns being the point of origin for most domestic visitors to the Reef and the primary destination of international visitors.[1499]

Economic output of Australia's marine industry continued to grow despite the effect of the COVID-19 pandemic restrictions on some subsectors. In the 2020–21 financial year, Queensland accounted for 14 per cent of the total output of the Australian marine industry, with an output of $16.2 billion, driven mostly by domestic marine tourism, and water transport and ports.[1198]

Following a strong rebound after the COVID-19 crisis, the Queensland economy was forecast to grow by 2 per cent in the 2022–23 financial year, driven by an ongoing rebound in tourism and education services exports, with growth forecast to strengthen to 3 per cent in 2023–24.[1500] However, the global economy faces increased uncertainty and volatility with risks to the outlook skewed to the downside. The International Monetary Fund downgraded its global growth outlook for 2023, reflecting the sharp interest rate rises required to curb inflation, deterioration in financial conditions, the impacts of the Russia–Ukraine conflict and rising geopolitical tensions.[1500] Similar to the global economy, national economic growth is expected to slow in coming years, weighed down by slowing growth in consumption, public spending and exports according to the Reserve Bank of Australia. National gross domestic product growth slowed from 2.7 per cent in 2022 [1501] to 1.5 per cent in 2023,[1502] but it is expected to increase gradually to 1.8 per cent by the end of 2024.[1503]

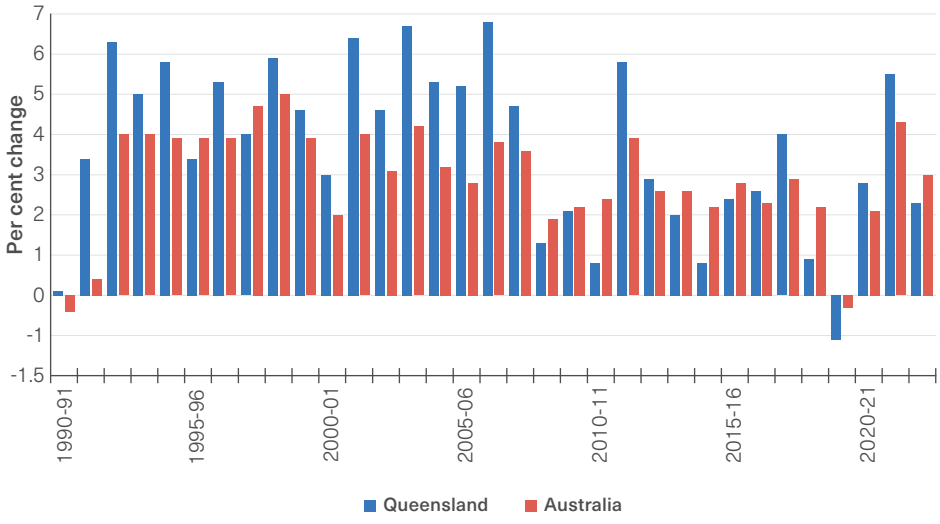


Figure 6.2 **Economic growth in Queensland, 1990–91 to 2022–23**
Annual change in the Queensland gross state product (chain volume measure) and in the Australian gross domestic product, for financial years. Source: Australian Bureau of Statistics (2023)[1494]

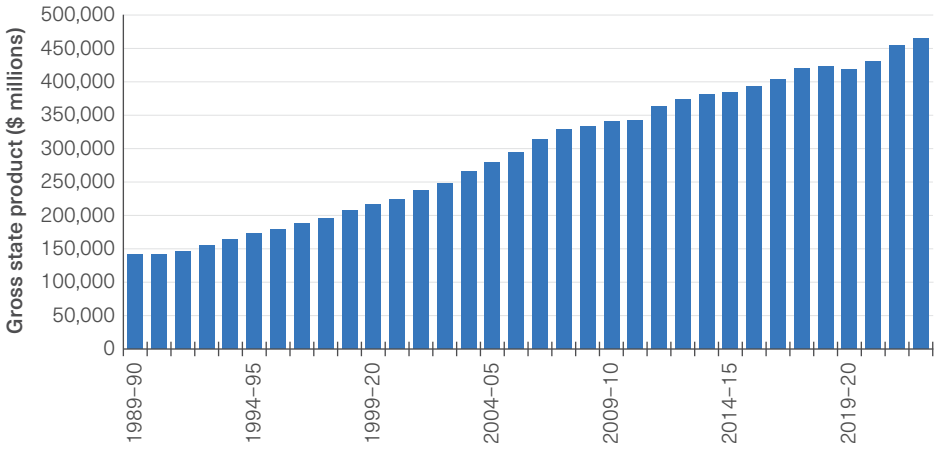


Figure 6.3 **Total economic activity in Queensland, 1989–90 to 2022–23**
Total economic activity in Queensland based on gross state product (chain volume measure) for financial years. Source: Australian Bureau of Statistics (2023)[1494]

6.2.2 Population growth

Population growth is one of the drivers affecting the Region. The increasing number of people living close to the coast may intensify pressure on the Reef, primarily due to coastal development and recreational fishing.

Population growth is higher in the Region than elsewhere in the country

In June 2022, the Catchment population was 1,251,818 persons, with an annual growth rate of one per cent over 5 years (0.8 per cent over 10 years). Townsville had the largest population with 198,143 persons, and Fraser Coast and Whitsunday had the fastest population growth over 5 years of 1.9 per cent.[1504] The Catchment population is aging with a median age of 41 years in 2021, an increase of 3.3 years since 2011.[1504] The percentage of First Nations peoples in the Catchment is 7.9 per cent compared to 4.6 per cent for Queensland.[1504]



Cairns Esplanade. © Dieter Tracey 2024

The Catchment population is expected to rise to 1.53 million by 2046, an increase of 0.9 per cent per year over 25 years.[1504] Townsville is projected to have the largest population, rising to 264,899 persons by 2046, and Livingstone is projected to have the fastest growth in population with an average annual growth rate of 1.8 per cent.[1504]

Behaviour changes triggered by the COVID-19 pandemic resulted in a flow of people from major cities to regional cities, with the largest internal migration to Queensland, which received 29 per cent of all interstate migration arrivals in 2020.[1505,1506] Queensland's and the Reef Catchment's annual population growth rates in 2022 were higher than those of any of the other states and territories.[1504,1507]

The growth of coastal communities generates a variety of impacts, including increased recreational fishing (Section 5.4) and other direct uses of the Region (Section 6.6), coastal development (Section 6.4), and pollution (land-based runoff; Section 6.5). Coastal infrastructure, such as roads, marinas and boat ramps, housing development and the demand for more urban support services, such as sewage and stormwater treatment and energy infrastructure, will increase with an expanding population.

6.2.3 Technological development

Technological development refers to the application of knowledge to create tools to solve specific social, economic or environmental problems. Technological development can drive change in our understanding, management and use of the Region, and can help reduce environmental impacts.

Global cooperation across various industries and sectors is required in order to mitigate the effects of climate change. The most significant technological development in terms of reducing greenhouse gas emissions is large-scale deployment of renewable energy. In December 2023, the Australian Government pledged to triple its renewable energy capacity by 2030,[1508] and the Queensland Government has committed to 70 per cent renewable energy by 2032 and 80 per cent by 2035.[1509] This is accelerating development of infrastructure and now Queensland has 53 large-scale renewable energy projects (operating, under construction or financially committed). Several renewable energy zones are proposed to be established within the Catchment to help coordinate development in areas of high renewable potential. Technological development, innovation and social buy-in will be driving forces in improving energy efficiency and uptake of renewable energy. Globally, Australia has the highest uptake of solar photovoltaic systems per capita, with around 3.4 million rooftop installations in use.[1510] Carbon capture, utilisation and storage is still in the early stages of development and is being considered by governments at different rates around the world.[1511]



Rapid advances in technology are improving understanding of the Reef

Technology plays a crucial role in improving understanding of the Region and its management. Remotely sensed satellite data, machine learning,[1512] artificial intelligence,[1513] robotics, drones[1514] and other remotely operated vehicles, acoustics,[1515] advanced data analytics and modelling tools, enable scientists to predict and monitor impacts on the Reef. By collecting and analysing large datasets, researchers can simulate various scenarios and develop strategies to mitigate threats such as crown-of-thorns starfish outbreaks and forecast coral larval dispersal.[927,1516] Advanced algorithms and deep learning processes are being used to aid in analysis of vast amounts of underwater imagery to identify fish, corals, coral bleaching and crown-of-thorns starfish with increasing precision.[1517,1518,1519] Using such technology can improve ways to measure and

monitor coral reefs with fewer resources. Increased data storage and access through cloud computing technologies has made collaboration in near real time possible.[1496,1517]

Recent technological developments in sewage treatment, which use macroalgae to remove nitrogen and phosphorus from wastewater, may help to reduce nutrient loads in outputs if current trials prove successful and can be scaled up.[1520]

The genomics revolution (Box 2.1) represents a transformative era in biological research, propelled by advancements in DNA sequencing and analysis.[14,1521] The results have broad implications for environmental conservation, allowing scientists to understand the genetic diversity within populations, track the impact of environmental changes, and develop targeted strategies for biodiversity preservation and interventions.

Environmental DNA (eDNA) provides easy access to DNA-based identification to better quantify and identify species diversity and will allow for better provision of ecosystem community baselines against which future surveys can be compared.[19] However, because eDNA concentration is low in marine environments, the reliability of eDNA to detect species diversity can be limited.[27] A comprehensive library of genomes upon which the eDNA analyses are based is still limited.



Researchers using a drone at Broadhurst Reef. © Commonwealth of Australia (Reef Authority) 2021

New ‘interventions’ technologies are being developed and trialled that may support the resilience of the Reef (Box 5.4). The current research and development program includes interventions such as: cooling and shading; rubble stabilisation; cryopreservation; coral relocation; coral aquaculture and mariculture; development, via assisted evolution and treatments, of more resilient species and their deployment on the Reef.[1522] The effectiveness of these techniques on the Reef will be strongly influenced by feasibility at scale and through understanding and mitigating potential risks.

6.2.4 Societal attitudes

Societal attitudes are the beliefs, feelings and behavioural tendencies generally held by people in a particular society towards a person, place, thing, issue, event or symbol.[1523, 1524] They are formed by culture, social norms, values and experiences, and are influenced by ecological, social, economic and political events. Societal attitudes are drivers of change as they underpin social values (Section 4.5.1) and can shape group or individual behaviour and actions.[1525] Understanding changes in societal attitudes can help shape more adaptive management approaches. Community views regarding threats to the Reef, which can be more directly influenced by management in the Region, are reported separately in Section 9.3.1.



Societal attitudes are drivers of change that shape behaviours and actions

Since 2019, many important events have affected broadscale societal attitudes. The world has undergone its most significant global social upheaval in modern times with the COVID-19 pandemic. Inflation has since climbed rapidly, and geopolitical instability has risen.

The United Nations Biodiversity Conference (COP15) took place in Canada in 2022, and the Intergovernmental Panel on Climate Change (IPCC) released its Sixth Assessment Report (AR6) Synthesis Report in 2023. This report provides a best estimate of 1.5 degrees Celsius of global warming between the late 2020s and mid-2030s.[536] In Australia, 2019 was the warmest year on record, and there has been a multitude of extreme weather events, including the 2019 Townsville floods, the 2019–2020 east coast bushfires and the 2021–2022 east coast floods. The Reef experienced mass coral bleaching events in the 2020 and 2022 summers. In 2023, the Great Barrier Reef World Heritage Area was considered for inclusion on the list as a World Heritage in Danger.

Concern about cost of living is the dominant issue for Australians at present and is at its highest level of the past decade, while environmental concerns dip.[1526,1527] Levels of national pride, belonging and a sense of social justice are lower now than before the COVID-19 pandemic.[1528] Trust in all institutions has decreased and is resulting in increased polarisation.[1529]

The topic of climate change has been prominent in media coverage and policies in recent years but has also varied over time.[1530] Australians’ climate scepticism has been shown to reduce over time as hotter global temperatures are recorded.[1531] The Griffith Climate Action Survey, conducted annually since 2010, reports an increase in national concern about climate change.[1532] The survey reports that, in 2022, 71 per cent of Australians felt ‘fairly’ or ‘very’ concerned about climate change, similar to 2021 results (72 per cent) and markedly higher than in 2010 to 2011 (35 per cent).[1532] However, while Australians are concerned about climate change, belief that it is an ‘extremely serious problem’ has been declining since 2021.[1532] Australians are increasingly conscious and concerned about the impact of climate change and support decarbonisation; however, support for renewable energy may face challenges during periods of high inflation.[1526,1528,1533,1532]

Living a sustainable lifestyle is important to most Australians, but only about a quarter claim to be very or extremely knowledgeable about sustainability.[1527] Action on 'sustainability' in general is less prioritised than specific concerns about household waste, health of waterways, deforestation and bushfires.[1526] Self-reported engagement in several sustainable behaviours is also down.[1526]

Intervention activities are increasing in many research and industry sectors, including tourism. Australian attitudes toward restoration and adaptation options in the Reef influence the support for interventions.[1534] While members of the public appear to value the benefits of deploying novel interventions on the Reef, promoting awareness of potential risks and benefits associated with intervention through media platforms will be important to increase public knowledge of associated risks and benefits.[1162]

6.3 Climate change

Climate change due to human activities is a global issue that affects all ecosystems and the services and benefits they provide. Climate change is the most pervasive and persistent influence on the Region. The most immediate and current threats from climate change are ocean warming resulting in thermal extremes that cause mass mortality and sublethal impacts in corals and other organisms and extreme rainfall events that reduce water quality.[540,1535] Other impacts of climate change, such as sea-level rise and ocean acidification, are also increasingly affecting the Region, but they are not having the same immediate and Region-wide impact as increases in sea temperature. The present-day frequency and severity of climate change-related impacts are increasing and interacting with the other key threats (Sections 6.4 to 6.6), compounding their effects.

In 2016 and 2017, the Reef experienced 2 consecutive summers of severe mass coral bleaching towards the end of the most severe, widespread, and longest-lasting global-scale coral bleaching event on record (Section 2.3.5).[1536] These bleaching events caused widespread mortality of corals across the Region.[1537] Between 2018 and 2022, coral cover in offshore reefs recovered rapidly, led by fast-growing plating and branching corals.[182] Further recovery was also facilitated by limited cyclone activity and flood impacts, and mitigation of further coral losses from the ongoing crown-of-thorns starfish outbreak through targeted control actions across much of the Marine Park.[182] Recovery occurred despite a further, albeit less severe, mass coral bleaching event in 2020 and continued until the trend plateaued in response to the cumulative effects of the 2022 mass coral bleaching event and localised crown-of-thorns starfish impacts.[161] Another widespread mass coral bleaching event unfolded in the Region in early 2024 (Box 2.3 and Section 3.2.6).

Of the 4 main factors influencing the Region's values in the Outlook Report 2024, climate change is assessed as having the highest negative impact, with impacts on natural and heritage values already apparent and expected to increase.

6.3.1 Trends in climate change

Changes to the global climate interact with existing climate drivers (Box 6.1) to determine climate patterns in the Region.[1538] Changes brought about by global warming can either amplify or reduce the effects of these regional drivers, leading to altered weather patterns and changes in the timing, duration and intensity of extreme events.[1539,1540] There is also evidence some drivers are themselves being altered as the climate changes, affecting the way regional climates are linked to distant climate phenomena and causing permanent shifts to drier or wetter conditions in some areas.[540,569,1540] For example, recent increases in both the strength and frequency of El Niño–Southern Oscillation events have been

BOX 6.1

Major climate influences in the Region

Several broadscale climate drivers interact to influence the Region's climate, causing it to vary greatly from one year to the next.[540,1563,1540] These drivers operate with different spatial patterns and seasonality over timescales from weeks to decades.[1540] Some of the most important of these in the Region are the Australian Monsoon, the Madden–Julian Oscillation, the El Niño–Southern Oscillation and the Indian Ocean Dipole.[1563,540,1539]

The **Monsoon** is part of the usual evolution of the seasons in northern Australia, with active phases bringing heavy rainfall.[1564] It forms when a seasonal reversal of prevailing winds brings a band of low pressure known as the monsoon trough over northern Australia, drawing moist air from the surrounding seas. The monsoon is the major driver of the Region's rainfall, which occurs mostly in the wet season from December to April.[1564] The timing, variability and strength of the monsoon is modulated by a global scale feature of the tropical atmosphere known as the **Madden–Julian Oscillation**.[1565,1566] This eastward moving 'pulse' of cloud and rainfall can change the odds of a wetter or drier period on weekly to monthly timescales and increase the chances of cyclones forming in the Region.[1565] At the start of the wet season, it can encourage the monsoon trough to form.[1565]

Over year-to-year timescales, the **El Niño–Southern Oscillation** is the most important driver of climate variability in the Region and across the tropical oceans.[1540] It is also the main contributor to inter-annual cyclical variations in global temperatures.[1540] It is associated with a sustained period (many months) of warming (El Niño) or cooling (La Niña) in the central and eastern tropical Pacific Ocean.[540] Strong El Niño events cause the centre of Pacific rainfall to move eastward, away from the Australian coast towards South America.[1540] Common results include drought across eastern Australia [632] and unusually warm late-summer sea surface temperatures in the Region.[540,632,633,1567] Strong El Niño events occurred in the Region in 1982–83, 1997–98 and 2015–16, coinciding with worldwide climate extremes.

La Niña years typically bring more clouds, rainfall and cyclones, which can all help to cool the waters over the Reef.[1568] The year 2022 marked the third consecutive year of La Niña conditions, a duration reached only 3 times over the past 50 years.[582] During extreme La Niña events, the Australian summer monsoon is more vigorous than usual, with more cyclone activity in the Region.[538,539] This often results in above-average rainfall and river flows.

The El Niño–Southern Oscillation interacts with the Madden–Julian Oscillation, and the **Indian Ocean Dipole**, another major inter-annual climate driver. The Madden–Julian Oscillation can trigger or strengthen El Niño and weaken or disrupt La Niña. The Indian Ocean Dipole can also increase or decrease the intensity of El Niño and La Niña events in the Region.[1569,1540] A positive Indian Ocean Dipole may also be associated with warmer-than-average sea temperatures in the Region, and this contributes to the development of marine heatwave conditions.[634,246]

observed over various timescales, though it is not yet clear whether these are outside the range of historical variability.[1540,1541,1542] It is also projected that future El Niño and La Niña events may become more intense as the climate continues to warm.[1543] Other potential effects, such as shifts in the timing and duration of these events, remain subject to considerable uncertainty.[1544]

Projecting climate change involves addressing uncertainties arising from limitations in understanding both the physical climate system and societal trends.[1538] The Sixth Assessment Report of the IPCC[1538] incorporates both factors using an expanded set of Shared Socio-economic Pathways (SSPs) to model future greenhouse gas concentrations in the atmosphere.[1545,1546,1547] These illustrative pathways span the range of possible future emissions scenarios, from very low to very high emissions. For example, SSP1–2.6 portrays a sustainable, low-emissions future resulting in limited warming of 1.8 (very likely range 1.3 to 2.4) degrees Celsius this century; SSP5–8.5 depicts a fossil fuel-driven development path of intensifying emissions resulting in severe global warming in the order of 4 degrees Celsius; while SSP2–4.5 represents a middle-ground scenario in which social, economic and technological trends do not shift markedly from historical patterns.[1546]

Developments such as emerging climate policy and the rapid growth of renewable energy deployment make very high emissions scenarios like SSP5–8.5 less plausible now than in 2019.[1548] Under all considered emissions pathways, the best estimate is for global average temperature to reach 1.5 degrees Celsius above pre-industrial levels between the late 2020s and mid-2030s.[1538] The risk of exceeding 2 degrees Celsius depends strongly on emissions pathways, but under medium to high emissions this is likely by the middle of the twenty-first century.[1544]

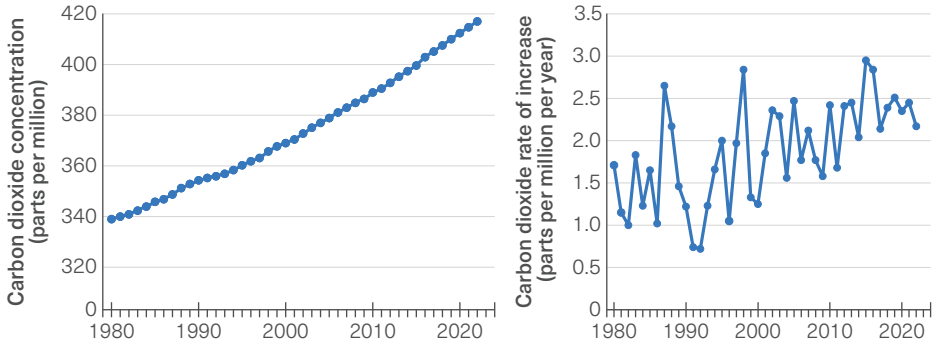


Figure 6.4 **Changes in global atmospheric carbon dioxide concentrations since 1980**
Global carbon dioxide concentrations in the atmosphere have been rising for at least the past 173 years, at a faster rate than any time over the past 800,000 years.[1541] Global carbon dioxide concentrations (left) rose steadily between 1980 and 2023. The annual mean carbon dioxide rate of increase between 1980 and 2022 (right) shows signs of slowing since 2019. Trends shown are based on globally averaged marine surface data. Source: Lan *et al.* (2023)[1561]

Warming of the global climate system is driving climate change. This warming is unequivocal, as confirmed by all major temperature monitoring datasets.[608,1549,1550, 1551,1552] It is primarily driven by the release of carbon dioxide and other greenhouse gases due to human activities.[1538] In 2023, the carbon dioxide concentration reached a global average of 419.3 parts per million in the atmosphere,[1553] the highest levels on Earth in at least 2 million years[540] (Figure 6.4). Globally, 2023 was approximately 1.45 degrees Celsius warmer than pre-industrial levels (with a margin of uncertainty of 1.33 to 1.57) and the past 9 years have been the hottest in the 174-year instrumental record[582,1554] (Figure 6.5).

Warming is generally higher over land than over the ocean, but the pace of warming in the oceans is accelerating.[1555,540] At the ocean surface, temperature has increased by

around 0.9 degrees Celsius since the late nineteenth century, with around two-thirds of this warming occurring since 1980.[608] Global surface temperature has increased faster since 1970 than in any other 50-year period over the past 2000 years.[1538] The magnitude of these changes exceeds the extent of natural variation over glacial–interglacial time scales.[1556,1557,1558] A recent temperature-proxy study on long-lived sponges in the Caribbean indicates that human-caused warming may have begun earlier and may be greater than previously recognised.[1559]

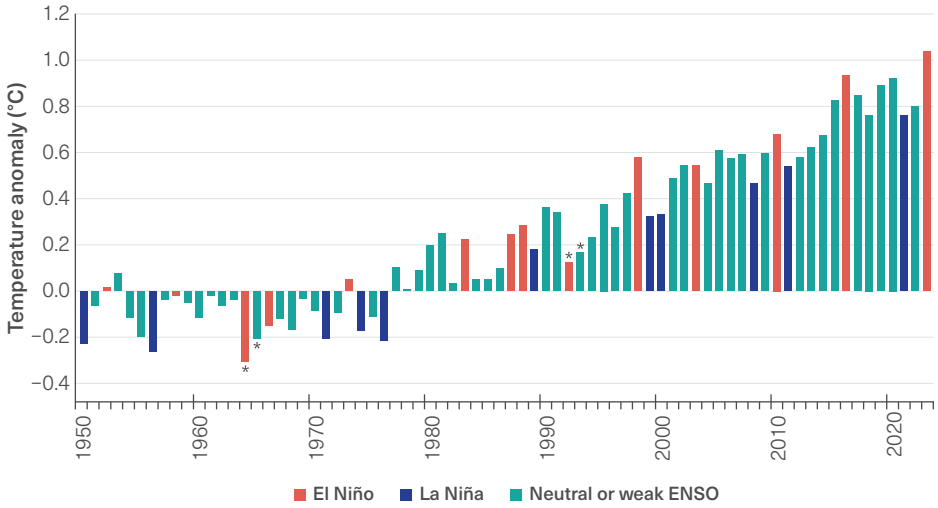


Figure 6.5 **Annual global mean surface temperature anomalies (land and ocean)**

Global mean surface temperature (GMST) was extracted from the Met Office Hadley Centre for Climate Prediction and Research (HadCRUT5 dataset). Anomalies are with respect to the 1961 to 1990 standard averaging period. The average for 2023 is incomplete with months included to October. The NOAA Oceanic Niño Index (ONI) is defined as the 3-month mean of ERSSTv5 sea surface temperature anomalies in the Niño 3.4 region, based on a rolling 30-year base period. Moderate and strong El Niño and La Niña events in this figure (coloured orange and dark blue respectively) are defined by the ONI being +1.2 °C or above (−1.2 °C or below) in at least one 3-month period during the 12 months from July to June. The asterisks indicate years where notable volcanic activity affected global temperatures. Sources: GMST data from Morice *et al.* (2021)[1562], ONI data from NWS/NOAA (2023). Adapted from CSIRO and Bureau of Meteorology (2022).[540]

Around 90 per cent of the extra heat generated by global warming is absorbed by the oceans,[1560] causing the heat content of the global ocean to increase since at least 1970.[540,582,608] The average warming rate for the surface layers of the ocean (to 2000 metres depth) is 71 per cent higher from 2006 to 2022 compared to a longer baseline (1971 to 2022).[582] Ocean heat content is certain to continue to increase over the twenty-first century. Associated warming of the climate system will likely continue until at least 2300, even for low-emissions scenarios, because of the slow circulation of the deep ocean.[608] Although continued warming is inevitable, the extent to which the climate will change in coming decades depends on current and future greenhouse gas emissions.[1039,1539]

The frequency and intensity of marine heatwaves is increasing

The most direct impact of climate change in Australia has been an increase in air and sea surface temperatures.[540,1539] Temperatures over Australia have increased by an average of 1.47 degrees Celsius since 1910, at a rate considerably higher than the global average.[540] Future warming is likely to be similar to the global average.[1539] The number of days with dangerous weather conditions for bushfires has increased in nearly all locations across Queensland[1570] and this trend is projected to continue.[540,566] Across the Region, sea surface temperatures are projected to increase by between 0.3 and 1.2 degrees Celsius

under a low-emissions pathway by 2030 (relative to a baseline of average temperatures between 1986 and 2005), with little further increase during the twenty-first century.[1571,565] However, in a very high emissions pathway, warming would range from 0.6 to 1.3 degrees Celsius by 2030 and 2.3 to 4.7 degrees Celsius by 2090.[565,566,1571]

Sea temperature increases at the ocean surface in the Australian region have been around 1.05 degrees Celsius since 1900,[1572] with the Reef warming by 0.94 degrees Celsius over the same period.[660] Since the 1980s, sea surface temperatures have warmed at a rate of between 0.1 and 0.3 degrees Celsius every decade (Figure 3.8). Annual sea surface temperature anomalies for the Region since 1910 are shown in Figure 3.9. Globally, the sea surface temperature is projected to increase on average by about 1.3 degrees Celsius above pre-industrial levels under a low-emissions pathway and by about 3.2 degrees Celsius under a very high emissions pathway.[1573,1574] Projected changes to sea surface temperatures across the Region range from 2.1 to 3.5 degrees Celsius by 2090 under very high emissions.[565,566,1571] Changes to temperature extremes often lead to greater impacts than changes to the average climate, and these extreme events are becoming both stronger and more frequent because of climate change.[582,1538] This trend is projected to continue.[1575] A return to near present-day conditions by 2100 is only plausible under a scenario that embraces large net negative emissions to limit warming to 1.5 degrees Celsius.[159]

Globally, marine heatwaves have doubled in frequency since the 1980s and become longer-lasting, as well as more intense and extensive.[608,1572,1576,1577] Despite La Niña conditions (Box 6.1), 58 per cent of the global ocean surface experienced at least one marine heatwave during 2022.[582] This trend will continue, with marine heatwaves at the global scale expected to increase four- to eight-fold by the end of this century, depending on emissions pathways.[608] In the Reef and Coral Sea, marine heatwaves are increasing in frequency, intensity and extent.[246]

Globally, average sea levels are rising as a direct consequence of anthropogenic global warming.[613] Two main processes are driving **sea-level rise**: thermal expansion (an increase in the volume of sea water as it warms) and increased melting of land-based ice.[540,614]

Global average sea level rose faster during the twentieth century than in any prior century during the past 3000 years. Since the late 1960s, sea levels rise has accelerated from 3.7 (2006 to 2018)[608,615,1578] to 4.6 (2013 to 2022)[582] millimetres per year. Global average sea level reached a new record high for the satellite altimeter record (1993 to 2022) in 2022.[582]

Increasing loss of land ice from glaciers and ice sheets, including a four-fold increase in the contribution of meltwater from Greenland and Antarctica in 2010 to 2019 compared to 1992 to 1999, has made this the largest contributor to global sea-level rise since 2006.[608] Recent research suggests that a continued trend of ice sheet loss from West Antarctica is now inevitable well beyond 2100, irrespective of future emissions pathways.[1579] Global average sea level is projected to rise by 0.15 to 0.29 metres by 2050 and by 0.28 to 1.1 metres by 2100. Sea-level rise could be several tenths of a metre higher (and approaching 2 metres under very high emissions) if Greenland and Antarctic ice sheets disintegrate faster than anticipated.[608,1580] Projected sea-level rise across the Region is similar to the global average.[565,1571]

Sea-level rise caused by climate change is superimposed on the normal, frequent fluctuations in sea level associated with tides, storm surges, and ocean waves (swell and wind waves) in the order of metres. Sea-level fluctuations are also affected by cyclical variations of 20 to 30 centimetres over years or decades caused by climate drivers, such as El Niño–Southern Oscillation.[608] As these sea level fluctuations occur on a higher baseline, they will lead to increases in the frequency of sea level extremes,[608] including

storm surges associated with the passage of cyclones. If increases in the Region (Figure 6.6) are similar to the global average, extreme sea level events that previously occurred around once per century will occur about 20 to 30 times as often by 2050 and 160 to 530 times as often by 2100 compared to the recent past.[608,629] Sea-level rise is also expected to interact with the complex bathymetry of the Reef to locally increase or decrease tidal ranges such that some coastal areas will be more affected than others.[630]

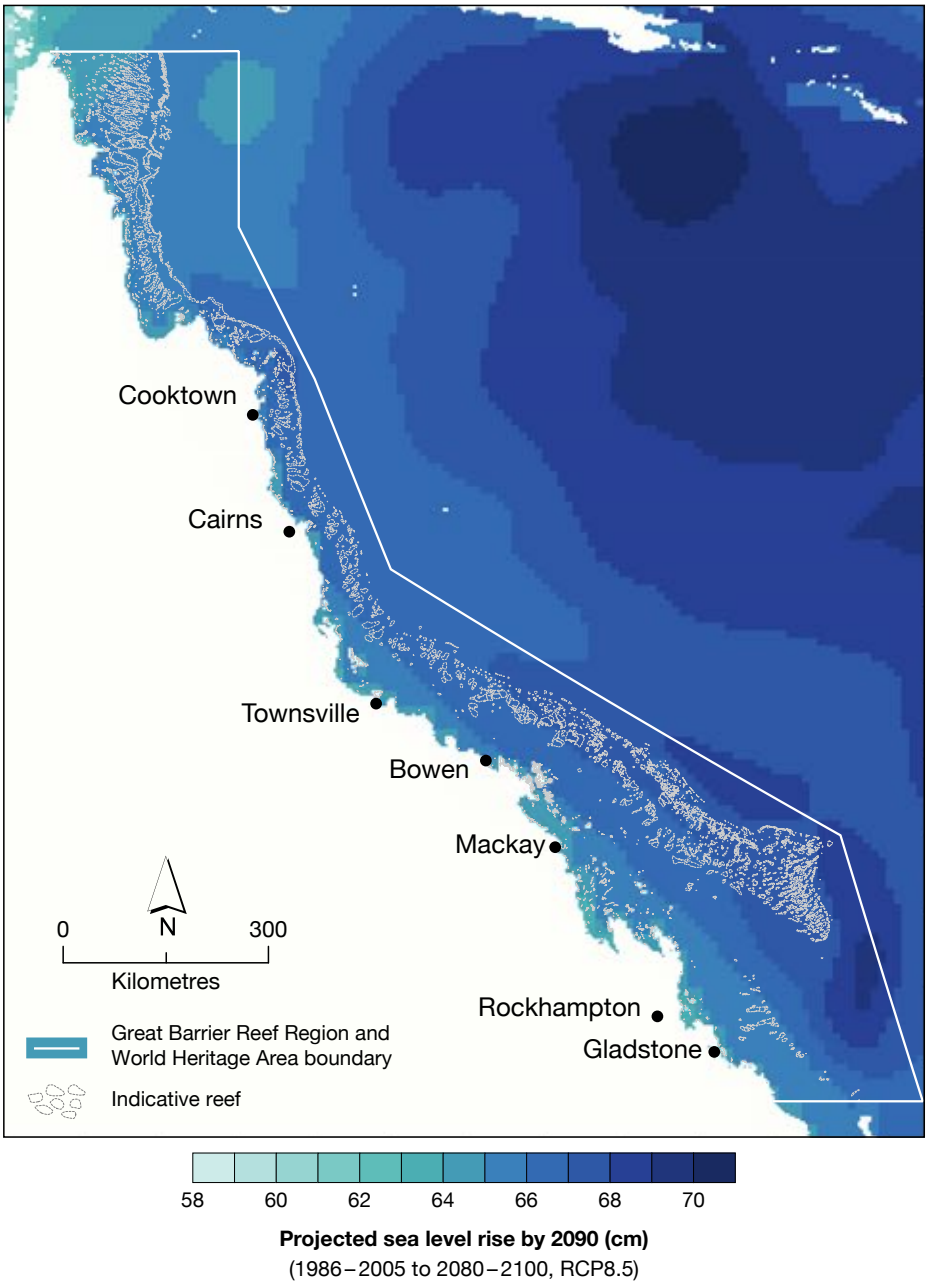


Figure 6.6 **Projected sea level change within the Region under a future high emissions scenario**
Sea level is projected to rise within the Region under representative concentration pathway (RCP) 8.5 over the period 2080 to 2099 relative to the period 1986 to 2005. Projected changes vary spatially across the Region. Source: Zhang *et al.* (2017)[1581]

The absorption of carbon dioxide alters ocean chemistry in a process commonly referred to as **ocean acidification**.[1582] The ocean takes up about a quarter of annual global carbon dioxide emissions[1541] and has absorbed roughly one-third of anthropogenic carbon dioxide emissions since the beginning of the Industrial Revolution.[1572,1583] The absorption of carbon dioxide leads to a shift in carbonate chemistry involving a decrease

in the concentration of carbonate ions and an increase in both bicarbonate and hydrogen ions.[1582] This process also lowers the saturation state of aragonite, the form of calcium carbonate used by many marine organisms including reef-building corals, to produce skeletons and shells.[1572] One consequence of this process has been a global decrease in ocean pH by approximately 0.1 units (a 26 per cent rise in acidity) since the pre-industrial period (Section 3.3.2)[1541,1584,1585] to its lowest level in at least 25,000 years.[1541] The increase in acidity is occurring at a rate estimated to be occurring at least 10 times faster than at any time within the past 65 million years. [1541,1582,1586] The rapid rate of contemporary changes in ocean chemistry is important in determining the magnitude and impacts of change because the processes by which oceans buffer these changes occur over many thousands of years.[1582]

Ocean acidification is also progressing rapidly in the Region, with long-term trends predominantly driven by increasing atmospheric carbon dioxide.[1539,1587,739] These changes are superimposed on increasing daily and seasonal fluctuations linked to patterns in sea temperatures and stratification, changes in net production and in seasonal transport of offshore waters onto the Reef.[535] Concentrations of dissolved carbon dioxide increased by an estimated 6 per cent from 2009 to 2019, and by approximately 28 per cent since 1958.[739] The extensively carbonate seafloor has been unable to buffer the seawater against atmospheric changes.[739] There are indications that the rate and magnitude of increases of carbon dioxide concentrations are more significant on inshore reefs than those further offshore.[1588,1589] For the Reef's coastal waters, average annual seawater pH is projected to decrease by 2090, compared to that for the period between 1986 and 2005, by an additional 0.15 to 0.33 units under moderate to very high emissions (a 40 to 100 per cent rise in carbon dioxide concentrations, respectively).[1571,565] Between 1960 and 2009, the aragonite saturation state likely decreased by 0.33 units.[739] Further median declines (compared to 1986 to 2005) of 0.34 to 0.41 units by 2030 and 0.34 to 1.55 units by 2090 are projected to values below critical levels for coral reefs to be able to maintain net calcification, depending on emissions trajectories (Section 6.3.2).[535,1571,565]

Ocean acidification is directly linked to atmospheric carbon dioxide concentration

Global atmospheric and ocean circulation patterns and rising temperatures influence ocean currents (Section 3.2.1).[608] Australian boundary currents and their associated eddies have immediate impacts on the circulation of water over the relatively narrow continental shelf, with flow-on effects for the entire marine ecosystem.[1572] The major boundary current affecting the Region, the East Australian Current, has been intensifying in recent decades,[1572,608] and this trend is expected to continue.[608] This intensification has been associated with an increase in both current strength and the frequency of its southward extensions,[1590] contributing to marine heatwaves in south-eastern Australia.[1572] More detailed projections of future ocean circulation and **altered ocean currents** remain a key knowledge gap. The present generation of climate models have a limited ability to forecast the future state of boundary currents, such as the East Australian Current, and do not adequately represent associated eddies or deep ocean and continental shelf interactions.[535,1572] Downscaled modelling of climate change projections at resolutions that may better resolve these effects in the Region is underway.[535]

The number of cyclones has decreased globally during the twentieth century.[1591] They have also decreased across northern Australia since reliable satellite observations began in 1982.[540] Additional non-satellite observations suggest there has also been a longer-term reduction since 1900.[540] The number of cyclones is projected to decrease in the future, but it is expected that a greater proportion will be higher intensity, with continuing large variations in cyclone numbers from year to year (Section 3.2.2).[540,1592,1593] Whether or not

cyclone-generated waves will become more damaging to coral reefs depends on cyclone size and forward speed as well as intensity. Modelled data are not yet robust enough to make reasonable predictions of these characteristics, especially at fine scales.[549] It is projected that average peak wind speeds will increase globally with warming.[1575] No climate change effect on spatial extent (size) of cyclones has yet been detected, in part because cyclone size is highly variable, but potential effects are a subject of active research interest.[1575] Since 1979, the proportion of intense cyclones has increased by around 25 per cent, which is around 6 per cent per decade and consistent with physical process understanding and climate model predictions.[1594,1595] Although observed trends in cyclone intensity remain inconclusive,[1596] in part due to the limitations of satellite-based estimates, indirect measurements suggest that cyclones at all intensity categories have strengthened over the past 30 years.[542]

Model projections indicate that, relative to pre-industrial conditions, cyclones in north-east Australia will have both higher wind speeds (by 5 to 10 per cent on average) and heavier rainfall (by up to 27 per cent for average hourly rainfall rates) under moderate- to high-emissions future climate change.[565,1571] Predicted increases in peak rainfall rates have already been substantiated by attribution studies, which indicate that higher temperatures have augmented cyclone-associated rainfall.[1596] As a result of this effect, rainfall totals in particular locations are likely to increase in the future, bringing a higher risk of associated flooding.[1566] An observed slowdown of forward speed over Australia (by 22 per cent since 1946) suggests flooding risk may also be increased by cyclones remaining over a given location for longer,[1597] but future trends in the speed of travel and spatial extent of cyclones remain uncertain.[549] In contrast, one of the most assured future impacts from cyclones will be an increase in coastal flooding when storm surges are superimposed on higher sea levels (Section 3.2.5).[540,553]

Changes in patterns of cyclone activity from year to year may also change over the course of this century.[1544,1598] The number of cyclones making landfall in the Region is highly variable over different timescales.[537] The frequency of landfall is higher during La Niña years than El Niño years.[538,539,1599] This pattern may change; there are indications that cyclones will become more frequent during El Niño events (and less frequent during La Niña events) by the end of the twenty-first century.[1544,1598]

Observed and projected changes to broadscale **rainfall** patterns occurring globally[582,1541] and in some regions of Australia[540,1539] are not as evident or well resolved in the Region.[565,1571] Recent research has shown that seasonal rainfall has changed in northern Queensland as the climate has warmed, with wet season rainfall increasing and becoming more variable since the pre-industrial period.[569] Continued warming of the climate will have important effects on rainfall, particularly through the amplification of extremes of drought and flood. Rainfall in the Region is strongly seasonal, with around 60 to 80 per cent occurring in the wet season from December to April.[1564] This rainfall is often associated with the monsoon trough and the passage of low-pressure systems and cyclones, which can bring flooding across the Region (Box 6.1).[1564,1600] It is modulated in part by climate drivers, such as the Madden–Julian Oscillation.[1565] Variation from year to year is strongly linked to other major climate drivers, especially the El Niño–Southern Oscillation. [1565,1601,1602]



A warmer atmosphere holds more water vapour

The varied temporal and spatial patterns of rainfall across the Region are superimposed on decadal rainfall trends occurring due to climate change.[1539,1541] One of the most important of these is that **heavy rainfall events** are becoming more intense.[540] Daily rainfall totals associated with thunderstorms have increased since 1979, particularly in northern

Australia and this trend is expected to continue.[540] On a global scale, approximately 20 per cent of global heavy rainfall events over land are attributable to the observed temperature increase since pre-industrial times.[1603] For heavy rain days, total rainfall is expected to increase by around 7 per cent for each degree of warming. [540,1566] More-intense rainfall increases the likelihood of surface-water and flash floods[1566] (Section 3.2.3) and large flood events are occurring more frequently than in the past (Section 6.5.1).[575]

Climate across the Region is changing. Changes have already been widely documented in terms of rising air and sea temperatures as well as changing ocean chemistry. Trends for rising sea levels and increasing intensity of storms are increasingly evident. Anticipated changes, such as increases in the intensity of El Niño and La Niña events, vary in certainty but are potentially consequential for the Region's values.

6.3.2 Vulnerability of the ecosystem to climate change

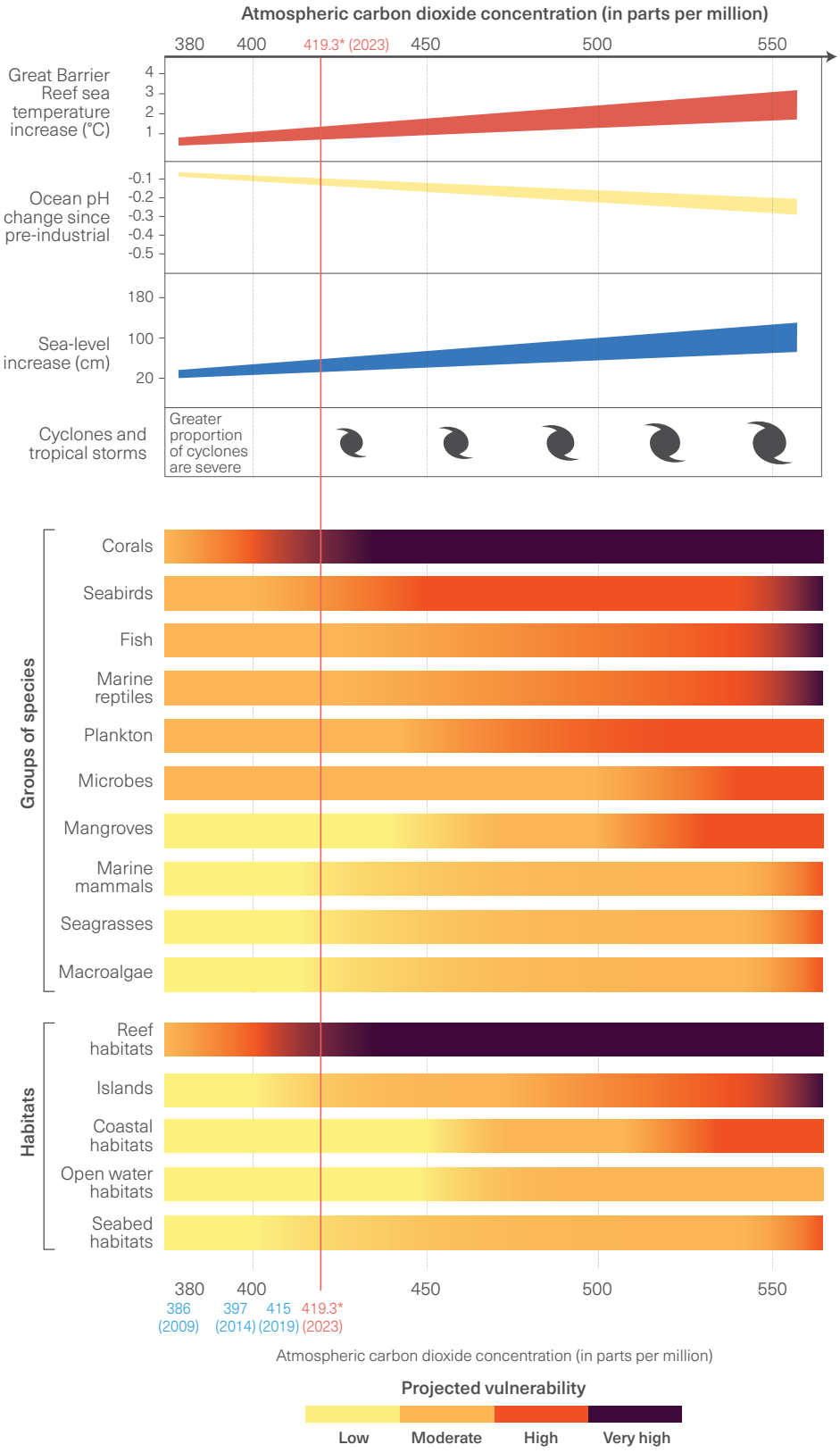
The Region is particularly vulnerable to the pervasive influence of a rapidly changing climate [536] that is amplifying exposure to both pre-existing (for example, cyclones) and emerging (for example, marine heatwaves and ocean acidification) disturbances (Figure 6.7). The primary concern is the vulnerability of the Region's key habitats and habitat-forming species, such as corals, seagrasses, mangroves and wetlands, based on their roles in supporting ecosystem resilience and maintaining biodiversity.[535]

The vulnerability of ecosystems is determined by the level of exposure and sensitivity of species and habitats to disturbances and the ability of ecosystems to tolerate and recover from impacts. The Region's key habitats have a natural resilience against acute physical disturbances such as cyclones, intense rainfall, freshwater flood plumes and heatwaves. However, climate change is exacerbating both acute and chronic disturbances in the Region, shrinking recovery windows and affecting ecological processes that underpin ecosystem resilience.[541,632,644,1604]



Recruitment of corals, such as the small colonies pictured, can lead to recovery if there is enough time between disturbances. © Matt Curnock 2022

Climate change is shrinking recovery windows and undermining ecosystem resilience



*For the first time since human existence, the planet's atmosphere has reached 419.3 ppm

Figure 6.7 **Projected vulnerabilities of components of the Reef ecosystem to climate change**
Vulnerability differs for a number of ecosystem components and depends on total atmospheric carbon dioxide concentrations. Changes in sea temperatures, ocean pH and sea level are indicative only, based on latest climate projections.[535,1609] Source: Johnson and Marshall (2007)[1610]; adapted from values presented in Gattuso *et al.* (2015)[741] and Hoegh-Guldberg *et al.* (2018)[1611] and updated to reflect recent findings from IPCC (AR6).[1609]

The magnitude and pace of global warming (Section 6.3.1) will be pivotal drivers of ecosystem vulnerability by determining exposure to climate impacts. The combined impacts of near-term warming, ocean acidification, sea-level rise, increased ultraviolet radiation,[1605] and increased frequency, severity, and duration of extreme events, will negatively affect other species and habitats across the Region.[109,1572] For some habitats, direct climate impacts are likely to be the dominant drivers of change over the coming century. For example, in *Halimeda* bioherms and meadows (Section 2.3.8) these drivers are likely to be rising sea temperatures and ocean acidification, as well as changing ocean circulation patterns. Deoxygenation in the water column due to rising sea temperatures could have implications for a range of species and habitats (Box 6.2). Increasing fire frequency is a threat to coastal and island ecosystems[968] and may affect water quality through altered catchment hydrology (such as erosion rates and vegetation dynamics affecting runoff patterns)[1606,1607] and the atmospheric transport of limiting nutrients.[713] The sensitivity of other habitats, such as coral reefs, seagrass meadows, and mangrove forests, to climate impacts will be affected by concurrent near-term trends in other pressures, such as those associated with coastal development (Section 6.4), land-based runoff (Section 6.5) and direct use (Section 6.6). Studies have highlighted the potential for reducing near-term climate impacts through the targeted management of these local stressors.[535,1608]

The repercussions of ecological vulnerability to climate change are potentially far reaching due to the diversity of the Reef's ecosystem services.[1612] For example, reductions in the structural complexity of coral reefs reduces their effectiveness as natural barriers against ocean waves.[153] This would not only reduce their effectiveness as buffer zones for coastal communities[1613] (Section 6.3.3) but also for nearshore and coastal ecosystems, such as mangroves and seagrass meadows, which also play important coastal buffering roles.[1614] On regional to global scales, changes in the condition of coral reefs and other ecosystems may indirectly affect the climate. For example, climate change may affect the release of sulfur compounds, which play a role in cloud formation (Section 3.3.1), from coral reefs into the atmosphere and surrounding waters.[722]

Coral reef habitats and coral-dependent species are among the most vulnerable to **sea temperature increases** (Figure 6.7).[1615] Proximity to their thermal limits brought about by ocean warming signifies a precarious condition for the Reef's corals, as evidenced by the four mass coral bleaching events since 2016 (Sections 2.3.5, 2.4.4 and 8.3.1). These marine heatwave events were not equal in their severity or extent, and while the back-to-back 2016 and 2017 events resulted in cascading effects on coral-associated fish and invertebrates,[1616,1617] rapid recovery of coral cover was recorded up to 2022, with little change reported in 2023.[163] The rapid increase in coral cover across the Region reflects a lower disturbance regime since 2017 compared with the preceding decade. Despite their widespread impacts, the 2020 and 2022 mass coral bleaching events did not cause as much coral mortality as the 2016 and 2017 events. While coral mortality from crown-of-thorns starfish has occurred across the Region, outbreaks have been suppressed effectively and coral has been protected on reefs that have received targeted, timely and sufficient cull effort.[163,187,1015] While the recovery trend of coral cover in the mid-shelf and offshore reefs over the past 5 years is encouraging, the recent pause in recovery of coral cover highlights that exposure to even moderate disturbances (for example, the 2022 mass coral bleaching event and crown-of-thorns starfish losses) can have a widespread effect.[163] Potential increases in the strength of El Niño–Southern Oscillation events may amplify the impacts of future marine heatwaves.[1618]

As the climate continues to change, the capacity of reef-building corals to survive, grow and reproduce will be increasingly compromised,[1549,1619,1620] with resulting consequences for other species dependent on coral reefs (Section 2.3.5). Warming already locked into the climate system will lead to an increasing frequency of thermal stress events in the Region, and intensifying emissions could lead to severe bleaching conditions occurring annually

BOX 6.2

Deoxygenation

Loss of oxygen in the ocean (deoxygenation) occurs as a result of both increasing ocean temperature and oxygen consumption by living organisms. Warming reduces the solubility of oxygen in water and the mixing of ocean layers, as well as increasing biological oxygen demand. Algal growth fueled by excess nutrients can also cause deoxygenation in coastal areas — a process known as eutrophication.[657]

Analyses indicate that global ocean oxygen levels dropped by approximately 2 per cent over the 50 years from 1960 to 2010.[1708] Models predict continued decline in global ocean oxygen, with an estimated reduction of between 1 and 7 per cent by the year 2100[1709] although these projections may underestimate true deoxygenation rates.[1710,1711] The vast majority of global reefs are likely to experience weak to moderate hypoxia by 2100, with severe hypoxia likely in about 30 per cent of reefs.[642] Despite this, the impacts of deoxygenation on tropical coastal ecosystems are less well studied than for equivalent temperate ecosystems.[643,1712,1713]

Loss of oxygen from the global ocean has significant implications for marine life.[643,1713] Decreased oxygen levels reduce the available habitat for marine species, and can limit growth, reproduction, health and survival, with potential consequences for species richness, diversity and ecosystem function.[1712,1714,1715]

For mobile species, reduced oxygen can lead to shifts in behaviour and distribution,[643,1715] with potential impacts most likely to be observed in pelagic species with high energy requirements.[1716] Low oxygen conditions have been linked to coral bleaching,[857,1717] reduced rates of calcification,[1718] coral disease and increased algal dominance on reefs,[1719] as well as negative impacts on seagrass growth, metabolism and survival.[1712] Co-occurring climate stressors, such as warming, acidification and deoxygenation, are often compounding[1720,1721] and may limit species' natural tolerances for low oxygen.[1721]

While impacts of deoxygenation on tropical ecosystems are demonstrated, the degree to which deoxygenation is currently affecting the Region remains a knowledge gap. It is anticipated that impacts on species and habitats will be observed within the Region in future if global and coastal deoxygenation of our oceans continues alongside other climate related impacts as predicted.

by 2080.[159] The extent to which reef-building corals and other key species can adapt to rising sea temperatures is a major knowledge gap and a critical area of current research interest.[535,1621] For corals, their limited [1622] ability to adapt to changing conditions could be a critical factor influencing the future health and resilience of coral reefs (Figure 6.8).[109,1623] Improved understanding of the various genetic, physiological and ecological components of adaptation and acclimatisation to thermal extremes is vital to manage the response of coral reefs to climate change.[1621,1624] Some species might be able to shift their occurrence range southward as temperatures warm[1619] but their ability to move will depend on the availability of habitat outside the Region[1572,1620] and is fundamentally constrained by limited light availability at higher latitudes.[1625] Coral reef connectivity is projected to decline as the climate warms, primarily due to increased larval mortality and reduced competency duration in warmer waters.[932]

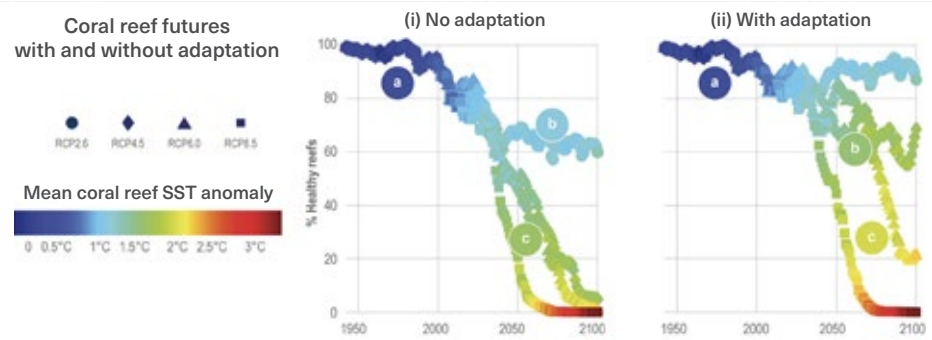


Figure 6.8 **Coral reef futures with and without adaptation to increasing sea surface temperatures**
Graphs show simulated proportions of healthy coral reefs, in which corals are not substantially bleached, under four different emissions pathways, i) without and ii) with adaptation of corals to become more thermally tolerant. Average temperature anomalies (increases above the 1861 to 2010 baseline) are shown by changes in colour. For low- to moderate-emissions scenarios scenarios, adaptation results in a much greater proportion of healthy reefs by 2100.[1623] Although some decline from historical reef condition (a) is inevitable, the temperature increase needed to push coral reefs to a lower diversity state (b) or a degraded state with little prospect for recovery (c) is much lower if corals are unable to adapt.[109] Source: Adapted from Cooley *et al*. (2022) [109]

Locating potential climate refugia, including deeper banks and reefs where favourable hydrodynamic conditions confer a degree of protection from thermal extremes, is another area of active research interest.[158,180,664] One study identified 13 per cent of the Reef as potential refugia that avoid significant warming more than expected by chance.[158] These areas are potentially capable of delivering larvae to 58 per cent of the Reef.[158] Shallow reefs along the path of the North Queensland Current have been identified as potential refugia from bleaching because of upwelling of cooler waters.[246] Deeper coral communities (Box 2.4) are also more likely to escape the effects of surface marine heatwaves.[181,246] Tidal and wind mixing of warm water away from the sea surface provides relief from warming for some local reef communities.[667] These potential coral refugia are predicted to persist until global warming exceeds around 3 degrees Celsius.[667]

Studies show that extremes of warm temperature cause physiological stress to numerous other marine organisms including some species of fish, sponges and seagrasses.[535] Sponges have been posited as potentially benefiting from reduced competition with corals under climate change[1626] but this hinges on yet uncertain effects on ecosystem primary production.[795] Additionally, some sponges can lose symbiotic microorganisms (bleaching)[1627,1628] and exhibit reduced reproductive output,[1629] decreased feeding behaviour[1630] and mortality[1627,1630] when exposed to prolonged thermal stress. Increasing water temperatures affect the energy balance of photosynthetic organisms, such as seagrasses and *Halimeda*.[1631] Seagrass meadows are less vulnerable to temperature increases than coral reefs,[1632,1633] but a growing body of evidence links marine heatwaves to substantial losses of seagrass habitat,[109,1632,1634,1635] which may reduce the effectiveness of these ecosystems for trapping and storing atmospheric carbon.[133,1636]

Temperature extremes cause physiological stress to many marine organisms

Mobile organisms such as fish have more capacity than benthic species to escape temperature stress, but the limited number of studies on reef fish have shown them to be vulnerable to both direct and indirect effects of temperature increase.[535] Most marine organisms are ectotherms so are unable to regulate their body temperature. Increases in temperature affect their performance and fitness.[1637,1638] Studies have shown that increased temperatures have been associated with reduced pelagic larval duration,[1639]

pre-settlement growth rates,[1640] and growth of juvenile and adult reef fishes.[1641] Varied thermal tolerance between species[1642] has led to shifts in community assemblages as temperatures continue to rise.[1643,1644] Temperature experiments involving coral trout, one of the larger commercial species, found declines in survivorship, metabolism and swimming activity with relatively moderate increases in temperature.[1645,1646] Increasing energetic limitations with body size may have ramifications for fisheries productivity and ecosystem functions.[1647] Direct physiological effects of ocean warming may exceed the indirect effects of habitat loss on coral reef fish productivity.[1648]

Herbivore populations can benefit in the short term from increased algal resources following coral bleaching and associated mortality.[1649] However, the subsequent loss of structural complexity has indirect impacts on coral-associated fishes, such as damselfish, including reduced recruitment[254] and decreased fish abundance.[1650] Similarly, bleaching of sea anemones has been linked to impaired threat responses in anemonefish.[1651] Thermal stress reduces reproductive rates and alters behaviour in crustaceans (Section 2.4.5).[322,323] Although the sublethal effects of temperature are often inconspicuous, they can potentially de-stabilise how the ecosystem operates.[322,323,1652] Nevertheless, how various effects on individual species will manifest at the ecosystem level remains a major knowledge gap.[165]

Rising temperatures are altering the sex ratios of marine turtles (Section 2.4.10), as the sex of hatchlings is determined by sand temperatures during incubation.[535] Feminisation of green turtle hatchlings in the northern Reef has been an ongoing trend for more than 2 decades.[1654] This shift in the sex ratio of hatchlings may confer some adaptive capacity to these species[1655] — since the sex that increases future fecundity (females) is produced in greater proportion — but the near complete feminisation of hatchlings under higher rates of warming compromises the future viability of sea turtle populations.[535,1656] Marine turtles are also subjected to the effects of rising sea levels on nesting habitat, and can experience changes in reproductive periodicity, shifts in latitudinal ranges, and changes in foraging success.[1657]



Loss of reef-building corals affects reef calcification rates. © Matt Curnock 2020

Latitudinal shifts in species distributions and changes in the timing of biological events in response to temperature increases have already been shown for several plankton, bony fish and invertebrate species.[1539,1658] Little quantitative evidence exists about current shifts in the geographic ranges of tropical benthic species.[535] Effects of increased sea surface

temperatures, such as changes in timing of breeding and body size of breeding adults and loss of adequate food supplies, have been observed in many bird populations within the Region.[1659,1660,1661] Under rates of projected warming, the persistence of many other species will depend on them moving well beyond the biogeographic realm where they are endemic, at rates of redistribution not previously seen.[1662] For example, projections of the future distribution of seagrasses suggest a poleward shift due to increasing seawater temperatures.[1663] However, a species' ability to migrate will depend on habitat availability.[1539,1620]

Ocean acidification is affecting many calcifying organisms, with corals and calcifying algae the most vulnerable[535,540,1664,1665] (Section 3.3.2), but with considerable variability between and within species groups.[1666] Groups such as bivalves and sea urchins are recognised as generally sensitive to projected levels of acidification.[1666] Other marine calcifying organisms, such as benthic foraminifera, many echinoderms, crustaceans, bryozoans, polychaete worms and cephalopods, appear to be tolerant to the levels of ocean acidification expected this century.[1666,1667,1668] There is some evidence that calcifying zooplankton in the Region may be sensitive to falling aragonite saturation at the range of values currently observed.[359] Acidification has also been linked to an increased dominance of environmental microbes at the expense of those that contribute to a healthy coral holobiont.[781]

Changing ocean chemistry makes it harder for corals to build their skeletons

Even relatively small decreases in ocean pH are associated with changes to carbonate chemistry that reduce the capacity of corals to build skeletons, which in turn reduces their capacity to create habitat[743,1669] (Section 3.3.2). Reef-building processes are also affected, with increasing ocean acidity leading to faster dissolution of calcium carbonate sediments in lagoons and interreefal areas[757,758] and affecting calcification rates of organisms involved in the cementation of the coral reef matrix, such as crustose coralline algae[743,744] and calcifying microbes[776] (Section 3.4.8). The palaeo-record shows that the microbial calcification process is highly sensitive to ocean acidification.[889,1670] Individual organisms and reef structures weakened by ocean acidification are less able to resist and recover from physical damage caused by cyclones.[1671]

Declines in calcification rates of *Halimeda* (Section 2.3.8) are anticipated under high emissions scenarios,[1672,1673] although the ability to regulate carbonate chemistry within the intercellular spaces where calcium carbonate is precipitated is likely to insulate these algae to some degree from the effects of ocean acidification.[1674] Some species, such as copepods that are a significant component of the reef lagoon infauna and an important food source for higher trophic levels, have been shown to increase under low pH conditions.[757] Increases in carbon dioxide also provide photosynthetic organisms, such as seagrass and algae, with improved access to an essential resource for photosynthesis.[1675] The ecosystem consequences of relative winners and losers under ocean acidification represent a major knowledge gap.[1666,757]

The relative saturation of aragonite is a key factor in reef development.[535] Observed declines in aragonite saturation state[739] are well on the way to exceeding thresholds associated with steep changes in reef biota and may exceed thresholds for positive reef accretion within decades[281] (Section 6.3.1). Numerous studies have documented decreases in community calcification in the Region and globally, although at widely varying rates.[749,898] More than 55 million years ago, under high atmospheric concentrations of carbon dioxide, a reduction in calcification occurred.[1676,1677] It took tens of thousands of years for those changes to reverse,[1678] suggesting emerging risks associated with ocean

acidification will be essentially irreversible on human timescales.[665] Many of the effects of ocean acidification on reefs, such as proliferation of algae, greater bioerosion, negative effects on coral recruitment and crustose coralline algae, are similar in their direction to the effects of poor water quality, suggesting water quality improvement may mitigate some of the effects of ocean acidification on inshore reefs.[535]



Coral reefs exposed to below average thermal stress could serve as crucial refuge areas. © Matt Curnock 2022

Towards the end of this century, **sea-level rise** is projected to place significant pressure on coral reefs,[1679] mangrove forests[95,1680] and seagrasses, as well as on saltmarshes and islands.[1681] For these habitats to maintain their extent, growth and migration must keep pace with sea-level rise.[1679] The compounding pressures of current climate change threaten the ability of reef-builders to keep pace with future sea-level rise.[884] Losses of biodiversity and functional integrity are likely to occur over decades on the Reef's ecosystems in which upward growth is insufficient to keep pace with rising waters.[1679,1682] The Reef's low-lying coral islands are likely to exhibit considerable variability in their vulnerability to sea-level rise and other climate-related stressors. Factors affecting reef-building process affect island geomorphology but indirectly and over longer timescales.[100] The capacity of any individual island to continue to grow vertically with rising sea levels depends on a complex set of factors,[884,1683] including the physical characteristics of the cay itself, the local carbonate budget and surrounding oceanographic and weather patterns.[100,1684]

Small increases in average sea level can greatly increase the impacts of coastal inundation

Overall, future warming is expected to drive range shifts in mangrove forests, with significant losses projected under all future emissions scenarios by mid-century and substantially greater losses by 2100.[109,95] Recent research suggests that vertical growth of mangroves and saltmarshes will be likely to fall behind a relative sea-level rise (Section 3.2.5) of 4 millimetres per year and highly likely to do so at 7 millimetres per year.[95] Losses will be greatest where space for retreat is constrained or where other non-climate drivers exacerbate risk from climate-induced drivers.[591,109] The effects of sea-level rise will take time to manifest in ecosystems and regional communities, but the effects will continue for centuries and are highly dependent on emissions trajectories (Section 6.3.1). Under a very high emissions scenario leading to 3 degrees Celsius of global warming, nearly all the

world's mangrove forests and coral reef islands and almost 40 per cent of mapped tidal marshes are estimated to be exposed to relative sea-level rise of at least 7 millimetres per year.[95] Losses of this habitat would be accompanied by losses of associated ecosystem services, including wave-energy attenuation, habitat provision for biodiversity, food production and carbon storage.

One of the most certain impacts of climate change over the course of this century will be increases in the frequency of extremes of sea level, such as king tides and storm surges being superimposed on a rising baseline.[629,1685] Intertidal coastal habitats are at risk from exposure to physical damage from these events.[1686] More frequent coastal inundation will also contribute to salinisation of coastal wetlands and shifts in intertidal species distributions.[1687] Year-to-year sea level fluctuations linked to the El Niño–Southern Oscillation (Box 6.1) can cause widespread dieback of mangroves, such as occurred in the Gulf of Carpentaria during the 2015–2016 summer.[1688,1689] The potential for future increases in the intensity of El Niño–Southern Oscillation events (Section 6.3.1) therefore has important implications for intertidal coastal ecosystems, such as mangroves and saltmarshes.[1690]

Altered weather patterns and increases in the intensity and duration of severe weather events are likely to bring both acute and chronic impacts to the Region's ecosystems. For example, increasingly extreme rainfall events[540,554] are likely to be associated with greater pulsed delivery of sediments, nutrients and pesticides in land-based runoff.[535] Projected increases in the frequency of droughts in southern catchments will likely affect the condition of wetlands and other coastal habitats and lead to greater sediment delivery during drought-breaking floods.[535] The loss of 2.3 per cent of mangroves in parts of the Mackay Whitsunday region from 2009 to 2019, attributed to storms and precipitation variation,[1691] illustrates the sensitivity of these ecosystems to changes in weather patterns. Seagrass meadows in coastal areas are vulnerable to physical damage from severe storms and cyclones as well as to protracted impacts caused by declines in water quality from rainfall and discharge.[535] Likely increases in flooding and strong winds are linked to enhanced coastal erosion but may also deliver sediments needed for vertical growth of wetlands.[535]



Higher peak rain rates can cause intense flooding

Projected changes to the character of cyclones (Sections 3.2.2 and 6.3.1) are a key focus because of their pivotal role as drivers of ecosystem structure, diversity and change.[1692,1693,1694,1695] The coastal effects of cyclones depend on their intensity, size, track and speed of travel.[1575] Coastal fringing and intertidal habitats, and shallow areas of the lagoon floor, as well as coral reefs, are all susceptible to damage, with flow-on effects for associated species.[535] The attribution to cyclones of 48 per cent of losses in coral cover between 1985 and 2012,[1696] and 41 per cent between 2008 and 2020,[1697] underscores the central importance of cyclones in driving disturbance dynamics on the Reef. Although cyclones are forecast to increase in average intensity,[1575] a critical knowledge gap is whether cyclone damage to ecosystems above and below water will also increase.[535,549] Rises are projected in sea level, average cyclone intensity and rainfall rates; each generally acts to further elevate storm surge and freshwater flooding.[1575] Since damage increases exponentially with wind speed, an increase in peak wind speeds is likely to produce greater overall wind damage.[535,1575] Underwater cyclone damage depends on wave generation, with large, slow-moving intense cyclones causing the most damage because they maximise wave height.[549] Wave barriers, such as upwind reefs, reduce damage. Trends in determinants of damage other than peak wind speeds remain uncertain.[549,1575]

Damage can be widespread, for example coral damage from cyclone Yasi extended up to 250 kilometres from the cyclone track.[544] However, damage to reefs tends to be highly variable at local scales, depending on the intensity and duration of wave exposure.[544,1698,1699] The extent of damage to corals is species-specific, with branching and plate corals more vulnerable than massive and encrusting corals.[1700,1701] It is certain that cyclones will continue to be a major source of disturbance in the Region and will contribute to increasing cumulative pressure on ecosystems.[535] Changing patterns of cyclone activity will also have interactive effects with temperature, since the cooling influence of cloud cover associated with cyclones has been shown to moderate the intensity of marine heatwaves at regional scales.[555] Predictions of the determinants of damage, as well as the spatial patterns of future changes in cyclone distributions, are critical knowledge gaps.[549]

Altered ocean currents will have flow-on effects on the entire marine ecosystem, from planktonic production to pelagic and reef fish distribution.[356,1572,252] Intensification of the offshore East Australian Current has been linked to increased nutrient supply and hence increased ocean productivity.[1702] As the East Australian Current strengthens and moves warmer water further south, some tropical species are expanding southwards along the south-east coast of Australia.[252,1030,1703] As southern waters continue to warm, particularly during winter, these species may persist and establish new populations.[1704,1705] Different species compositions could result in a reorganisation of ecosystem functions, particularly if displaced species are habitat forming and lose their dominant position in the ecosystem.[1706,1707]

Local scale changes to stratification and upwelling are likely to affect the locations of thermal refugia[246] and reduce the availability of nutrients on which, for example, *Halimeda* meadows depend,[203] but key knowledge gaps remain in predictive modelling at this scale.[535]

6.3.3 Implications of climate change for regional communities

Regional communities now recognise climate change as the greatest threat to the Reef[1075] (Section 9.3.1). Climate change is an important driver of change and risk for communities living in, or adjacent to, the Region through an increase in climate extremes (record-breaking temperatures, floods and droughts), climate-associated economic costs,[1722] and declining ecosystem condition.

Climate change impacts on the Region's ecosystems (Section 6.3.2) will have flow-on effects for regional communities and dependent industries. For example, both actual and perceived declines in coral reef condition affect tourism visitation rates and visitor satisfaction.[1077,1723] The diverse social and economic benefits derived from the Region include income and employment from fisheries and tourism, coastal protection and cultural values.[1323] Globally, climate change has already reduced fisheries productivity,[1724] positive tourism experiences,[1723] and coastal protection by mangroves, seagrasses and coral reefs.[153,1725,1726] Projected global declines in marine fisheries catches [1727,1728] highlight the challenges posed by climate change for sustainable fisheries management in the Region.[1729,1730] In particular, projected reductions in coral reef habitat structure could seriously affect reef fisheries productivity,[1731,1732] with impacts depending on the degree of resilience and functional redundancy in the ecosystem.[371]

Without strong mitigation of global warming, these impacts will worsen over the course of the coming century.[1538] The vulnerability of Reef-reliant industries largely depends on their exposure and sensitivity to climate impacts, as well as their ability to anticipate and adapt to change. For example, marine tourism operators have shown adaptability and resilience since 2019 (Section 8.5.1), so significant economic losses for this reef-dependent industry

due to climate change impacts have not yet been realised. Insufficient understanding of the nature of potential impacts is a significant barrier to adaptation. Improved community understanding of the challenges posed by climate change would enable communities to better prepare for, and mitigate, its impacts. Building stronger, more resilient communities will be critical for the future sustainability of Reef-reliant industries.[1733]

6.4 Coastal development in the Catchment

The catchments, coastline and islands of the Region are human landscapes, accommodating approximately 1.2 million people and a range of different activities and land use practices (Figure 6.9). Coastal development includes all development activities, construction and land uses in the Catchment, coastlines and islands. Since the arrival of Europeans in the Region in the mid-1800s, broadscale changes have occurred in land use, resulting in widespread changes in landscapes. These historical changes, along with current activities, affect Reef ecosystems.[1734]

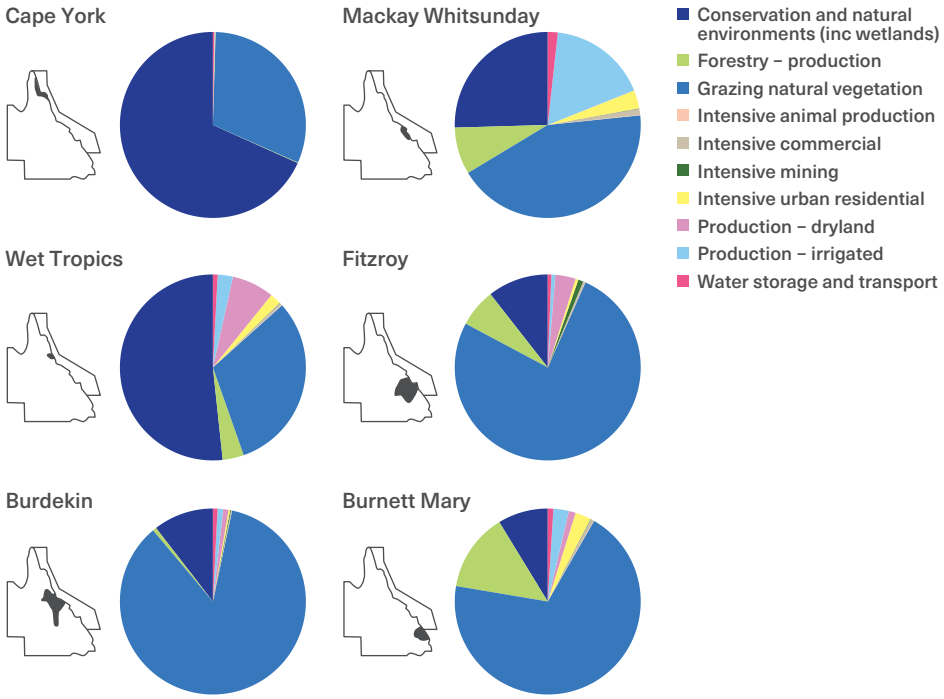


Figure 6.9 **Proportion of land uses in the Catchment by natural resource management region**
Catchment land uses are grouped according to similarities in the ecological functions they provide to the Reef. The graphs (right) present the data captured in 2021 for each natural resource management region (left) in the Great Barrier Reef Catchment. Source: Adapted from Queensland Department of Environment, Science and Innovation (2023).[1735]

Coastal development in the Region is driven by a range of factors, with major land use changes in the Catchment over the past 150 years linked to national and state development schemes and global market forces,[332] as well as the needs of the local population. Population growth drives coastal development, particularly in urban areas, intensifying infrastructure demands; for example, more roads and larger stormwater networks, more sewage treatment, increased food production and expansion into previously remote areas of the Catchment. Proposed infrastructure plans for Queensland now include renewable energy zones within the Catchment,[1736] upgrading infrastructure to encourage major energy projects such as large-scale wind, solar and hydrogen power stations, as well as the world's largest pumped storage hydropower scheme which is proposed across the Pioneer Valley and Burdekin Basin catchments.[1509] Overall, a range of the land uses that can significantly impact the Reef's condition are at, or close to, historical highs of landcover and production, including cattle, cropping and aquaculture.

6.4.1 Trends in coastal development

Agriculture

Despite global and local disruptions due to the COVID-19 pandemic[1737] and a short period of decreased growth, the total value of Queensland's agriculture has rebounded. It is estimated at $24 billion in the 2023–24 financial year, 6.8 per cent greater than the average for the past 5 years.[1738] Many of the important agricultural industries in the Catchment are at historical highs, particularly beef, bananas and cotton, which have all recorded their highest annual production numbers and land use areas since 2010.[1734]

The total land area under cropping in the Catchment was 1,086,754 hectares (10,867 square kilometres) in 2021, dominated by grain crops and sugar cane (Figure 6.10). This area is less than it has been in the past, mainly driven by cropping declines in the Fitzroy and Burnett Mary natural resource management (NRM) regions from historical highs in the late 1900s. Other NRM regions have steadily increased in area under cropping and are currently at or around their historical maximums.[1734]



Beef cattle grazing in the Fitzroy region. © Queensland Government 2013

Between 2018 and 2021, agricultural land uses accounted for the greatest areas of vegetation clearing in the Catchment. The motivations for clearing on agricultural land are to maintain or increase productivity, to maintain or increase the market value of the land, or to harvest fodder.[1739] On grazing lands in the Catchment, 440,829 hectares (4408 square kilometres) of vegetation were fully cleared and 39,946 hectares (399 square kilometres) were partially cleared between 2018 and 2021.[1740]

Agricultural land uses account for the greatest areas of catchment vegetation clearing

Vegetation management laws passed by the Queensland Government in 2018 regulate clearing in order to: conserve remnant vegetation and regrowth along waterways in all catchments; minimise land degradation; maintain ecological processes; and prevent the loss of biodiversity.[1741] By 2020–21, this change had led to a 24 per cent reduction in overall land clearing rates in the Catchment when compared to 2018–19.[2171,2172] The loss of riparian woody vegetation in the Catchment, often linked to agricultural uses, was 47,519 hectares (475 square kilometres). Most of this loss occurred in the Fitzroy, Burnett Mary and Burdekin regions and the bulk of this clearing was lawful.[951]

Ground cover levels in the Catchment are strongly influenced by the timing and amount of rainfall across the Catchment, and they have varied substantially since 2019. In 2020, 35 per cent of grazing lands within the Catchment had insufficient late-dry-season ground cover for effective erosion control, driven in large part by low levels in the Burdekin and Fitzroy regions.[1741] In 2022, this had dropped to 8 per cent.[951]

Trends in agricultural land management practices that affect water quality are examined in the land-based runoff section (Section 6.5).

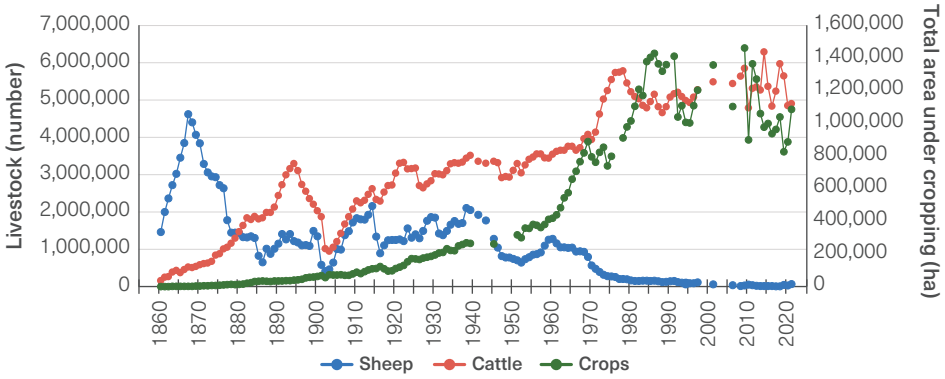


Figure 6.10 **Agricultural data time series for the Great Barrier Reef Catchment area**
Numbers of cattle, sheep, and total area under cropping (ha) between 1860 and 2021 for the Great Barrier Reef Catchment area. The key crops that dominate the total cropping series are grain crops and sugar cane. Source: Adapted from Lewis *et al.* (2021).[1734]

Mining and resources

Queensland has rich endowments of mineral and energy resources and is a major global producer of high-quality coal. The Catchment includes the Bowen Basin, which is the most important coal-bearing region in Queensland. The resource sector has been a key contributor to the Queensland economy and was worth more than $74 billion in the 2021–22 financial year,[1494] accounting for nearly one-fifth of the Queensland economy. The sector continues to be a key source of employment, with nearly 71,000 people directly employed in the sector on average in 2022–23.[1742]

The resources sector continues to be a key source of employment and revenue

Queensland's annual exploration expenditure has increased from $436 million in 2015–16 to $771 million in 2022–23, driven by both coal and mineral exploration.[1743] However, the number of exploration permits for coal declined by 40 per cent over the same period, while the number of mineral development licences for coal increased slightly since 2015–16. In 2022–23, around 85 per cent of coal-related exploration permits for coal and mineral development licences with a granted status were located in the Great Barrier Reef Catchment.[1744]

Statewide, coal production (coking and thermal net output) has declined from an average of approximately 243 million tonnes per annum between 2015–16 and 2019–20, to approximately 220 million tonnes in 2021–22.[1744] The number of operating coal mines has remained roughly stable with between 52 and 55 operational mines in the financial years between 2015–16 and 2021–22. Of the 54 operating coal mines in Queensland in 2021–22, 49 were in the Reef Catchment producing 135.4 million tonnes of metallurgical coal and 68.6 million tonnes of thermal coal.[1744]

In 2023, the proposed Central Queensland Coal Project was refused under the *Environmental Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act) due to unacceptable risks from increased sediment loads to the Great Barrier Reef World Heritage Area, Great Barrier Reef National Heritage Place and Great Barrier Reef Marine Park.[1745] This is the first rejection of a coal mine in the Catchment under national environmental law. Multiple legal challenges to applications and approvals for coal mines in the Catchment, including since 2019, have been based on direct impacts to the Great Barrier Reef and on the broader contribution of coal mines to the drivers of climate change.[1746,1747]

Urban and industrial development

Urban and industrial development occupies a small proportion, 1.1 per cent, of the Catchment.[1735] These highly modified environments create downstream impacts, including the generation of sediment and nutrient inputs that enter the Region through point source releases, and diffuse runoff (Section 6.5). While urban and industrial point source releases are regulated, diffuse runoff remains difficult to quantify and regulate.

Overall, the impact on water quality and Reef condition is considered localised and is generally restricted to major urban centres such as Townsville and Cairns. Diffuse urban runoff is also a lower threat than runoff from other major land uses, such as agriculture, due to its relatively small per cent contribution to total load (Section 6.5.1), [40,1748] and given the established regulatory framework for urban and industrial development (Section 6.5). The increasing impact of land-based marine debris, much of which is derived from urban and industrial areas, is an ongoing concern and considered in Section 6.5.

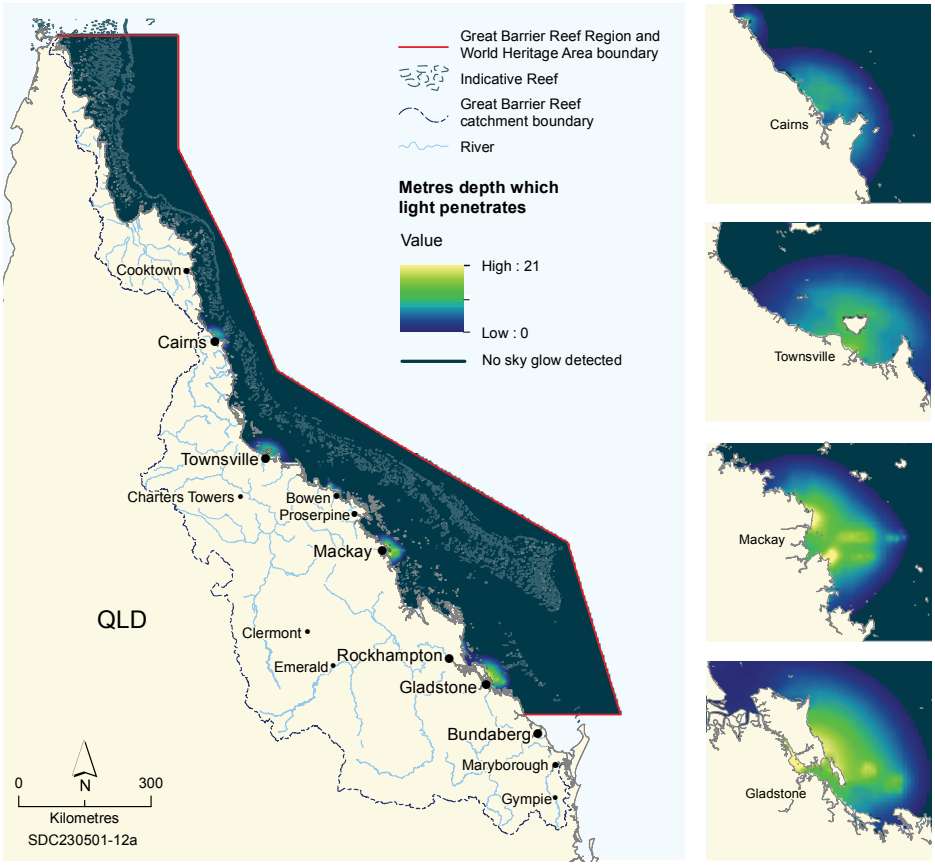


Figure 6.11 **Modelled depth at which biologically meaningful light pollution can be detected across the Region in August**

This image excludes impact of direct illumination. Inset panels depict the impact of light pollution from Cairns, Townsville, Mackay and Gladstone. Source: Derived from Smyth *et al.* (2021).[1750]

Artificial light from coastal urban and industrial infrastructure has impacts on the coastal environment that is directly illuminated (nearfield effects). Artificial light pollution from coastal urban areas, industry, ports and marinas also generates an artificial skyglow that is bright enough to elicit biological responses in surrounding marine habitats kilometres from the actual source (Figure 6.11).[1749] Biologically meaningful artificial light pollution may cause impacts at depths greater than 1 metre across approximately 13,000 square kilometres of the Reef, depending on the month. During June, July, August and September, these light impacts tend to penetrate deeper waters due to higher water clarity. In February, March and April, these light impacts are usually confined to shallower depths due to lower water clarity.[1750] Trends in the extent and depth of light pollution are currently not available. The near-field effects of artificial light from sources such as ports, marinas and ships in anchorages remain a knowledge gap.

Artificial light affects Reef species and the coastal environment



Urban centres can have downstream impacts on the Reef's ecosystems, Townsville City. © Nick O'Carroll 2020

Sewage treatment plants

About 60 gigalitres of treated sewage is released in the Catchment's coastal waters annually, with yearly volumes fluctuating between 66 and 46 gigalitres.[1751] Nitrogen and phosphorus are present in treated sewage. Improvements at treatment plants have significantly reduced nitrogen and phosphorus concentrations in treated sewage released into the Catchment. Overall, average concentrations of nitrogen and phosphorus have fallen between 2016 and 2019 (Table 6.1). Between 2010 and 2019, the annual total load of nitrogen released from sewage treatment plants fell from around 330 to 223 tonnes. Total phosphorus load fell from 95 tonnes in 2017 to 60 tonnes in 2019.[1751]

Table 6.1 **Total average concentrations of nitrogen and phosphorus from treated sewage released into the Region**

Source: Queensland Department of Environment and Science, (2021).[1751]

	2016	2019
Average nitrogen concentration (milligrams per litre)	4.7 mg/L	3.7 mg/L
Average phosphorus concentration (milligrams per litre)	1.6 mg/L	1 mg/L

A high level of nutrient treatment is being achieved at sewage facilities

Based on the monitoring of discharge locations, 50 per cent of council sewage treatment plants are achieving better than 3.3 milligrams per litre total nitrogen and 0.71 milligrams per litre total phosphorus, suggesting a high level of nutrient treatment is being achieved at these facilities.[1752] Overall, the modelled contribution of sewage treatment plants to anthropogenic dissolved inorganic nitrogen loads to the Region is minor (1.8 per cent) compared with other sources.[1748] The downstream impacts of sewage treatment plants, such as nutrient loads, are subject to water quality targets set out under the Reef protection regulations, and facilities may adopt offset schemes to meet targets. However, a systematic understanding is lacking about the contribution of septic systems to nutrient loads.

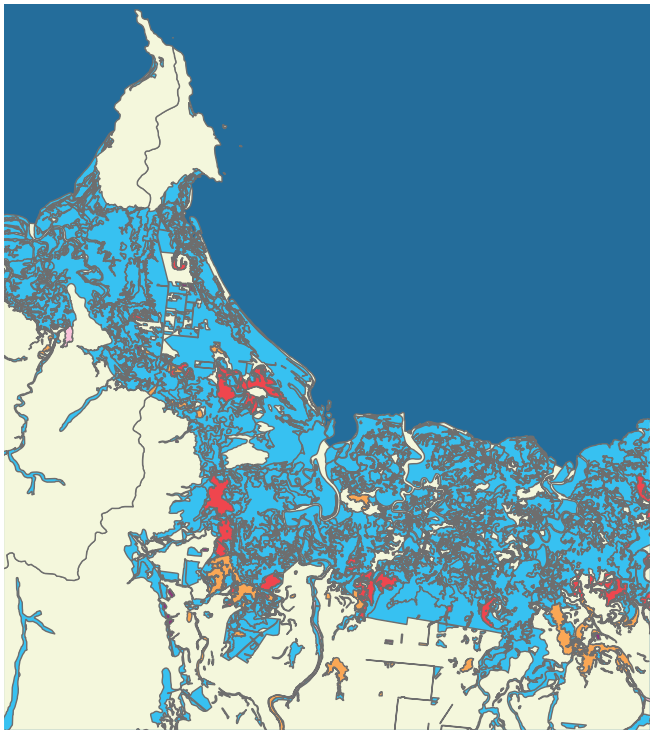
Barriers to flow

Barriers across rivers and channels, such as weirs and dams, change the upstream and downstream hydrology and ecology of systems.[1753] Barriers over land, such as bund walls, levees, roads and rail infrastructure, disconnect large areas of habitat.[1754] Structures of all sizes that impede water flow have an influence on waterway condition and function. Almost all estuary–wetland systems, in all but the most northern catchments, have been affected by barriers to flow.[1754]

In 2019, 236,751 hectares (2368 square kilometres) of wetland were in a state modified by barriers in the Catchment and adjacent intertidal areas. More than half (142,735 hectares or 1427 square kilometres) of this wetland area has changed from one wetland type to another as a result of these barriers, including 93,571 hectares (936 square kilometres) of lacustrine systems that were originally riverine systems and 42,826 hectares (428 square kilometres) of freshwater wetlands that were originally intertidal wetlands (saltmarsh, saltflats and mangroves) (Figure 6.12).[1755]

Limiting fish movement across the landscape, through originally connected systems, is a key impact of barriers to flow. Some instream structures, such as high-velocity pipes and culverts that do not present major barriers to hydrological connectivity, can still present a barrier to fish migration. Fish passage barriers have not been systematically recorded across the Catchment, and this remains a knowledge gap. Detailed mapping has occurred across some regions,[1756] and for Ramsar Wetlands.[1757] Impacts differ substantially among regions. In the Wet Tropics region, most river basins are relatively free from impoundments; however, substantial lengths of the Barron and Tully rivers are impounded.[128] In the Mackay Whitsunday region, all basins except for the Don River are in a 'moderate' or 'poor' state in relation to fish barriers. The impoundment condition of the Proserpine River recently declined to 'poor'.[1758] Recent assessments have found more than one potential fish barrier per square kilometre in both the Murray and Lower Herbert rivers and the Mackay Whitsunday basins.[1759,1760]

Works are continuing in the Catchment to restore hydrological and ecological connectivity. Works include removing barriers for large-scale restoration of natural hydrology to wetland ecosystems. Examples include causeway removals to restore the Rodd's Harbour Fish Habitat Area, Rodds Peninsula,[1761] and bund wall removals at Mungalla Station.[1762] These kinds of barrier removal works can provide long-term benefits. For example, the removal of a bund wall in the Mungalla wetlands in 2013 reinstated tidal connection, leading to major reductions in freshwater weeds, the reappearance of native vegetation, improvements in water quality and a tripling of fish diversity over a period of 4 years.[938] In the Catchment, coordinated monitoring and evaluation of wetland restoration projects is lacking despite existing frameworks.[1763]



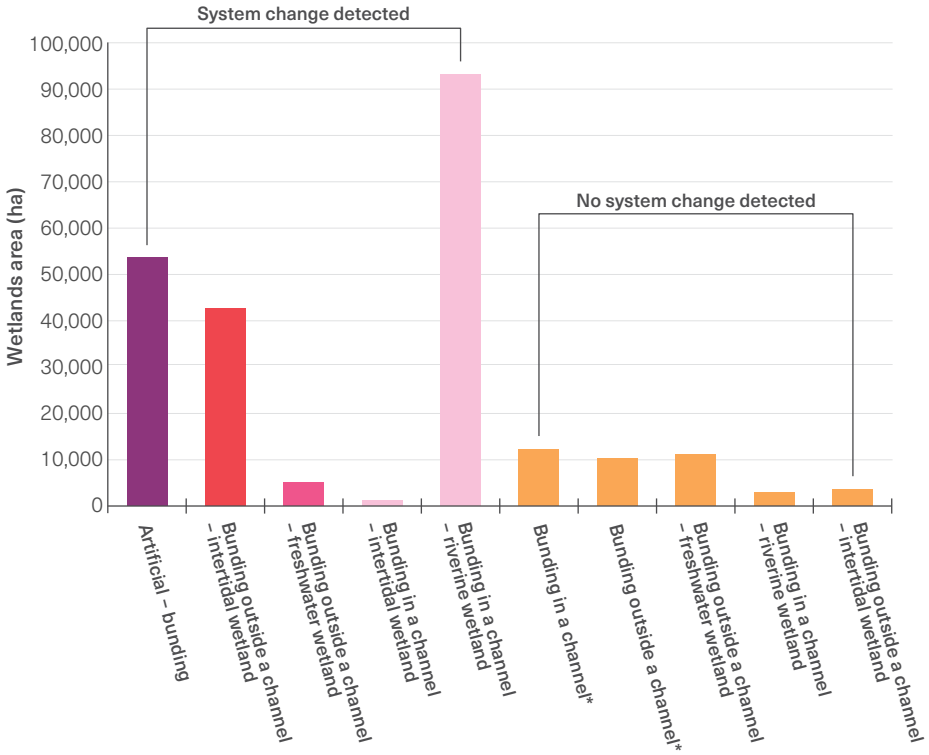


Figure 6.12 **Wetland modifications caused by bunding, a barrier to flow**

The total extent of bunded wetlands in the Catchment and adjacent intertidal areas in the Region is 236,751 hectares. The bar chart breaks down the total bunded area (hectares) by the ecosystem effects of that bunding. Asterisks (*) indicate that the status of system change is unknown. The map depicts a sample area of the Reef Catchment and Region — Bowling Green Bay and surrounds. The map colours match the categories in the bar chart and the light blue areas show wetlands where no bunding has been detected. The map excludes subtidal wetlands. Source: Queensland Department of Environment, Science and Innovation (2023).[1755]

Work has also been carried out to enable fish passage. Fish passage works, such as fishways, do not necessarily ensure historical hydrological connectivity, but they usually make barriers more navigable during periods of flow. At least 127 waterway barriers with fishways existed in the Catchment in 2022.[1764] An approvals process is in place to control new barriers to fish passage under the *Planning Act 2016* (Qld) and *Fisheries Act 1994* (Qld). This process results in new waterway barrier works having design elements that promote fish passage through or over the structure. Between 2018 and 2022, 326 development applications and 3332 accepted development requirement notifications were submitted for waterway barrier works in local government areas of the Great Barrier Reef Catchment.[1765]



Road infrastructure creating a barrier to flow in an intertidal wetland, Cape Cleveland, QLD, Australia. © Nick O'Carroll 2024

While physical works represent substantial improvements at the scale of particular wetland systems, and legislative arrangements reduce the threat of uncontrolled installation of future barriers, legacy barriers remain a widespread impairment to the Reef ecosystem health.[1754]

Tidal works

While quantifiable extent data are available for some works, comprehensive and systematic data on all tidal works and their cumulative impacts are lacking. In 2015, 9 per cent of the Region's mainland coastline was estimated to have been modified by engineered structures.[1766] Most structures occur in marina and port developments, with 60 per cent located within the lower 3 kilometres of estuaries.[1766] Contemporary data since 2015 remain a knowledge gap. Beach nourishment and dune restoration are being actively pursued along parts of the coastline, including the Capricorn Coast, Mackay, Burdekin and the Cassowary Coast.[1767] Tidal works, such as seawalls, marinas and port infrastructure, create novel marine habitats in the Region, and these urban–industrial seascapes can contain abundant fish communities,[1768] though the effects of these structures at the wider population and community level remain difficult to determine.

Linear infrastructure

Privately and publicly owned roads, rail and tracks are types of linear infrastructure. They are not confined to built-up areas and are present across the Catchment.[1769] This infrastructure can create a barrier to flow when they cross waterways, and alter flows overland during periods of flooding. New or upgraded roads make marine and coastal areas more accessible and can increase direct use of the Reef. Erosion from linear

infrastructure has been identified as a significant sediment source within particular parts of the Catchment[1770] and a vector for pests and weeds into remote coastal ecosystems. As of 2021, there were 87,437 kilometres of roads and 41,899 kilometres of tracks in the Catchment.[1769] Unsealed roads can be a source of subsurface erosion, which is not currently accounted for in Reef sediment budgets.[1771] Comparable data on the number and type of barriers to flow created by linear infrastructure across the Catchment are not available. In remote far northern parts of the Catchment, where a large proportion of roads are unsealed, linear infrastructure is potentially the most significant sediment source of any land use impact.[1772] In 2021, there was 454 kilometres of linear infrastructure across tidal waterways, mostly local roads and tracks.[1773,1769] The frequent transit of vehicles across intertidal areas causes physical and ecological damage, removing habitat-forming vegetation and altering animal assemblages.[1774,1775]

Aquaculture

Aquaculture can affect the marine ecosystem, particularly through the modification of coastal habitats and the water quality of point source releases, leading to, for instance, deoxygenation impacts.[1777] Since 2018, Queensland-wide production value has increased dramatically, by approximately 90 per cent, from $118 million in 2018–19 to $225 million in 2021–22. This growth has occurred alongside an increase in the relative importance of aquaculture to Queensland's total fisheries production.[1318] The bulk of this value is derived from land-based aquaculture operations in central and northern Queensland, particularly in Cairns, Townsville and Mackay.[1318] The most valuable sectors of the Queensland aquaculture industry continue to be prawn and barramundi.[1318]

In 2021–22, the total ponded area in the Catchment was 990 hectares (9.9 square kilometres). Where increases in production have been made, in most cases they were achieved by intensification rather than expansion of farm footprint.[1318] However, 9022 hectares (90 square kilometres) of land-based marine aquaculture development areas have been identified within the Catchment for the aquaculture industry in Queensland.

Since 2019, there has been an expansion of the Proserpine Prawn Farm in the Mackay Whitsunday region. Proposals to roughly triple the production pond footprint are under assessment under the EPBC Act.[1778,1779] Seaweed production is being trialled in farms across the Catchment, including the Proserpine Prawn Farm[1780] to reduce nutrients in wastewater discharge.

No marine-based aquaculture facilities are currently operating in the Region. Recent developments in black lip oyster hatchery production indicate new potential for oyster farming activities to expand into and adjacent to the Region.[1781] The downstream impacts of aquaculture, such as nutrient loads, are subject to water quality targets set out under the Reef protection regulations, and facilities may adopt offset schemes to meet targets.

Port development

Port development undertaken directly in the Region is described and assessed in Section 5.7. Land-based aspects of port activities (above the low water mark, including reclamation) form part of the coastal development assessment. Land reclamation occurs when an area is restricted from tidal influence and converted into land above the high water mark. Systematic reporting of land reclamation above the low water mark, and of historical land reclamation in the Region since European settlement for port and other purposes, remains a knowledge gap.

Point source pollutants from ports are regulated, and impacts on the Region are largely localised, but port activities continue to present a continued risk of point source pollution. Between 2019 and 2022, 138 pollution incidents were reported within the port limits of

Gladstone, Mackay, Townsville and Cairns.[1782,1783,1784,1785] Coordinated data on the scale and impact of these incidents are not readily available.

Marine access infrastructure

Marine access infrastructure and launch facilities, such as boat ramps, pontoons and marinas on islands, in rivers and on the mainland coast support local, recreational and tourism access to the Region. Since 2018, 2 new boat ramps have been installed in the Cairns region, 2 in the Mackay region and 3 in the Gladstone region. A new lane was also added to an existing location in the Cairns region, and upgrades were made to existing facilities in all regions[1786] (regions refer to Maritime Safety Queensland Regions).

Seven new boat ramps have been installed to provide access to the Region

Along the Reef coast, the Whitsundays region has been identified as most in need of additional marine access facilities. In late 2023, the Queensland Government announced investment in marine infrastructure at Hook Island, Long Island and Keswick Island.[1787,1788] While some of these facilities are outside the Region, impacts from installation and operation of these facilities may affect the values of the Region.

Between 2019 and late 2023, a total of 161,475 cubic metres of material was dredged in activities associated with state-owned marine access infrastructure adjacent to or within the Region, including both capital and maintenance dredging.[1789] Local governments and port authorities also own public marine access infrastructure in coastal areas adjacent to or within the Region, and they undertake mechanical maintenance activities of these facilities, though coordinated data are not readily available.



Cairns Marina. © Dieter Tracey 2024

Island development

Most of the land area of the Region's islands are natural landscapes. The remaining area is mainly occupied by forestry (147 square kilometres on Curtis Island) and grazing land (70 square kilometres, mostly on the islands of Broad Sound). Commercial and urban development (31 square kilometres) on some of the Region's islands supports tourism resorts, port infrastructure around Townsville and Gladstone, and permanent residential

populations.[1735] The principal residential islands include Palm Island (2098 residents) and Magnetic Island (2475 residents), with relatively stable populations over time.[1790] The Queensland Government plans to introduce new public facilities in protected areas on islands to enhance ecotourism.[1791] This includes plans to rejuvenate resorts on Reef islands and build new public access jetties to increase visitors and encourage investment in new and existing island tourism operations.[1792] For example, the proposed draft master plan for Woppa (Great Keppel Island) includes a new public plaza, jetty, cultural centre and supporting infrastructure.[1793] Some decommissioned infrastructure, such as the underwater observatories on Green Island and Hook Island, has been actively removed.[1794]

6.4.2 Vulnerability of the ecosystem to coastal development

The Region's ecosystems remain vulnerable to the effects of legacy as well as current and future coastal development, compounded by interactions with other factors like climate change (Section 6.3). The effects of different land uses and activities combine to modify coastal ecosystems, alter connectivity across landscapes, directly remove and replace intertidal and subtidal marine ecosystems, and create chronic changes in the marine environment. The primary pressure from coastal development is poor water quality from agricultural land use. Barriers to flow across the landscape, and modifications to wetlands, increase the risks posed by poor water quality. By comparison, direct pressures from urban, industrial and mining development are currently relatively minor.

The Reef remains vulnerable to legacy, current and future coastal development

Modifying coastal ecosystems for coastal development limits their ability to provide ecosystem functions and services that support the values of the Reef (Section 3.5). Two key impacts from modifications are the removal of natural vegetation, leading to major erosive processes and altered ecosystem functions and connections across landscapes. Coastal development for agriculture reduces the ability of groundcover in intact natural ecosystems to prevent **sediment runoff** and **nutrient runoff** from the Catchment. Agricultural activity is the major cause of erosive processes that contribute to land-based runoff (Section 6.5.1). Both historical and active land clearing expose the land to erosive processes. Land throughout the Catchment has been cleared over the past 150 years for agricultural purposes, and agriculture remains the predominant purpose for contemporary land clearing.[1740]



Normanby Station, Clayhole gully erosion management. © Cape York NRM 2021

Remediation works in the Catchment are aimed at reducing these sediment and nutrient loads. The extent to which retention or rehabilitation of catchment vegetation can mediate loss of sediments, nutrients and other pollutants is highly variable, depending on the condition and functional traits of vegetation as well as factors like climate and topography.[1795] Different forest types do not have equivalent roles in this regard. Channel erosion can be directly linked to the extent of woody riparian vegetation, [1796,1770] yet improvements in water quality through streambank rehabilitation are harder to quantify[1797] and require improvements at sufficiently large scales.[1798] Streambank rehabilitation work is proceeding in several areas and sediment reductions are assessed using the CSIRO Gully and Streambank Toolbox. For example, the NQ Dry Tropics' Landholders Driving Change project undertook major gully remediation, streambank and site erosion control works in the Bowen, Broken and Bogie catchments.

Monitored gully remediation sites have shown significant improvements in land condition, vegetation cover and sediment loads.[1799,1800] A net increase in private protected areas in the Catchment between 2019 and 2023 (158,415 hectares (1584 square kilometres) of additional area) may also contribute to mitigating the downstream effects of land-based runoff.[1801] For example, the conversion of the Springvale Station to a nature refuge, and subsequent destocking, has resulted in significant ground cover benefits in the Normanby catchment. Active erosion control works are underway in many nature refuges across the Catchment.[1802] Targeting potential hotspots for erosive losses as priorities for protection can have outsized effects on downstream impacts.[1796,1803]

Changes to coastal landscapes from clearing and modified hydrology alter ecological functions and the flow of productivity across the Region. The marine ecosystems of the Region rely on land-based ecosystem processes occurring in the landscapes of the Catchment to: supply nutrients and sediments through stream flow and seasonal flooding; slow overland flows;[1804] buffer nutrient, sediment and pollution loads through wetland cycling;[1805,1806,1807] and deliver animal biomass through food chains, migration and complex life cycles.[1808] For example, many tropical snappers, such as mangrove red snapper, spend their juvenile phase in coastal habitats, such as the inland upper tidal reaches of estuaries, while their adult phase is spent on coral reefs. A diversity of crustaceans, fishes, sharks and rays, including many important fisheries species, move between coastal and reef ecosystems to access habitats and food sources supported by land–sea connectivity.[1808,1809]

This land–sea connectivity is interrupted in landscapes with extensive **barriers to flow**, degraded wetland condition and increased sediment deposition, which change the extent and distribution of coastal habitats (Section 3.5) and disrupt ecosystem functioning at a variety of scales.[1754] While it is well understood that barriers to flow place the lifecycles of many species at risk, relevant species-level ecological information in the Region is still lacking, resulting in an inability to accurately assess and predict the vulnerability of the marine ecosystem to these factors.[1808] Long-standing legislative arrangements mean the Region's exposure to additional impacts from new ponded pastures infrastructure, which create barriers to flow, should be limited.[943]

The impacts of coastal development manifest over widely varying spatial scales. Broadscale impacts encompass those changes to physical characteristics of the marine environment operating over large areas, whereas local-scale impacts are generally restricted to specific, delimited areas. Localised impacts are generally more amenable to targeted management efforts (Section 7.3.10). Broadscale impacts present unique challenges for management, requiring coordination across jurisdictions and ecosystems.

Broadscale impacts of coastal development

Agriculture, port activities, point source discharge from sewage and aquaculture, and urban and industrial infrastructure have combined to change the regime of physical stressors on the marine ecosystem. Land-based runoff (Section 6.5) presents the greatest affect on vulnerability posed by coastal development. Anthropogenic sediment and nutrient catchment loads affect marine water quality in several ways.[1810] **Barriers to flow**, particularly large dams, can reduce **sediment** and particulate **nutrient runoff**. However, fine sediments (particles less than 20 micrometres) are generally poorly trapped in these reservoirs and the overall reduction does not outweigh the effects of other drivers of land-based runoff.[959] New large dams can facilitate more intensive land-uses in the Catchment that may contribute to land-based runoff. In-water activities from coastal development also contribute to this altered regime of stressors (for example, marine infrastructure development and impacts of ports Section 5.7.3). Resource extraction and export activities in the state facilitate the global use of fossil fuels, the primary driver of climate change and ocean warming (Section 6.3).



Burdekin Falls Dam. © Dieter Tracey 2007

Other chronic changes include **artificial light** at night from skyglow. Light is a major driving force of key processes in marine ecosystems, and artificial light pollution is known to affect coastal ecosystems by changing schedules of feeding, hiding and resting across trophic levels.[1811] Skyglow can inhibit seabird and sea turtle navigation, change foraging and predation patterns, inhibit zooplankton diel vertical migration, and disrupt coral broadcast spawning synchronisation.[1812,1813] Marine ecosystems close to the mainland coast are at greatest risk from these chronic changes. Shallow inshore ecosystems, including inshore corals and seagrass, are most vulnerable to the full suite of impacts from coastal development given their proximity to the coast[130] and their greater ecological integration with a range of coastal and catchment ecosystems.[838]

Localised impacts of coastal development

Some activities create unique vulnerabilities that have the potential to cause serious localised damage to the marine ecosystem. Tidal works, such as foreshore seawalls and groynes outside, and encroaching, on the Region, can affect inshore marine habitats by altering local hydrology, permanently removing inshore marine habitats and diminishing local aesthetic attributes. The risk of impacts from these changes is increasing as regional communities expand in the coastal zone.

Direct localised impacts of **artificial light** adjacent to the Region include disorientation of emerging marine turtle hatchlings as they have a reduced ability to find the sea in the presence of artificial light (Section 2.4.10).

Acid, metals and other contaminants in soils can affect many species at a local scale, both immediately and through accumulation in the food chain. Activities that may disturb **acid sulfate soils** have been regulated in Queensland since the early 2000s, reducing the risk of exposure of the Region to such impacts.

Mining and other resource activities cover a very small proportion of the Catchment compared to other land uses, but they can expose the Region to impacts that are hard to reverse. **Pollutants**, such as contaminated tailings water, flowing into the Region or water table are a current and future threat. However, these threats are regulated through existing environmental protection legislation.[1814,1815]

6.4.3 Implications of coastal development for regional communities

Coastal development occurs in areas of the Catchment where most of the population reside. The perception of coastal development as a threat to the Reef by regional communities has decreased over time (Figure 9.1).[1075] For both urban and rural communities, coastal development provides broad economic and social benefits via employment, economic activity and housing. More specifically, people derive benefits from the Reef: coastal development increases access to the Reef ecosystems, which can in turn be enjoyed by more people, more frequently and/or more easily. For example, roads reduce travel time and boating facilities increase access points. However, poorly managed coastal development that threatens the health of the ecosystem can reduce the ecosystem services that these regional communities can derive from the Region. In particular, reduced water quality can affect activities such as recreation and tourism (Section 6.5.3). Along with land clearing, reduced water quality can negatively affect critical habitats, such as mangroves, which provide coastal protection to residents of the Region. The effects of climate change (Section 6.3) are likely to amplify the effects of coastal development (urban, industrial and rural) on the Region. The implications of coastal development, therefore, cannot be considered in isolation.



Coastal development provides economic and social benefits to regional communities

6.5 Land-based runoff

Land-based runoff refers to freshwater flow (Section 3.2.3) from the terrestrial environment and what is carried with it into receiving waterbodies, such as rivers, creeks, wetlands, and nearshore marine waters. Land-based runoff is often associated with increased supply into the Reef lagoon of pollutants, such as suspended sediments, particulate and dissolved forms of nitrogen and phosphorus, and pesticides.[1816] Activities, such as the application of fertilisers, deforestation, coastal development (Section 6.4), livestock management, pest control, stormwater and sewage management, aquaculture, mining and fracking and earthworks, can all influence land-based runoff and negatively affect downstream water quality.

Land-based runoff remains the greatest contributor to reduced water quality, resulting in the declining state of many inshore marine ecosystems in some areas of the Reef.[1817] The main contemporary source of the primary pollutants (nutrients, sediments, and pesticides

including herbicides, insecticides and fungicides) from the Catchment is diffuse source pollution from agriculture.[40,1818,1819] Groundwater also has a potential role in nutrient and pesticide transport into the marine environment.[1820,1821,1822,1823] The impact of pollutants found in riverine plumes is evident up to 20 to 30 kilometres offshore during large flood events, and will depend on the size and duration of the event.[1824]

The *Reef 2050 Water Quality Improvement Plan 2017–2022* [1825] (Reef 2050 WQIP) seeks to improve the quality of water flowing from the catchments adjacent to the Reef and support the resilience of the Reef's ecosystems. The whole-of-Reef water quality targets in the Reef 2050 WQIP to be achieved by 2025 include a:

- 60 per cent reduction in anthropogenic end-of-catchment **dissolved inorganic nitrogen** loads
- 20 per cent reduction in anthropogenic end-of-catchment **particulate nutrient** loads
- 25 per cent reduction in anthropogenic end-of-catchment **fine sediment** loads
- **Pesticide** target: to protect at least 99 per cent of aquatic species at the end-of-catchments.



Aerial view of Coolbie. © Nick O'Carroll 2024

6.5.1 Trends in land-based runoff

Land-based runoff of pollutants has sharply increased since European settlement along the Queensland coast.[1734 40,1748] The development of adjacent catchments is the major contributor to the decline of water quality entering the Reef (Section 6.4). However, changes in land use varies between catchment areas. For example, almost 80 per cent of the grazing land area is contained within the Burdekin and Fitzroy natural resource management (NRM) regions, while much of the area of sugarcane and horticulture crops is in the Wet Tropics, Mackay Whitsunday, and Burnett Mary regions.[40] The targets set by the Reef 2050 WQIP consider regional differences in the type of land use and pollutants likely associated with each of the Reef's 35 coastal catchments, which is crucial information to guide collective effort to improve the water quality flowing to the Reef from land-based sources.[693] The catchment profiles provide information about each area including size and rainfall, land use, targets, the priorities for water quality improvement

and sources of pollutants management.[1826] The highest priority areas for reducing fine sediment, dissolved inorganic nitrogen and pesticide loads are:

- **fine sediment and particulate nutrients:** Burdekin, Herbert, Fitzroy and Mary catchments
- **dissolved inorganic nitrogen:** Herbert, Haughton, Mulgrave–Russell, Johnstone, Tully and Plane catchments
- **pesticides:** Mulgrave–Russell, Johnstone, Herbert, Haughton, Proserpine, O'Connell, Pioneer, Plane and Fitzroy catchments.

Progress towards targets for fine sediments and dissolved and particulate nutrients (Table 6.2) is reported using modelled end-of-catchment loads, which account for seasonal and climate variability.[40,951,1748,1827] This modelling approach enables the estimation of year-to-year reductions in pollutant loads resulting from the adoption of improved land management practices. Additionally, *in situ* information is collected to validate the models that report on marine condition.[951]

A concentration-based end-of-catchment assessment is used for the pesticide target that aims to protect at least 99 per cent of aquatic species from all pesticides. The assessment includes 22 pesticides (including herbicides and insecticides) with a focus on reducing concentrations that directly relate to species protection rather than loads.[1828]

Long-term water quality monitoring data from the end of the catchments are used to validate and improve model estimates over time.[1829] Results are reported to June 2022 against the anthropogenic baseline load for 2009.[951] *In situ* inshore marine water quality monitoring, including sediments, nutrients and pesticides, is also conducted to complement the end-of-catchment water quality monitoring.[363,1830]

Table 6.2 **Progress towards 2025 targets for per cent reductions in anthropogenic end-of-catchment loads for the Great Barrier Reef and Natural Resource Management (NRM) regions**

MCL: maintain current loads. Source: Queensland Department of Environment, Science and Innovation (2024)[951]

NRM Region	Dissolved inorganic nitrogen		Particulate nitrogen		Particulate phosphorus		Fine sediments		Pesticides
	Target %	% Reduced (2009–2022)	Target %	% Reduced (2009–2022)	Target %	% Reduced (2009–2022)	Target %	% Reduced (2009–2022)	Condition (% of aquatic species unlikely to experience harmful effects) (2022)
Reef-wide	60	28.4	20	15.4	20	18.5	25	16	95
Cape York	MCL	–	5	14.8	5	20.2	5	13.1	99+
Wet Tropics	60	29.2	25	13.9	30	22.9	25	15.1	96
Burdekin	60	36	25	18.4	25	19	30	19.3	94.6
Mackay Whitsunday	70	29.1	20	14.8	20	16.8	20	14.3	80.3
Fitzroy	MCL	–	15	7.7	20	11.1	25	11.7	94.4
Burnett Mary	55	34.2	20	11.2	20	16.5	20	9.5	96.2

Modeled particulate nitrogen and phosphorus at the end of the catchment has slightly reduced

Nutrients

Land-based runoff is one of the largest sources of excess nutrients entering the Reef.[1816] Since European settlement, loads of dissolved inorganic nitrogen — the nutrients of most concern in marine ecosystems — exported from the Catchment have approximately doubled (and rates have more than doubled from 11 of the 35 catchments).[1748,1831] Other sources of excess nutrients include wind resuspension and remineralisation of particulate nutrients.[1832] Nutrient cycling by phytoplankton[1833] also occurs (Section 3.3.1). The nitrogen-fixing cyanobacteria *Trichodesmium* is a source of nitrogen to the Region[1834] that may be responding to increased availability of phosphorus[356,1835] (Section 3.3.1). Understanding of the relative contribution and potential impacts of *Trichodesmium* remains limited.[710]

Loss of nutrients to the environment through runoff and leaching is of particular concern from cropping systems in which large quantities of fertilisers are applied in high-rainfall areas, and where transport to waterways following intense rainfall events is more likely.[1748] Additionally, urban and industrial development contribute 7 per cent to Reef-wide loads of dissolved inorganic nitrogen, particularly around the urban areas of Townsville and Cairns.[1748]

Dissolved inorganic nitrogen

The Wet Tropics region is the source of almost half (47 per cent) of the total modelled dissolved inorganic nitrogen exported into the Reef lagoon, and almost half of this amount is from sugarcane plantations.[1748] Sugarcane-growing areas in the Mackay Whitsunday, lower Burdekin, and Burnett Mary regions are considered hotspots for excess generation and export of dissolved inorganic nitrogen to the Region's waterways (Figure 6.13).[1748,1836,1837]

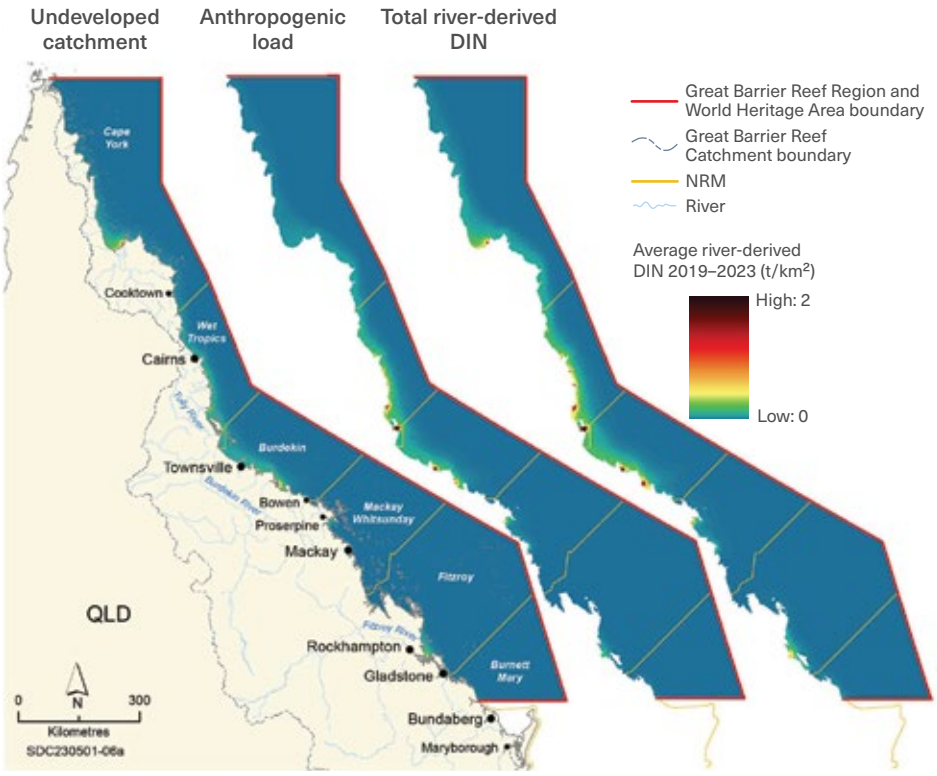


Figure 6.13 **Average modelled dispersal of river-derived dissolved inorganic nitrogen (DIN) loads for water years 2019 to 2023 (1 October to 30 September)**
The maps represent an average from 2019 to 2023 of: (left) DIN loads from a modelled undeveloped catchment; (middle) the anthropogenic component of river-derived DIN; and (right) total river-derived DIN load from the Catchment. Source: Gruber *et al*. (2024)[579]

Widespread flooding in the Burnett Mary catchment in early 2022 resulted in large pulses of dissolved nutrients entering nearshore waters south of the Region[579] and contributed to further declines in abundance and resilience of seagrass meadows at Rodds Bay.[145] Nitrate is also elevated in groundwater in many areas under intensive agriculture.[1838] The Cape York and Fitzroy regions contribute minimal anthropogenic dissolved inorganic nitrogen loads, and no end-of-catchment targets have been set for dissolved inorganic nitrogen.[1839] Relatively small areas are under banana cultivation in the Cape York region, and under sugarcane cultivation in the Fitzroy region.[1748] The aim in these regions is to maintain current loads to avoid increases in nutrients entering the Reef lagoon.

Modelled end-of-catchment loads of dissolved inorganic nitrogen from anthropogenic sources decreased by 28.4 per cent across the Region between 2009 and 2022 (Table 6.2).[951] Improvements in the Wet Tropics region (cumulative reduction of 29.2 per cent), including a 6.4 per cent improvement in the Johnstone catchment for 2020, were mainly attributed to the adoption of improved management practices in sugarcane cultivation and use of mill mud, a processing byproduct.[951] Large improvements for the Haughton catchment (slightly over 50 per cent reduction from the 2009 baseline) have contributed to a 36 per cent reduction in dissolved inorganic nitrogen loads for the Burdekin region to 2022.[951]

In the Mackay Whitsunday region, a 29.1 per cent reduction to 2022 included a decrease of 2.3 per cent in modelled end-of-catchment loads since 2016.[951] A reduction of 34.2 per cent for the Burnett Mary region has been attributed to improved mill mud management in the Mary catchment and improved sugarcane nutrient management where nitrogen application rates were reduced in the Burnett and Burrum catchments.[951]

In the marine environment, dissolved inorganic nitrogen concentrations in inshore waters of the Wet Tropics region have been above local guideline values since monitoring started in 2005. From 2017 to 2022, elevated levels of nitrogen remained prevalent across the Wet Tropics region.[363] In the Mackay Whitsunday region, dissolved inorganic nitrogen concentrations in inshore marine waters have been stable over the past 5 years, but remained well above (up to 7 times) guideline values despite 3 years of below-average discharge between 2020 and 2022 (Section 3.2.3).[363]

Particulate nitrogen and phosphorus

Most of the terrestrial phosphorus and up to a third of the nitrogen discharged into the Reef is carried in particulate form, often bound to fine sediment particles.[1770,1819] Particulate nutrients must be remineralised before they become bioavailable,[1840] but they are important sources contributing to excessive nutrients, particularly dissolved nitrogen, in some nearshore Reef waters[595,693] (Section 6.5.2). Hillslope losses are considered the major source of particulate nutrients across the Region.[40,1770] The proportion of particulate nitrogen and phosphorus in runoff is similar across the Catchment, with the Burdekin and Fitzroy regions the largest contributors of total loads reaching the Reef.[40] It is estimated that the Fitzroy region contributes 22 per cent of the particulate nitrogen and 29 per cent of particulate phosphorus exported to the Reef, mainly associated with high loads of sediments in this region.[40]

Across the Region, end-of-catchment particulate nitrogen and phosphorus showed a modelled reduction of 15.4 and 18.5 per cent, respectively (Table 6.2).[951] Reductions have been detected in all NRM regions but vary across the Region. In the Wet Tropics region, recent gains have been largely due to improved soil management practices in sugarcane areas, especially in the Johnstone catchment.[951] Reduced grazing pressure in the Burdekin catchment, improved soil management projects in the Haughton catchment, improved grazing practices in the Mackay Whitsunday region, and riparian fencing projects in the Burnett Mary region, all contributed recent reductions in loads of particulate nutrients.[951]

Improved hillslope management in grazing areas and improved soil erosion management in cropping areas have contributed to modest reductions in particulate nutrient loads from the Fitzroy region.[951] Cape York, which has lower intensity livestock grazing and limited intensive cropping compared to other regions, is meeting its end-of-catchment reduction targets for particulate nutrients.

In the Wet Tropics region, concentrations of particulate nutrients in marine waters have remained stable and below local marine guideline values in the Barron, Daintree and Johnstone catchments.[363] However, between 2017 and 2022 increased particulate nitrogen was detected in the Herbert and Tully catchments at concentrations above local guideline values.[363] In inshore marine waters adjacent to these catchments, both particulate nitrogen and phosphorus decreased over the past 3 years, and concentrations are meeting guideline values.[363] In inshore marine areas in the Burdekin region, particulate phosphorus has been stable and below guideline values since monitoring began in 2005,[363] while particulate nitrogen has declined over the past 5 years but remains above guideline values.[363]

In the Fitzroy region, inshore marine concentrations of particulate and dissolved nutrients have been stable for the past 2 years, but they have not been meeting guideline values.[363] While improvements have been made in modelled end-of-catchment nutrient loads in Cape York,[951] dissolved and particulate nitrogen concentrations have often exceeded guideline values in the inshore marine environment over the past 5 monitoring seasons,[363] possibly driven by wind resuspension as opposed to land-based runoff.[579] Particulate phosphorus in this region met guideline values in 2021–22 after consecutive years of improvement.

Sediments

The main source of sediments to the Region is sub-surface erosion (gully, streambank, and deep rill erosion from hillslopes).[40,1770,1819,1836] A large proportion of river-derived sediment loads is anthropogenic (Figure 6.14).[574] Since European settlement, fine sediments entering the Reef lagoon are estimated to have increased between 1.4 to 5 times and, in some catchments, up to eight-fold.[574] Fine sediment (less than 20 micrometres) is the fraction most likely to reach the Reef lagoon and is the dominant proportion in monitored fine sediment loads across the Region.[586,1770] Although most land-sourced sediments are deposited close to river mouths and remain within inshore areas, some fine sediments can be carried long distances away from river mouths, as well as being resuspended by wind and tidal currents in shallower waters[586] (Section 3.2.4), with consequent chronic impacts on exposed species and habitats[39] (Sections 3.2.4 and 6.5.2).



Large variability in sediment delivery is linked to rainfall and flooding

Export of fine sediments to the Reef is dominated by the Region's 2 largest rivers, the Burdekin and Fitzroy, with the Burdekin River the largest individual contributor.[1841,1816] A study reconstructing land use changes on river catchments from extended coral growth records, documented a 3-fold increase in suspended sediment loads delivered by the Burdekin River flood plume to the Region relative to pre-European baseline levels.[1842] The Burdekin region has an estimated average annual fine sediment load of 3.7 million tonnes, contributing nearly 45 per cent of the total loads exported (total loads of ~8.5 million tonnes) from the Catchment,[40] followed by the Fitzroy (18 per cent), and the Wet Tropics and Burnett Mary regions (each 15 per cent).[1843,40] Nevertheless, large variability in sediment delivery is linked to rainfall and flooding, particularly in the large dry tropical catchments and, as a result, relative catchment contributions — and the marine regions affected — can vary greatly from year to year.[1819,586]



Catchment gully erosion. © Matt Curnock 2019

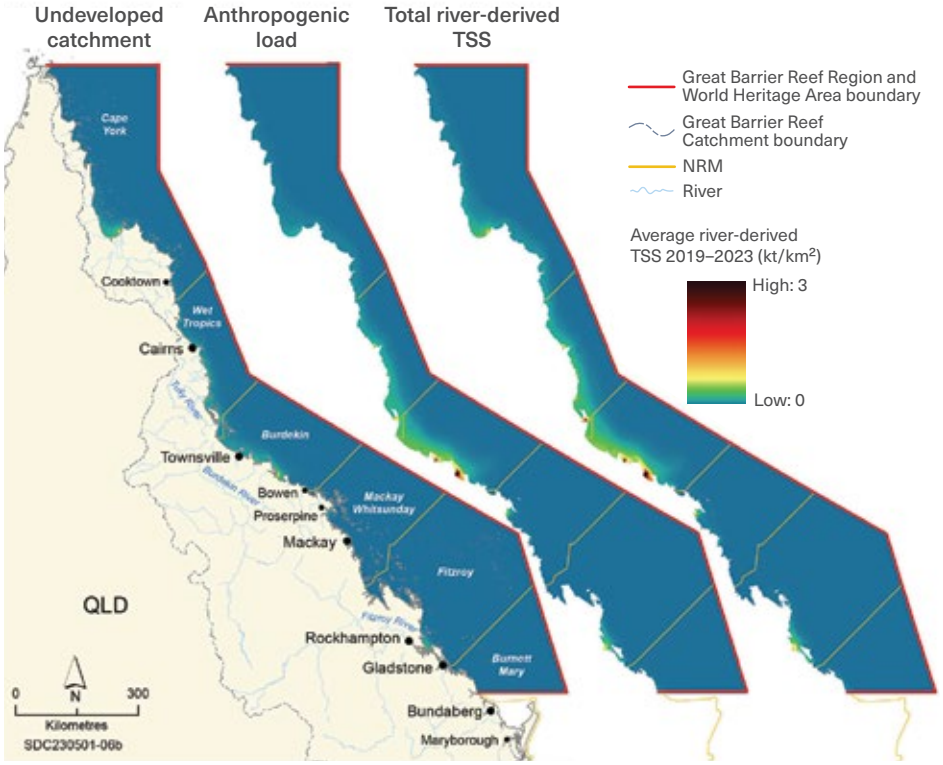


Figure 6.14 **Average modelled dispersal of river-derived total suspended sediment (TSS) loads for water years 2019 to 2023 (1 October to 30 September)**

Maps represent an average from 2019 to 2023 of: (left) TSS loads from a modelled undeveloped catchment; (middle) the anthropogenic component of river-derived TSS; and (right) total river-derived TSS load from the Catchment. Source: Gruber *et al.* (2024)[579]

Across the Region, dry tropical grazing lands are the dominant source of fine sediment loads, sugarcane contributes significantly to exports in the Wet Tropics and Mackay Whitsunday regions, and dryland cropping contributes the most in the Fitzroy region.[1819] Locally, specific catchment characteristics are often important. For example, intensively cropped basalt areas in the Fitzroy basin make a disproportionate contribution to fine

sediment loads in that region.[1844] In the Wet Tropics and Mackay Whitsunday regions, fine sediment export is proportionately lower than for nutrients, due mainly to more consistent rainfall and year-round surface vegetation cover, but sugarcane and banana cropping areas have high sediment yields per unit area.[1770] Some parts of the Wet Tropics have high natural sediment loads.[1770]

A Region-wide cumulative reduction of 16 per cent has been observed against the 25 per cent end-of-catchment load target for fine sediments (Table 6.2), although only a small reduction of 0.8 per cent was modelled from 2020 to 2022.[951] The largest modelled reduction in sediment loads during 2020–2022 was of 1.4 per cent (approximately 17 kilotonnes) in the Fitzroy region, with most of the load reduction attributed to grazing management change throughout the broader Fitzroy catchment and streambank restoration in the Lower Fitzroy sub-catchment. Cape York had a 5 per cent target and has been successfully maintaining the current loads, seeing continued improvement with an annual modelled reduction of 0.9 per cent from 2020 to 2022 (approximately 1.5 kilotonnes). The Reef 2050 WQIP proposed a 30 per cent reduction (8.9 kilotonnes) target for the Burdekin River, the largest individual contributor to sediment loads across the Region.[1825] Queensland and Commonwealth governments have invested over $50 million for landscape remediation and catchment repair within Burdekin catchments since 2016 towards this aim. Progress towards this target is lagging, with a cumulative 19.3 per cent reduction modelled against the 2009 baseline.[951]

In the Wet Tropics, results were mixed in terms of modelled reduction of end-of-catchment sediment. Overall, a cumulative reduction of 15.1 per cent to 2022, below the target of 25 per cent, has been modelled. Catchments such as the Barron and Daintree have minimal anthropogenic load and are expected to maintain their current loads. The Mulgrave–Russell have met the target over the past four reporting periods, while the Murray catchment met the reduction target of 20 per cent in 2022.[951] However, progress towards achieving the 2025 targets has been slower in the other southern catchments of Johnstone, Herbert and Tully rivers. For example, in the Herbert catchment a cumulative reduction of 10.1 per cent (compared with the 30 per cent target) was observed from 2009 to 2022. In the Mackay Whitsunday region, the Proserpine River and Plane Creek catchments are successfully maintaining current loads, but the O'Connell and Pioneer catchments have progressed more slowly, with a modelled cumulative reduction of sediments of only 6.1 per cent for the Pioneer catchment to 2022. In the Fitzroy region, a cumulative reduction of 11.7 per cent to 2022, and an annual reduction of only 1.4 per cent (approximately 17 kilotonnes) from July 2020 to June 2022[951] was achieved. Among NRM regions, the smallest reduction in anthropogenic fine sediment load was detected in the Burnett Mary region, with a reduction of 0.3 per cent between 2020 and 2022, and a cumulative reduction of 9.5 per cent to date.[951]

In the inshore marine environment, fine sediment concentration has been increasing in some regions and decreasing in others.[363] In the Burdekin region, where fine sediments are an ongoing issue, trend analysis showed that from 2017 to 2022, mean concentration of sediments improved, but only marginally, and fine sediments are currently exceeding guideline values at most sites. In the Fitzroy region, nearshore concentrations of sediments have increased over the past 2 years. In the Wet Tropics, inshore sediment concentrations have been improving since 2017, and they are meeting guidelines at most sites in all 3 subregions (Barron–Daintree, Mulgrave–Russell, and Herbert–Tully). The concentrations of sediments in the inshore marine region of the Mackay Whitsunday region showed improvement from 2017 to 2022 and they are currently meeting guideline values, likely driven by below-average rainfall over the past 3 years. Sediment concentrations often met guideline values in Cape York, except after heavy rainfall events. From 2019 to 2022, enclosed coastal sites influenced by the Normanby River frequently exceeded guideline values.[363]

Pesticides

Pesticides, including insecticides, herbicides, fungicides, miticides and rodenticides, are widely used in Australian agriculture and are often detected in Catchment waterways and inshore marine monitoring sites in the Region.[1830,1845,1846,1847,1848] Pesticides represent a group of anthropogenic chemicals that were not present prior to European settlement.[574] The concentrations of many different pesticides, and therefore the combined risk associated with all those pesticides, are highest in areas of intensive agriculture, including sugarcane, and horticultural crops, such as bananas.[1734,1849,1850]

Pesticides are often detected in waterways and inshore monitoring sites

The downstream concentrations of individual pesticides, and the risk associated with mixtures of pesticides, reflect the type and intensity of upstream agricultural land uses. In current Reef water quality reporting, that risk is expressed as a Pesticide Risk Metric,[1850] both in the freshwater catchments[951] and in the inshore marine waters.[1830,1851]

Different agricultural land uses are characterised by the use of different pesticides. In terms of major land uses, the Burnett Mary, Fitzroy, and Burdekin regions are all dominated by grazing (more than 70 per cent), which does not require large amounts of pesticide apart from tebuthiuron.[1852]

Sugarcane cropping is one the main sources of pesticide risk to aquatic ecosystems in the waterways of the Wet Tropics, Burdekin, and Mackay Whitsunday NRM regions. Several pesticides generally contribute to that risk, including photosystem II-inhibiting (PSII) herbicides, such as diuron, atrazine and hexazinone, the insecticide imidacloprid and other herbicides, such as metolachlor and imazapic.[1829,1853] PSII herbicides disrupt a key step in plant photosynthesis and can negatively affect the health of exposed seagrasses and other marine plants and algae[1854] (Section 6.5.2).



Sugar cane cultivation in the Wet Tropics contributes to fine sediment export. © Dieter Tracey 2024

The PSII herbicide diuron and the neonicotinoid insecticide imidacloprid represent the largest contributors to risk downstream of intensive sugarcane agriculture in the coastal catchments of the Wet Tropics and Mackay Whitsunday regions.[1847,1853] Diuron is typically associated with the intensive sugarcane farming in the coastal area of the Tully River and the Herbert River in the Wet Tropics region, and the Pioneer River and Sandy Creek

catchments in the Mackay Whitsunday region. Since monitoring commenced in 2010, diuron concentrations have typically been higher in marine waters adjacent to these catchments and regions than in other inshore areas.[1855] Atrazine, which is also registered for use in sugarcane crops, has historically been used extensively in the Barratta Creek and Lower Burdekin sub-catchments in the Burdekin region.[1855,1856]

The spatial pattern of pesticide concentrations in the marine environment reflects the dominant land use in the adjacent catchment, and the highest concentrations are found closest to the source.[589] In the inshore marine environment, the highest concentrations of pesticide are found at the Mackay Whitsunday region, in particular Flat Top Island, Repulse Bay and Sarina Inlet,[578] although low pesticide risk was reported for most inshore sites in the 2022–23 wet season.[1851]

Across the Catchment, the pesticide risk condition in 2022 indicated that 95 per cent of aquatic species at the end of catchment were unlikely to experience harmful effects of pesticides (Table 6.2), a reduction of 2.4 per cent from previous reporting period. Within NRM regions, some catchments had a much lower level of protection and will require considerably larger improvements to meet the target. The Mackay Whitsunday region remains the region with the highest pesticide risk, and few signs of improvements were shown from 2016 to 2022.[951] In this region, monitoring results indicate that, in 2022, 80.3 per cent of aquatic species were unlikely to experience harmful effects from pesticides. In the Plane Creek catchment, this protection was 73.9 per cent, with a decline in protection of species from 2020 to 2022 from 76.5 per cent.[951]

Within the Wet Tropics region, the Daintree and Barron catchments were associated with a lower pesticide risk, relative to the region as a whole, and the Mulgrave–Russell, Johnstone and Herbert catchments were associated with a higher risk. The Tully catchment improved from a moderate to good rating from 2016 to 2020, associated with a notable decrease in the contribution of insecticides, particularly imidacloprid.[1741] However, the risk for the Tully catchment deteriorated to moderate again from 2020 to 2022.[951]

In the Burdekin region, pesticide risk levels decreased as a whole; however, the Haughton catchment scored as poor, and from 2016 to 2022, protection of aquatic organisms decreased from 86 to 80 per cent.[951] In the Fitzroy region, coastal intensive cropping is limited and risk rankings are generally low. However, widespread use of pesticides occurs in the Fitzroy River catchment — in the beef grazing areas where the herbicide tebuthiuron is used for 'woody weed' control.[1847] Additionally, the herbicide metolachlor represents an important contributor to pesticide risk at the end of the catchment and reflects the irrigated cropping agriculture further up the catchment.[1829] At the end of catchment, 94.4 per cent of species are protected from pesticide risk, representing a small decline from 2019.[1741]

Cape York remains a low-risk location due to minimal intensive cropping practices that require pesticide use. In the Burnett Mary region, particularly in the lower reaches of the Kolan catchment, which is dominated by sugarcane and horticultural crops, imidacloprid and the herbicides metsulfuron-methyl, diuron, atrazine and metolachlor represent important contributors to pesticide risk in several of the smaller catchments draining to the Reef lagoon.[1829]

Concentrations of pesticides in the Region's marine waters remain generally below guideline values. Pesticides in marine samples are often compared with Australian freshwater species protection guidelines since no guidelines are currently available for marine environments. Since 2019, no clear reduction in inshore marine pesticide concentrations has been linked to improved land management practices.[1828,1857] During the monitoring period 2019 to 2023, the most consistently detected pesticides at inshore

marine sites (for the majority of assessed locations) were diuron, atrazine and hexazinone, along with abundant PSII herbicides.[578,1830] These were also the highest concentration pesticides, reflecting land use in sugarcane, horticulture and grain cropping industries. Monitoring results from the 2022–23 wet season showed that atrazine and diuron were still detected at Low Isle and Sarina Inlet. After heavy rainfall in January 2023 in the Mackay Whitsunday region, diuron at a concentration of 312 nanograms per litre was reported at Sarina Inlet.[1830]

A recent temporal trend analysis of up to 14 years monitoring data, from 2005 to 2018, on 5 commonly found pesticides (ametryn, atrazine, diuron, tebuthiuron and hexazinone), at 11 inshore marine monitoring sites revealed a significant increasing trend for all 5 pesticides at several monitoring sites.[1845] Monitoring sites at Low Isles, Sarina Inlet and North Keppel Island presented statistically robust increasing trends in atrazine, diuron and hexazinone. Detection of pesticides in the North Keppel Island area remained generally low until monitoring in that region ceased in 2019.

Marine debris

The accumulation of anthropogenic debris, especially plastics, in marine and coastal areas has environmental, economic, aesthetic and human health impacts.[1858,1572,1859] Marine debris is a cause for concern due to its abundance, durability and persistence in the marine environment.[561,1860,1861] It is among the major perceived threats to biodiversity worldwide.[1862] Marine debris, primarily hard plastic, is prevalent in Australian waters,[1863,1864,1865,1866] with current and projected coastal development likely to increase its presence in the Region.[1867] Smaller plastic particles, including microplastics (less than 5 millimetres) are consistently detected in surface waters of the Reef[1868,1869,1870] and can represent up to 50 per cent of marine debris in some areas.[1869] Nevertheless, surveys conducted across the Region from 2019 to 2023 revealed that microplastic loads are generally low, especially in comparison to the more densely populated regions of the country.[1871] In addition to plastics, other items, such as glass, rubber, and foam comprised a substantial proportion of total debris found in Australian waters, both in coastal and offshore areas.[1872]



Goose barnacles growing on a plastic water bottle that has been washed into the ocean. © Johnny Gaskell 2024

Studies show that marine debris is often derived from a combination of marine and land-based sources.[1867] However, the contributions of likely sources, such as large commercial, military and recreational vessels, commercial fishing and tourism boats, aquaculture installations, sewage and storm water, industrial facilities, coastal tourism involving recreational visitors and beachgoers, and riverine transport of waste from landfills and other inland sources, is relatively unknown.[1867] Remnant plastic pieces (hard and solid) (227,395 items) and plastic lids and tops, pump spray and flow restrictors (100,430 items) remained the most common categories of debris collected from 2019 to 2022.[1866]



Alva Beach marine debris cleanup with Tangaroa Blue © Ashlee DeVore 2023

The quantity and relative contributions of some types of marine debris collected along the Reef's coast and islands vary from north to south.[1866] In 2022, a total of 27.3 tonnes of marine debris was removed in 296 beach clean-ups. Between 2019 and 2022, the heaviest mass (10,231 kilograms) and greatest density (0.12 items per metre) of debris was collected in the Cape York region. For the past 4 years, more than 85 per cent of the debris in every zone of the Cape York region is predicted to have come from offshore sources. Of all NRM regions, debris was least dense in Burnett Mary with just 0.004 items per square metre.[1866] Awareness of marine debris as a threat is increasing,[1873] and efforts to improve trends across the Region are underway.[1866,1874]

Other pollutants

Other pollutants, such as metals and metalloids, pharmaceutical and personal care products, persistent organic pollutants and fire retardants are found in the Region.[1867,1875] The sources of these pollutants are diverse and include point sources, such as urban and industrial wastewater treatment plans, and diffuse sources, such as land-based runoff.[1867] However, monitoring and long-term studies are still lacking for these groups of pollutants, so no temporal trend can be determined, and information is generally limited.

Metals and metalloids occur naturally in rock and soils and can enter the aquatic environment through weathering, erosion and atmospheric deposition.[1867] Human activities can increase the presence of metals in the environment. These pollutants are derived from a range of diffuse and point sources along the Catchment, including agriculture, mining and industrial runoff; urban centres; waste treatment and disposal; ports and harbours; atmospheric deposition; coastal and marine tourism; military areas;

and shipping.[705,1867,1875] Metals and metalloids have been detected in water and sediment in the Reef, including the ports of Abbot Point, Cairns, Gladstone, Hay Point and Townsville. Based on available monitoring information, dissolved metal and metalloid concentrations in surface waters were typically low.[1867] Metals have also been found abundantly in sediments and algal turfs around Lizard Island and Orpheus Island. Metal composition and concentrations at Orpheus Island suggest influence from land-based runoff.[1876]

Pharmaceuticals comprise a broad range of human and veterinary medical products including antibiotics, hormones and endocrine-disrupting contaminants.[1875] *Personal care products* comprise a large array of consumer products generally used on the human body, such as cosmetics, toiletries or fragrances that contain active ingredients to prevent diseases or alter odour, appearance, touch or taste.[1867] Both groups of compounds have been found in Reef waters in low concentrations.[1877,1878] Comparison between coastal and offshore locations demonstrated that the presence and concentrations of pharmaceuticals and personal care products are linked to proximity to sources of wastewater discharge into coastal waters,[1878] as well as high-tourism areas.[1875]

Persistent organic products (POPs) include polycyclic aromatic hydrocarbons (PAHs), petroleum products (associated with land use), chlorinated polychlorinated-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCB). The primary potential sources of POPs were associated with flood and runoff from urbanisation, industry, mining activities, as well as oil spills in the Marine Park.[1867,1879] Regular monitoring of POPs does not occur in the Region. However, most petroleum hydrocarbon contamination occurs around port areas, and POPs are likely to accumulate in sediments close to loading facilities.[1867] PAHs and PCBs are included in sediment monitoring at ports requesting to dispose of spoil material within the Marine Park.

6.5.2 Vulnerability of the ecosystem to land-based runoff

It has been long recognised that, due to changes in land use following European settlement, the Region's values are threatened by poor water quality resulting from increased concentrations of suspended sediment, nutrients, pesticides and other pollutants (Section 6.5.1).[42] The risk of specific pollutants — including the severity and duration of exposure, and the species, habitats and ecological processes affected — varies across the Region.[1880] Risk from pollutants is influenced by the volume and timing of seasonal rainfall and subsequent runoff events, which are determined by the highly variable monsoonal climate (Box 6.1) and extreme weather events, such as cyclones and hydrodynamic factors, including tidal regimes and currents.[693]

Pollutants in land-based runoff can affect ecosystem resilience by reducing biodiversity and destabilising ecosystem functions and services.[1840,1881] Inshore areas of the Reef experience the greatest impacts, whereas mid-shelf and outer reefs are less frequently affected due to their distance from river mouths and the primarily northward dispersion of most river plumes.[528] However, after large rainfall events and under atypical hydrodynamic conditions, flood plumes can reach these more distant areas,[586,919,1882] as evidenced by the Burdekin River floods in 2019.[771]

Understanding the exposure of the Region's ecosystems to pollutants in land-based runoff is important for identifying the most vulnerable areas and setting specific targets for reduction of pollutants entering the coastal and inshore areas[1883] (Section 6.5.1). Areas adjacent to the Wet Tropics, Burdekin and Mackay Whitsunday regions are of particular concern given their high loads of dissolved inorganic nutrients, suspended sediments and pesticides, respectively.[693] Inshore ecosystems such as seagrass meadows and coral reefs are the most susceptible to impacts due to their proximity to pollution sources. Different

pollutants can combine to produce compounding effects. For example, both elevated levels of suspended sediment in the water column, and the proliferation of phytoplankton caused by increased dissolved nutrients, reduce the available light for benthic organisms, such as corals and seagrasses.[175,1840]

Land-based runoff makes inshore marine ecosystems more vulnerable to disturbances

Inshore ecosystems generally exhibit a capacity for recovery in the absence of acute events, such as cyclones and large river discharge,[175,573] though this capacity can be reduced by chronic exposure to other stressors.[1880,1884] For example, in 2019 the Burdekin floods caused significant decline in seagrass condition, but by 2022 in the absence of major weather events, the condition of seagrass had started to recover, likely driven by the presence of large seed banks.[145] Chronic impacts of poor water quality caused by land-based runoff can lower the resilience of ecosystems making them vulnerable to future disturbances.[573,1405] The frequency of exposure to river plumes is negatively associated with the ability of corals[573,1405] and seagrasses [576] to recover after disturbance.

Nutrients

Excess nutrients from land-based runoff can cause significant deleterious impacts on the Reef's ecosystems. Nutrients are chemical elements or compounds that are essential to life but, when present in excessive amounts, can cause negative ecological consequences.[132,571,1840] Most discharge of nutrients from rivers to the Region occurs in the summer wet season, from December to April. Microbial mineralisation and mobilisation of particulate and organic forms are also important sources of bioavailable nutrients.[595]

Excess nutrients are associated with increased biomass of phytoplankton and zooplankton primarily in the inshore area.[703] Phytoplankton biomass responds positively to nutrient availability, leading to phytoplankton blooms following discharge of nutrient-rich flood waters.[1885] The impact of elevated phytoplankton on coral reefs and seagrass meadows is mostly via reduction of water clarity and consequently light availability for the photosynthesis of corals and seagrasses.[132,276]



Nutrients promote growth of macroalgae in inshore areas, Pallarenda. © Dieter Tracey 2013

Elevated nutrient levels, particularly dissolved inorganic nitrogen, have been associated with a lowering of thermal bleaching threshold in corals in the Region.[276,733,1886] Nutrients can also affect the coral microbiome, resulting in microbial imbalance (dysbiosis) and coral disease. Although nutrient enrichment can be broadly associated with coral disease, relationships with specific nutrient forms remains unclear.[731] On inshore reefs, the influx of land-based nutrients is associated with high cover of macroalgae. Once established, macroalgae are often highly persistent, as density-dependent feedback loops reinforce their competitive advantage relative to that of corals.[185] As a result, high macroalgal cover often hinders the recovery of coral communities after acute disturbances, such as heat stress or cyclones.



Elevated nutrient levels affect coral health and susceptibility to bleaching

Seagrasses can also be indirectly affected by nutrients. While elevated nutrients can enhance seagrass growth,[1887] they also promote the growth of phytoplankton, macroalgae, and epiphytic algae, which results in reduced light attenuation for seagrass leaves.[1818] Epiphytes and macroalgae can compete with and block light reaching seagrass leaves, thereby compounding environmental stress.[145] In the inshore seagrass monitoring sites, decreasing and low epiphyte cover on seagrass leaves across coastal habitats, accompanied by continued low macroalgae abundance across all habitats, has contributed to the recovery of seagrass meadows in the Region.[145]

Nutrient enrichment has also been often cited as a factor driving outbreaks of crown-of-thorns starfish[1010] (Section 3.6.2). Nutrients from land-based runoff during heavy river discharge events, which sometimes coincide with the pelagic phase of developing larvae, can result in phytoplankton blooms that increase the amount of food available for crown-of-thorns starfish larvae.[735] The observed sensitivity of crown-of-thorns starfish larvae to low-salinity waters associated with flood plumes[768] may partially explain why crown-of-thorns starfish are less common on inshore reefs. However, this sensitivity does not preclude a role for increased planktonic productivity linked to land-based runoff having positive impacts on larval survival and development.[1021] Although the role of nutrient enrichment in crown-of-thorns starfish outbreak dynamics remains unresolved,[735,1888] recent findings suggest only a weak link between the influx of nutrients from land-based runoff and the modelled response of phytoplankton productivity in the primary initiation zone of crown-of-thorns starfish outbreaks in mid-shelf waters of the Wet Tropics.[738] Oceanographic processes, such as upwelling and intrusive events, may be more important drivers of inter-annual variability in nutrient concentrations in this area than previously understood.[735,738]

Sediments

Influx of fine sediments from large flood events can have long-lasting impacts in ecosystems. Immediately after flood events, and for a few months afterwards, fine sediments can stay resuspended in the water column and decrease availability of light reaching the seafloor.[39] Flood plume sediment is often associated with increased nutrients delivered to inshore areas, which can favour an increase in macroalgal cover, affecting both coral and seagrass communities.[145,185] Sediments deposited on the seafloor can also increase turbidity through chronic wind- and current-driven resuspension, reducing photic depth for long periods of time.[1889,1890] Fine sediment primarily affects shallow inshore coral and seagrass communities, and organisms that rely on them.[185,145,1891,576] In reef fish, excess sediments can affect some species by inducing changes in feeding behaviour due to increased sediment loads within algal turfs,[1892,1893] doubling larvae development time,[1894] reducing growth rates,[1895] reducing the ability to find suitable habitat,[1896] changing predator–prey interactions[1897] and damaging gill structure.[1898]

Corals are highly sensitive to chronic exposure to fine sediments, which affects their biology by reducing recruitment and settlement success and smothering adult colonies.[39,910,1899,1900] At community level, in the Mackay Whitsunday region, coral communities have been slowly recovering from legacy effects of cyclone Debbie, which severely affected the region in 2017.[1901] Following the severe loss of coral cover at many sites post-Debbie, successful recovery relied heavily on the recruitment and survival of juvenile corals, which were significantly reduced by fine sediments present in the water column and deposited in shallow areas. Over the past 5 years, fine sediment deposited by cyclone Debbie has naturally and gradually moved away from the inshore reef region, allowing space for new corals to settle. Even though the density of juvenile corals continued to increase in past 2 years, juvenile density remains low on most reefs, suggesting a bottleneck for the recovery of these communities. Included among the increasing numbers of juveniles are the fast-growing genus *Acropora*; the survival and growth of these colonies will be central to the recovery trajectory of the coral communities in coming years.[185]



Fine sediments reduce the quantity and quality of light in Reef ecosystems

Fine sediments can affect seagrass condition by smothering plants and limiting light.[1890] The respiratory requirements for survival and growth cannot be met by photosynthesis under low light conditions.[1902] In inshore sites, seagrasses are often exposed to a very high frequency of turbid water resulting from resuspended fine sediment, even in low-discharge years. These turbid waters constrain the depth limit of seagrass occurrence and, therefore, influence their spatial extent and cause changes in abundance and resilience.[145] In extreme cases, when the disturbance is long-lasting, plant death, changes in species composition or even meadow loss can be observed.[145] The loss of seagrass meadows can have an indirect impact on dugong populations, as dugongs are highly dependent on seagrass for their diet.[1903,1904] Reduction in dugong populations, either by migration or by death from starvation, has been linked to reduced seagrass abundance in some areas of the Reef.[520,1904]

Pesticides

Pesticides are found ubiquitously in the Catchment and inshore areas of the Region.[1905, 1852,1830] Concentrations of pesticides above Australian guidelines are often found adjacent to and downstream of areas of horticulture and intensive cropping, particularly sugarcane.[1847] These areas are largely located in the Wet Tropics, Burdekin and Mackay Whitsunday regions.

Mean contributions of individual pesticides in catchment waterways and inshore areas also vary between regions. Pesticide risk and toxicity are assessed collectively as opposed to individually for each pesticide.[1850] In inshore areas of the Mackay Whitsunday and Wet Topics regions, diuron, imidacloprid and hexazinone are common, whereas tebuthiuron is often detected in the Burdekin inshore region.[1855,1830] 'Alternative' photosystem II and non-photosystem II herbicides are increasingly applied as substitutes for effective weed control to help achieve targeted reductions in priority herbicide loads.[1906] However, alternative herbicides can exhibit similarities in physico-chemical properties to the priority photosystem II herbicides and, in some cases, can be just as toxic to non-target marine species.[1907] Links between organism responses and pesticide exposure in the field are uncertain due to the possibility that other environmental factors, such as temperature, light and other pollutants, can confound responses.[1849] In addition, mixtures of pesticides can be associated with higher or lower risk than individual pesticides, depending on the specifics of chemical interactions.[1852]

Pesticides can impair photosynthesis and reduce calcification rates in corals

In the environment, pesticide runoff losses and degradation vary significantly among different types of pesticides. For example, PSII herbicides, such as diuron and atrazine, which are commonly found in the environment, are estimated to have half-lives between 40 and 100 days, respectively.[1846,1908] Although persistence in the environment is lower than some legacy pesticides (such as organochlorine pesticides like DDT), PSII herbicides can persist in marine waters for a significant period of time.[1909]

While *in situ* impacts of pesticides are difficult to quantify, deleterious effects have been studied in Reef organisms under controlled laboratory conditions. Pesticide toxic effects have been extensively demonstrated on organisms that rely on photosynthesis for growth and reproduction, such as seagrasses, hard corals, crustose coralline algae and symbiont-bearing foraminifera.[1910,1911,1912,1913] Among pesticides, PSII herbicides are commonly studied due to their extensive use and ubiquitous presence in the marine environment.[1855,1830] Diuron has been shown to impair photosynthesis and reduce calcification rates in corals and in the calcifying algae *Halimeda* under short-term exposure.[1907,1914] Photosystem II herbicides also negatively affect the growth and photosynthetic efficiency of coral symbionts.[1915] Growth rates of and photosynthesis in marine microalgae are also affected by herbicides.[1907,1916]

In addition to herbicides, exposure to several insecticides (diazinon, fipronil and imidacloprid) and fungicides (chlorothalonil and propiconazole) has been shown to negatively affect all life-history stages of corals.[1917] Insecticides inhibit fertilisation and metamorphosis, as well as reduce coral settlement.[1917,1918]

Pesticide concentrations in the inshore Reef are typically highest over the summer wet season,[1856] making inshore areas frequently co-exposed to herbicides and high seasonal water temperatures, which exacerbates the toxic effects of pesticides in reef species.[1914, 1919,1920] However, the cumulative effects of heat stress and pesticides on ecosystems remain poorly understood.

Marine debris

Marine debris is a major threat to the health and values of the Region and causes mortality of marine turtles, dugongs, dolphins and seabirds.[1865,1921] Marine debris is commonly found in the Region; however, the sources of marine debris, particularly plastics, vary with geographical position. Land-based sources contribute approximately 80 per cent of anthropogenic debris in marine environments. The vast majority of debris found in the Region is plastic.[1922] Land-based runoff and stormwater systems are believed to be the main source of marine debris and plastic in coastal and inshore areas.[1923,1872] Islands are often the repository of windborne plastics, as well as general waste associated with tourism activities (fishing, boating and presence on islands), commercial boating and fishing, and localised stormwater runoff.[1867,1868,1869,1924] Marine debris can float, sink, become entangled on rocky outcrops or reefs, or become buried in the sea floor where it can resurface after disturbances, such as cyclones and floods.[1921] It can also break down into smaller particles with long-lasting impacts in the environment.[1925]

Marine microplastics can bioconcentrate and bioaccumulate in reef organisms, but in contrast to other pollutants such as metals, biomagnification is not as common as previously described.[383,1480,1862] Microplastics also act as carriers for a range of toxic substances.[1925] Ingestion of microplastics is common and can affect the health of corals, fish, marine turtles, seabirds and cetaceans.[1926,1927,1861,1862] Coral reefs, and reef-building corals, in particular, intercept and accumulate microplastics.[1928]



Ghost nets can cause entanglement that leads to death in turtles. © Commonwealth of Australia (Reef Authority). Photographer: Rohana Rogan-Darvill 2021

Other pollutants

In the Region, pollutant sources — such as agriculture and mining runoff, ports and harbours, drainage from acid sulfate soils, industrial effluents and emissions, atmospheric deposition, urban centres and wastewater discharge — all contribute to elevated concentrations of **metals and metalloids** in receiving waters.[1867] Metals are highly persistent and remain in the environment indefinitely, binding to fine particulate sediment and settling on the substrate where concentrations are absorbed by reef organisms. Often, metals bioaccumulate at greater concentrations than those detected in the surrounding environment.[1929] High metal concentrations have been detected in inshore seagrass meadows, which are a key food source for some species of marine turtles.[1930,1931] Turtles are also known to graze on turf algae. Elevated metal loads in seagrass and turf algae could translate into accumulation of metals in turtle tissues.[1932] Similar accumulation could also occur in herbivorous and detritivorous reef fishes. High metal concentrations may also alter fish feeding behaviour.[1876] Accumulation of metals in key food sources for herbivorous animals may represent a pathway through which metals enter reef food chains and cause deleterious effects to marine mammals and other apex predators.

Many **pharmaceuticals and personal care products**, such as ultraviolet light filters and antibiotics, are persistent, bioaccumulative and potentially toxic.[1933] They may, therefore, affect the health of reef organisms. However, the persistence and potential impacts of such products on reef ecosystems are knowledge gaps.

Persistent organic pollutants (POPs) often bioaccumulate in food webs and can cause deleterious effects on growth, reproduction, metabolism and survival of reef organisms.[1879] These products often have long half-lives that range from decades to centuries. They

are considered resistant to metabolic, chemical, microbial and photolytic degradation procedures.[1934] However, the toxicity of POPs, such as petroleum hydrocarbons, can substantially increase in the presence of ultraviolet light, causing severe impacts on the settlement of coral larvae in shallow reef environments.[1935,1936] Exposure to oil derivatives can also alter habitat settlement and antipredator behaviours, reduce sheltering and shoaling, and increase risk taking in reef fish. These effects all exacerbate predator-induced mortality during recruitment, resulting in disruption of early life-history stages.[1937]

6.5.3 Implications of land-based runoff for regional communities

Pollution is perceived as the second major threat to the Reef[1075] (Figure 9.1). Coastal residents are substantially more concerned about plastic pollution than other types, mostly because their experiences are often limited to local beaches where the most visible threat is marine debris.[1075,1074]



Artwork made from ghost net and beach found rope: 'Beach Journal' (detail). Ghostnet Collective 2021
© Lynnette Griffiths and Marion Gaemers. Image © Chloe Schauble 2021

Both aesthetic and economic values can be degraded by pollution and poor water quality, primarily through decreases in tourism visitation and shoreline and water-based recreational activities.[1066,1168] For example, it is estimated that failing to reduce pollution from sediments can severely affect tourism in the Mackay Whitsunday region, with significant impacts on the local economy, potentially threatening hundreds of jobs.[1938]

Aesthetics and economic values can be degraded by pollution and poor water quality

Regional communities along the Reef consider improved land management to improve water quality as one of the main interventions for managing the Reef.[1075,1159] Government and community members, particularly farmers, continue to invest in and implement programs that improve water quality by reducing nutrients, sediments and

pesticides entering the Reef lagoon. These programs include voluntary adoption of improved agricultural practices driven by Reef protection regulation requirements and compliance.[1825] These programs also include the delivery of voluntary incentives that rely on non-government partners, particularly regional natural resource management organisations and agricultural industry peak bodies.[1939]

In 2023, evidence indicates that practice change has occurred among producers since implementation of the Reef protection regulations.[1940] Many producers consider the regulations have increased awareness of the impacts of nutrients and sediment on the Reef and acted as a catalyst for change towards more progressive and sustainable farm practices. However, adoption of new practices may be affected by the producers' perceptions, attitudes, goals and motivations.[1940,1941] This includes general scepticism about the need for the Reef protection regulations and a resistance to being regulated, mistrust in government and the evidence base for the regulations, and a belief that government officials do not understand farming.[1940] Research into how to navigate these challenges is ongoing.[1942,1943,1944,1945,1946,1947]

6.6 Direct use

Direct use of the Region includes commercial marine tourism, defence activities, fishing, recreation, research and educational activities, ports, shipping and the traditional use of marine resources. The current and projected trends in direct use are based on the relevant sections in Chapter 5. The analysis of the vulnerability of the Region's values to ongoing direct use as a whole (Section 6.6.2), and its implications for regional communities, align with the evidence and assessments presented in Chapters 2 to 5.



Increasing population, COVID-19, market activity and fisheries reforms have changed direct use

6.6.1 Trends in direct use

Commercial marine tourism continues to make significant contributions to the social and economic values of the Reef (Section 5.2). The COVID-19 pandemic led to significant declines in tourism visits in 2020 due to border closures. Visitation has slowly returned since but has not yet reached pre-pandemic levels. The Reef Authority's high standard tourism program remains in place, although uptake has slowed. Training for Reef tourism guides has increased, and tourism products have diversified since 2019, including edu-tourism and underwater artwork.

Defence activities, specifically training, are expected to increase in frequency and intensity (Section 5.3). While local impacts from modern defence training activities occur in the Region, balancing defence activities with conservation in sensitive habitats remains a high priority. As cumulative stressors increase, the risk of not achieving an appropriate balance will increase.

Fishing occurs throughout the Region. The extraction of biomass, interaction of animals with fishing equipment, and discarded catch are ongoing pressures from fishing. Illegal fishing and extraction remain a concern. Management of fisheries has undergone significant reform, with harvest strategies now in place for key fisheries. Protection of key fisheries within no-take areas is highly successful.[1948] Understanding of fishing impacts has improved since 2019 through stock assessments, risk assessments and stock status assessments. Some stocks remain depleted, outcomes from implemented reforms are yet to be fully realised and some knowledge gaps remain.

Recreational use (not including fishing) is one of the major direct uses of the Region. It encompasses short trips to the beach through to longer journeys to the Reef (Section 5.5). The number of recreational vessel registrations between 2018 and 2022 was the highest recorded and has increased in proportion to population growth. Use is increasing of smaller watercraft (for example jet skis) in inshore areas, and of larger vessels that access mid- and outer-shelf reefs. The impact of COVID-19 lockdowns and border restrictions on recreational access and use varied throughout the pandemic.

Research and educational activities occur in many parts of the Region, often around research stations. Understanding of cumulative effects of the impacts associated with research and educational activities remains limited (Section 5.6). Since 2019, research on climate change, resilience and adaptation of the ecosystem, intervention technologies and social–ecological values of the Region have continued to grow.

Ports provide significant economic and social benefit to the Queensland and national economies (Section 5.7). The decrease in throughput since 2019, reflects impacts from border closures and changes to market and freight and supply chains during the COVID-19 pandemic. Since 2019, there have been 3 capital dredging campaigns as part of expansion projects at the ports of Cairns, Townsville and Gladstone. All capital dredge material was disposed of on land. Approximately 30 hectares of new land was reclaimed at the port of Townsville. The average annual volume of maintenance dredging disposed of at sea decreased overall. Accessibility of information in relation to port activities has improved since 2019, though some gaps remain.

Shipping traffic through the Region was affected by the management of the COVID-19 pandemic, with a temporary decrease in cargo shipping and significant decreases in cruise ship arrivals (Section 5.8). Knowledge and management gaps remain around the impacts of ship anchoring, resuspension of sediments from ship propellers and light pollution from ships at anchor.

Traditional use of marine resources is a key part of the Reef's Indigenous culture and the ongoing connection of Traditional Owners to their Land and Sea Country (Section 5.9). Engagement of First Nations peoples in Sea Country management continues to increase. Since 2019, one new Traditional Use of Marine Resource Agreement has been accredited, bringing the cumulative area covered by these agreements to more than 43 per cent of the Region's coastline. Information on trends in traditional use remain limited despite an improvement since 2019 through deeper engagement of Traditional Owners in management and through Sea Country values mapping.

6.6.2 Vulnerability of the ecosystem to direct use

The 8 identified direct uses of the Region expose the Reef's values to a variety of impacts at a local scale and cumulatively. When coupled with the highest and most immediate threats to the Reef, such as sea temperature increase and altered weather patterns, the impacts of direct use are amplified. Activities such as tourism, defence, ports and research tend to be localised, whereas fishing, recreational use and shipping are more widespread. The effectiveness of the current management tools for the main types of direct use in, and adjacent to, the Region are assessed in Chapter 7.

Damage from direct use can be permanent or temporary. Permanent change is usually a result of **modifications to coastline** and island habitats from coastal development, or port and marine infrastructure activities. By contrast, direct use impacts that can kill and injure coral, such as anchoring, are usually temporary and smaller in scale. Damaged areas can return to a pre-disturbance state if recovery times are adequate. Accidental and intentional handling and manipulation of benthic organisms can lead to localised damage to the reef structure and increase the prevalence of outbreaks of disease.[1949]

Commercial marine tourism, fishing and recreation activities in some locations may interact with other uses — **incompatible uses** (with incompatible values) can affect or displace another user group. Displacement concerns have been raised between commercial marine tourism and Traditional Owners, recreational fishing and commercial marine tourism, and in terms of resource allocation between recreational and commercial fishers.

Defence activities continue to have localised impacts in and adjacent to the Region, including from unexploded ordnance and firefighting foam containing PFAS. The acute and chronic impact of PFAS chemicals on plant and animal communities is still unknown.

Marine debris is a threat to wildlife[1950] and is an emerging threat to the Region as the global human population increases (Section 6.2.1). Direct uses have the potential to add **marine debris** to coastal, island and marine habitats. Understanding of the quantity and ecological effects from microplastics in the Region is improving, although gaps remain (Section 6.5).

The number of reported vessel strikes on species of conservation concern is generally low. Surface-breathing marine animals, such as marine turtles, dugongs, dolphins and whales, are the species most often struck by vessels, with the collision often resulting in injury or death. Population growth in regional communities is a driver of human-induced impacts on the Region. More vessel use, larger ships and expansion of direct use activities are likely to increase **wildlife disturbance** across the Region.

Even though procedural controls are in place to respond to **oil spills** and some **chemical spills**, the Region remains vulnerable to **vessel groundings** and large spills of other foreign material (diesel and other cargo). Shipping (and other vessels greater than 50 metres in overall length), international fishing and recreational vessels (predominantly yachts) are vectors for **introduced exotic species**. If introduced and persistent, introduced species can have widespread effects on the ecosystem. Although limited pest incursions have occurred at ports and marinas since 2019, islands remain vulnerable.

Dredging and **disposal of dredge material** in inshore areas contribute to sedimentation by disrupting and resuspending sediments. Dredge disposal for reclamation may directly affect tidal inshore habitats, such as seagrass meadows.[1951] A growing shipping fleet and increased coastal development (including from ports) can increase **artificial light** into the Region.

Fishing is the single largest extractive activity in the Region. Target and non-target species from various trophic levels are directly removed from the ecosystem, with predatory fish being disproportionately targeted in the Region. Indirectly, other species and habitats may also be affected through anchor damage and **damage to the seafloor** (from trawling). Across the range of threats and impacts from fishing, **incidental catch of species of conservation concern**, such as dugongs, inshore dolphins and some species of sea snakes, marine turtles, sharks and rays, still persist under current management. However, changes in gillnet fishing may reduce this impact in the future. Dugong and turtle populations remain depleted following past commercial harvesting and are further threatened by climate change. These species remain vulnerable to entanglement and drowning when they interact with legal fishing gear, **marine debris** or **illegal fishing and extraction**. Illegal fishing in no-take zones and harvest of fish smaller or larger than relevant size limits can be perceived by fishers as a one-off, short-term impact. However, illegal fishing can have long-term impacts on biodiversity given some species take many years to reach sexual maturity (Section 8.3.4).

A deteriorating ecosystem reduces benefits for Reef-dependent industries and community

Climate change, habitat loss and delayed recovery of critical fisheries habitats make the ecosystem more vulnerable to direct effects from fishing and other direct uses. Deterioration of habitat that fisheries species rely upon will increase the vulnerability of the fishing industry through reduced catches, increased disease prevalence and a potential shift in fisheries species. This social–ecological vulnerability also applies to all other Reef-dependent uses.

6.6.3 Implications of direct use for regional communities

Since European settlement, use of the Region has changed and intensified. The Region is no longer a pristine ecosystem and it exists in a dynamic state. The dynamic state involves interactions with people and how they use the Region's natural heritage values and connect with Indigenous heritage values.

Direct use contributes to the wellbeing of regional communities through direct and indirect benefits that can feed back into how residents interact with the environment. Fishing and pollution-related threats are perceived as the second and third major threats to the Reef, respectively.[1075] Tourism, shipping, mining and coastal development were less commonly perceived as major threats.

Direct use contributes to the wellbeing of regional communities

For Reef-dependent uses, the condition of the ecosystem remains fundamental to the longevity of their various industries, economic prosperity and social wellbeing. The direct economic cost of climate change and ecosystem disturbance on Reef-dependent communities has not been fully quantified and remains a knowledge gap.

Non-Reef-dependent uses of defence activities, ports and shipping, which are not directly connected to the Region's natural values, are affected by external factors. The economic significance of ports and shipping is largely driven by global and domestic demand for resources and commodities. However, as an interconnected system, changes to the climate that affect the health and usability of the Region are likely to affect the suitability of the Reef as a transit corridor for ships.

6.7 Vulnerability of heritage values to influencing factors

Of the four main factors influencing the Region (climate change, coastal development, land-based runoff and direct use), climate change remains the greatest issue facing the Region's heritage values. The effects of climate change on the Reef's natural values are assessed in Sections 6.3 and 7.3.9.

The Reef's outstanding universal value and the connection of Traditional Owners with the natural environment are highly vulnerable to the factors influencing the Region. The identity of First Nations peoples is embedded in their Sea Country, moving beyond the physical dimensions of landscapes and seascapes; they are spiritscapes.[1114] Pressures exerted on the Region's natural heritage value (ecological and biological processes and habitats assessed in Chapters 2 and 3) equally apply pressure on the Region's Indigenous

heritage value (Section 4.3). Therefore, changes in the Region's habitats, species and ecosystem health may have far-reaching consequences on the natural and Indigenous heritage values of the Region.

Projections of intensified ocean warming (Section 6.3.1), and population growth (Section 6.2.2) will continue to place pressure on the Region's heritage values. Impacts of climate change threats (such as **ocean acidification**, **altered ocean currents** and **sea temperature increase**) on intangible heritage are likely to occur, although this remains a knowledge gap. Changes to the ecosystem due to **altered weather patterns** are inevitable under predicted climate change scenarios, and changes are already being observed.[933] Altered weather patterns and **sea-level rise** are likely to accelerate impacts on tangible heritage sites through physical weathering, erosion and inundation.[1952,1953] **Nutrient, sediment and terrestrial runoff** may also affect tangible underwater heritage sites by altering physical and chemical processes and potentially accelerating degradation rates.[1954]

The heightened level of vulnerability has seen managers embrace dynamic approaches to Reef and island interventions in the past 5 years. However, the onset and severity of some climate-induced impacts, makes planning difficult and complicates the assessment of potential benefits of some Reef interventions.[1955] The effect of interventions on Indigenous heritage values is a knowledge gap.[1956] Greater emphasis has also been placed on adaptation strategies and analysis of policy frameworks at a place-based level.[1956,1957]

Contemporary publications identify that, while Indigenous heritage values continue to be vulnerable to factors influencing the Region, First Nations peoples have demonstrated a capacity to adapt to a changing climate and other external pressures for thousands of years. An emphasis on 'old ways to new days' will act to reduce and mitigate the risk of **fragmentation of cultural knowledge** and support resilience in the face of climate change.[1958,1959,1960] For example, the Yuku-Baja-Muliku people, in collaboration with western climate change scientists, developed a process to assess the vulnerability of their Land and Sea Country near Archer Point in North Queensland to climate change using both Indigenous Knowledge and western science.[933] Through the Traditional Owner-centric assessment, the observations made by the Yuku-Baja-Muliku people on Land and Sea Country could be related to climate change impacts and to how those impacts are affecting their management efforts and customary activities.

Indigenous heritage values are vulnerable to multiple effects relating to **foundational capacity gaps** (Appendix 6), specifically uneven capacities and power dynamics that exist within society and Reef management.[1958] In 2019, foundational capacity gaps were included as a threat to the Region's heritage values in the Outlook Report for the first time. Since then, additional local and international studies and partnership initiatives have drawn attention to the improvements required in the enabling context for building capacity and self-agency of First Nations people (noting the disparity in the starting point). Self-agency and an enabling environment are essential to reducing foundational capacity gaps and the fragmentation of cultural knowledge.[1114,1961,1962,1963] Climate adaptation planning to reduce vulnerabilities and strengthen the resilience of First Nations peoples and Indigenous heritage values should involve mobilising cultural institutions, strengthening cultural practices, incorporating cultural knowledge and supporting decolonising.[1406,1960]

Self-agency and an enabling environment are key to reducing foundational capacity gaps

Indigenous and historic heritage is irreplaceable; therefore, where possible, impacts should be avoided or mitigated. An inherently difficult aspect of maintaining the resilience of historic heritage values is identifying and protecting sites and monitoring their condition and integrity. Where heritage values are known (for example, lightstations), ongoing maintenance reduces the asset's vulnerability. Historic heritage values (lightstations, shipwrecks and aircraft wrecks) continue to be vulnerable to natural degradation, severe weather events and some direct use activities.

As a multiple-use marine protected area, the Reef is a contested space. The range of users, and occurrence of **incompatible uses**, exert pressure simultaneously on the Region's Indigenous and historic heritage values at varying spatial and temporal extents. Implementation of co-management principles will help balance multiple objectives of different use in an environmentally sustainable way.[1181,1962] Indigenous heritage values remain vulnerable to **illegal fishing and extraction** of culturally significant species, but the scale of this issue is unknown.

Behaviours impacting heritage values occur at a site-specific scale. Direct use activities, such as tourism, recreation and fishing, can have adverse impacts on heritage values,[1964] especially in areas that are heavily visited or where heritage values are not well known or understood. High visitation or poor behaviours that affect the ecosystem values may affect heritage sites. Intangible heritage values can be disturbed or damaged by: an inappropriate presence of people at sensitive cultural sites; access by people of culturally inappropriate gender or seniority; and, high levels of visitor traffic or disrespectful behaviour at heritage sites. At a regional scale, knowledge gaps exist around the likelihood and geographic spread of impacts from direct use activities on certain heritage values, and the vulnerability of the Reef's heritage values to high levels of visitation is poorly understood. Commercialisation and commodification of intangible cultural heritage can affect Indigenous heritage values,[1965] but cultural tourism led by Indigenous people, who hold the appropriate cultural authority and knowledge, can minimise this threat.[1964]

Some culturally important species (such as marine turtles and dugongs) remain under pressure. Specifically, inshore and intertidal feeding and nursery habitats (such as seagrass meadows and beaches) are exposed to increased disturbances where coastal habitats are modified. **Damage to the seafloor**, such as through coastal development (**dredging** of ports and marinas) or fishing (trawling and anchoring), may cause irreversible damage or loss of Indigenous and historic heritage values.

Foundational capacity gaps have emerged as an increasing vulnerability, particularly for Indigenous heritage. Overall, tangible and intangible Indigenous heritage values and historic heritage values remain vulnerable to the changing climate and its associated impacts.

6.8 Assessment summary — Factors influencing the Region's values

Paragraph 54(3)(g) of the *Great Barrier Reef Marine Park Act 1975* (Cth) requires *'an assessment of the factors influencing the current and projected future environmental, economic and social values...'* of the Great Barrier Reef Region.

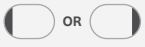
Section 176 (3)(e) of the *Great Barrier Reef Marine Park Regulations 2019* (Cth) requires *'an assessment of the factors influencing the current and projected heritage values...'* of the Great Barrier Reef Region.

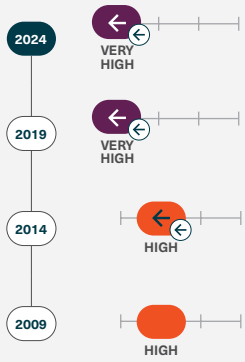
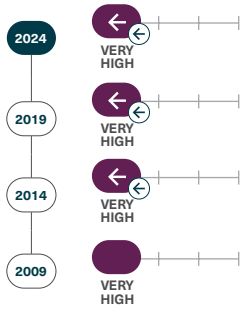
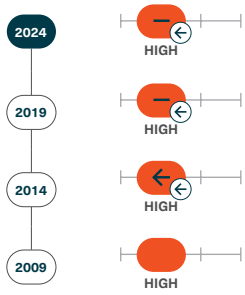
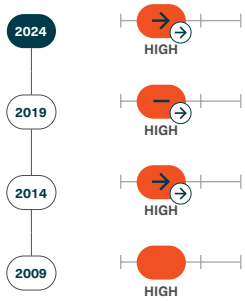
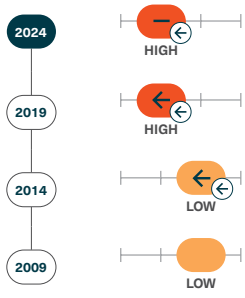
The assessment is based on four assessment criteria:

- impacts on ecological values
- impacts on heritage values
- impacts on economic values
- impacts on social values.

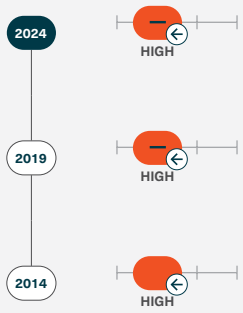
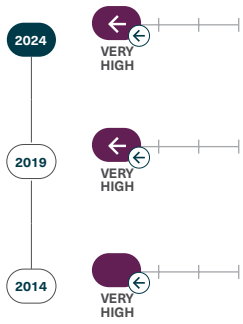
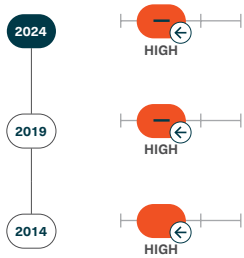
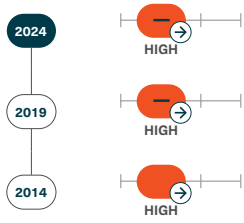
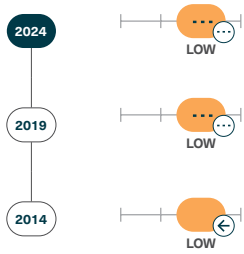
Grades for all components and attributes examined in the assessment, as well as the grade for the criterion, are allocated according to the statements in the table below.

6.8.1 Impacts on ecological values

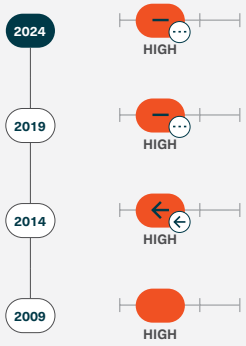
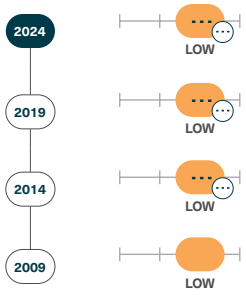
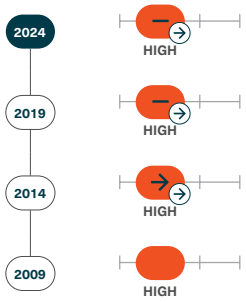
Grading statements — Impacts on ecological, heritage, economic and social values		Trend since previous report	Confidence
	**Very low impact:** Few or no impacts have been observed and accepted predictions indicate that future impacts on the Region's ecological, heritage, economic or social values are minor.	Increased Stable Decreased No consistent trend **Future trend** Increasing Stable Decreasing No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
	**Low impact:** Some minor impacts have already been observed and there is concern that, based on predictions, there will be significant but localised impacts on the Region's ecological heritage, economic or social values.		
	**High impact:** Current and predicted future impacts are likely to significantly affect the Region's ecological, heritage, economic or social values. Concern about serious ecosystem, heritage economic or social effects within the next 20–50 years.		
	**Very high impact:** Current and predicted future impacts are likely to irreversibly destroy much of the Region's ecological, heritage, economic or social values. Widespread and serious ecosystem, heritage, economic or social effects likely within the next 10–20 years.		
	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

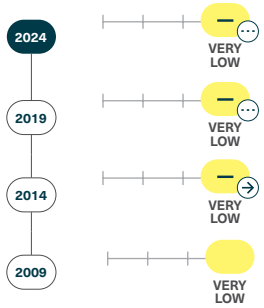
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Impact on ecological values: Climate change has had a widespread impact on ecological values fundamental to the Region's identity. Repeated mass coral bleaching events in 2020 and 2022 have affected the Reef's ecosystems. Evidence of cascading effects of coral loss on fish and invertebrate abundance and diversity continue to emerge. The strong influence of climate change exacerbates the cumulative pressures of land-based runoff, coastal development and direct use. The ongoing cumulative pressures of these local and global factors are likely to continue to affect the Reef's ecosystems and may limit the potential for ecological recovery.			
Climate change: Current and predicted climate change impacts will have far-reaching and irreversible consequences in the Region. Ocean warming, sea-level rise and ocean acidification are predicted to worsen over the next decades. While Reef ecosystems are resilient and can recover from impacts, increasing occurrences of widespread coral bleaching (including those caused by marine heatwaves in 2016, 2017, 2020 and 2022) are exceeding the limits of tolerance of reef organisms to climate change.			
Coastal development: Over the past 5 years, the extent of new coastal development has been minor, especially due to 2 years of decreased growth due to the COVID-19 pandemic. However, Queensland's populations are projected to grow in the coming decades, increasing pressures in the Region. Legacy and new coalmines in the Region's Catchment can further exacerbate the effects of climate change.			
Land-based runoff: Improvements in water quality across most inshore areas of the Reef are encouraging, despite slow progress towards reducing pollutant loads in adjacent catchments. Recovery of nearshore ecosystems is closely linked to increased water quality, as evidenced by improving condition of seagrass meadows in the northern regions. Impacts are generally decreased despite lag times with catchment improvements and considerable natural variability.			
Direct use: Changes across direct uses were driven by increasing population, management of the COVID-19 pandemic and fisheries reforms. Reductions in direct use through the pandemic have now mostly reversed. Certain impacts from fishing remain. The cumulative impacts of extraction and damage to the Reef by direct use, coupled with smaller recovery windows, will affect ecosystem resilience into the future.			

6.8.2 Impacts on heritage values

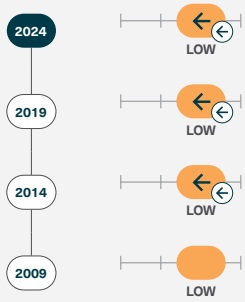
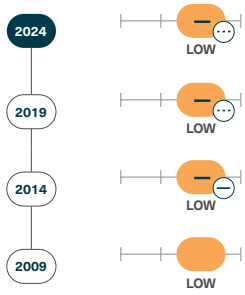
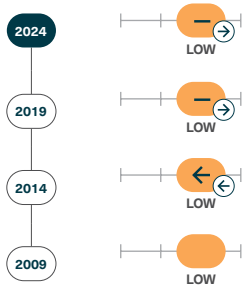
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Impact on heritage values: The Region's natural heritage value is already affected by climate change, transforming Reef's ecosystems through losses of species and habitats and altered ecological processes. As Indigenous heritage values and Traditional Owners' connection to Sea Country are closely linked to the natural heritage values, these values are under threat due to growing pressure from climate change and local anthropogenic impacts. Projections of intensification of ocean warming and population growth indicate that pressure will continue on the Region's heritage values.			
Climate change: The interconnectedness of the natural and Indigenous heritage values exacerbates the vulnerability of the Region's heritage values to the impacts of climate change. Some Indigenous and historic heritage values will be irreplaceable if lost or damaged. Changes in weather patterns, driven by ongoing ocean warming, is imposing strong current and predicted impacts on natural and Indigenous heritage values. Altered weather patterns, such as severe rainfall, flooding and cyclones can cause irreversible damage to natural, historic and Indigenous heritage values.			
Coastal development: Population growth in the Region and further coastal development will put pressure on natural, historic and Indigenous heritage values of the Reef. The approval of new coalmines in the Catchment can further exacerbate the effects of climate change. At a local scale, the number of ports and marinas has remained stable over the past 5 years, but maintenance of these facilities can affect nearby heritage values.			
Land-based runoff: Culturally significant species, such as dugongs and marine turtles that rely on inshore seagrass meadows, continue to be indirectly impacted and vulnerable to land-based runoff. Land-based runoff may affect underwater historic heritage sites through changes in physical and chemical processes.			
Direct use: Direct use can affect tangible and intangible Indigenous heritage values. Direct use has limited impacts on historic heritage values, except tangible underwater sites that can be physically damaged by some activities. Gaps in understanding around the nature and extent of impacts on heritage values from tourism and fishing activities remain (e.g. through damage to seafloor, extraction of herbivores and incompatible uses).			

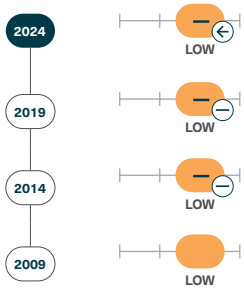
6.8.3 Impacts on economic values

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Impact on economic values: The economic value of Reef-dependent uses relies on a healthy Reef ecosystem. For non-Reef-dependent uses, economic value is aligned with market forces and population growth in the Catchment. Effects of ecological declines have become apparent over the past few years. Global and national disruptions due to management of the COVID-19 pandemic led to economic impacts on industries.			
Climate change: Climate change effects on the Region's natural heritage are expected to have major economic consequences for Reef-dependent industries, including tourism and fisheries. Tourism operators have shown adaptability and resilience since 2019, so significant economic losses for this reef-dependent industry due to climate change impacts have not yet been realised. Other industries, such as recreational and commercial fisheries, that are dependent on reef-associated fish can also be affected by climate change. More frequent severe weather also poses a significant economic and social risk to the Queensland community as ecosystem services provided by coral reef ecosystems, such as coastal protection, decline.			
Coastal development: Population growth, poorly managed land use, development and infrastructure in the Catchment may affect the marine ecosystem. Changes in land use resulting in poor water quality can also affect recreational and tourism activities, particularly in inshore and coastal areas. Indirectly, this would place pressure on the profitability of Reef-dependent uses.			
Land-based runoff: The Region is vulnerable to the effects of poor water quality. Resulting declines in ecosystem health will affect the economic growth of Reef-dependent industries. Slow progress in achieving water quality targets is likely to impair the recovery of inshore ecosystems, so it will continue to affect important inshore tourism sites. If improvements in land-based management practices continue, impacts may decrease in the future.			

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Direct use: Direct use of the Region continues to be a significant contributor to regional and national economies. All direct use was affected by management of the COVID-19 pandemic to some degree, with some significant economic impacts. However, in 2023 most industries are returning to pre-pandemic levels. Recreation, shipping and port activity are projected to increase. Future economic value of many Reef-dependent activities is intrinsically linked to the condition of the Reef.		ADEQUATE	LIMITED

6.8.4 Impacts on social values

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Impact on social values: Ecosystem decline as a result of climate change and land-based runoff will affect community health, wellbeing and enjoyment derived from the Region. An increased concern for the Region and its ecosystems has been recorded, particularly for Reef residents who report significant 'Reef grief'.			
Climate change: Climate-related changes to the ecosystem have affected patterns of use of the Reef and visitor satisfaction. People's awareness of the current and future effects of climate change is increasing their concern about the ecosystem. Emotional suffering associated with perceptions of damage to the Reef has been reported, particularly among Reef residents and tourists.		LIMITED	LIMITED
Coastal development: Coastal development provides broad economic and social benefits to regional communities adjacent to the Region through employment, commerce and places for recreation. Expansion into remote parts of the Catchment may provide social benefit from further access to the Region.		LIMITED	LIMITED
Land-based runoff: Ecosystem declines from poor water quality, particularly in inshore areas, can affect wellbeing and enjoyment of Reef users through degraded aesthetics resulting from turbid waters and presence of marine debris.		LIMITED	LIMITED

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Direct use: The Reef continues to be valued by national and international communities. Employment opportunities, knowledge, wellbeing and access contribute to the social benefits derived from the Reef. Traditional Owners' connections to Land and Sea Country are fundamental to the Indigenous cultural values of the Region.			

6.9 Overall summary of factors influencing the Region's values

The Reef is undergoing significant social, economic and environmental change. Cumulative impacts from climate change, land-based runoff, coastal development and direct use can threaten the Region's natural, Indigenous and other heritage values. Each of these 4 factors is assessed in terms of its impact on ecological, heritage, economic and social values. Understanding of the impacts (and trend in impacts) of these factors has continued to improve since 2019.

The main drivers of these pressures are economic and population growth. Societal attitudes can underpin social values and the way in which people interact with and value the Reef. Understanding changes in these attitudes can help to shape management approaches. Drivers of change can also lead to positive changes; for example, commitments to large-scale renewable energy by Australian and Queensland governments are driving infrastructure in the Region and will likely contribute to reducing greenhouse gas emissions. Technological developments are further leading to new ways to understand, monitor and manage the Reef's ecosystem.

Understanding changes in societal attitudes can help shape management

Of the 4 major influencing factors, climate change continues to have the greatest impact on the Region's values, with key indicators like seawater temperatures following ongoing trajectories that are directly related to global warming. The impacts of climate change are forecast to become more frequent, severe and widespread, and climate change will amplify the impacts of other threats. The resultant trend is one of increasing cumulative impacts on the Region's ecological, heritage, economic and social values.

Climate change continues to have the greatest impact on ecosystem and heritage values

Coastal development has a high impact on ecological and heritage values. Legacy effects of past coastal development, primarily agricultural land uses, barriers to flow, urban development and mining, are still significantly affecting coastal ecosystems adjacent to the Reef. Development is anticipated to increase in line with a growing population,

aquaculture is projected to increase within the Catchment, and existing and additional modification to coastal ecosystems and barriers to flow will encroach further upon natural and heritage values in the future.

The Region continues to be vulnerable to exposure to pollutants (mainly sediments, nutrients and pesticides) transported in land-based runoff resulting from unsustainable agricultural land management practices. Recent improvements in water quality across most inshore marine areas of the Reef are encouraging, despite slow progress towards reducing pollutant loads in adjacent catchments. Wind-driven resuspension of sediments will continue to affect water quality in nearshore areas. Despite lag times with catchment improvements, as well as considerable natural variability, the recovery of nearshore ecosystems is closely linked to improved water quality, as evidenced by the improving condition of seagrass meadows. Sustained water quality improvement remains critical for alleviating the compounding effects of climate change.



Improvements in water quality across most inshore areas are encouraging

Across the multitude of direct uses of the Region, the Reef's values are exposed to a variety of pressures, including local and widespread impacts. There have been changes across direct uses, driven by increasing population, the COVID-19 pandemic, market activity and fisheries reforms. Reductions in direct use through the pandemic have mostly reversed, and certain impacts from fishing remain. The cumulative impacts of extraction and damage to the Reef by direct use, coupled with broad influences of climate change and smaller recovery windows, will affect ecosystem resilience. It is critical that management actions effectively address direct use impacts to support the resilience of the Reef's ecosystems.

The success of Reef-dependent industries, such as commercial fishing and marine tourism, may be seriously affected by the major pressures on the Region. Knowledge gaps remain regarding the specific scale and nature of these effects. Cumulative impacts can also affect people's health, wellbeing, enjoyment, personal connection and appreciation of the Reef.



Cumulative impacts could seriously affect Reef-dependent industries and communities in the future



Staff from the Reef Joint Field Management Program participating in field training at Magnetic Island.

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Chapter 7

Existing protection and management

Existing protection and management

'an assessment of the existing measures to protect and manage the ecosystem...' within the Great Barrier Reef Region, s 54(3)(f) of the *Great Barrier Reef Marine Park Act 1975* (Cth).

'an assessment of the existing measures to protect and manage the heritage values...' of the Great Barrier Reef Region, Paragraph 176(3)(d) of the *Great Barrier Reef Marine Park Regulations 2019* (Cth).



Marine Parks vessel at Magnetic Island. © Queensland Government 2023

First Nations women across the Reef are connecting their traditional knowledge with marine science and technologies, enhancing understanding of the Reef's biodiversity. Their approach fosters a holistic and sustainable stewardship of Sea Country that values interconnected cultural, spiritual and ecological knowledge. Climate change and other impacts call for a strong network of Sea Country guardians to monitor, manage and protect biodiversity on the Reef.

"We're natural nurturers and our connection with other women empowers us to heal ourselves, each other and our communities. We can work with our communities now — using Indigenous knowledge systems and western scientific knowledge, using contemporary technologies and equipment."

— Francis Joyce, a Mamu Traditional Owner, program participant and ranger

First Nations women are taking a lead role in the management of Reef habitats through programs such as the Sea Women of the Great Barrier Reef program. This is an intensive capacity-building training program delivered on Yunbenun Magnetic Island, bringing together women from North Queensland, Zenadth Kes (Torres Straits Islands) and Papua New Guinea.

"Not many women have had the chance to get out and do this work. It's been male-dominated, and men have usually got first preference. It's a big step for women and we now also have a Queensland network of Indigenous female rangers, and it's growing all the time."'

— Olivia Mooka, a Girrungun Traditional Owner and program participant

The program enables selected women leaders to share their own Sea Country values and knowledge. Much of the training takes place on Yunbenun, Sea Country of Wulgurukaba Traditional Owners. They learn to merge cultural knowledge with marine science and practical marine skills they can take back to their Sea Country to build sustainable monitoring programs.

"I want to build capacity so the next generation can continue their cultural connections and care for Country."

— Francis Joyce

Source: Caring for Sea Country – Traditional Owner Stories from the Great Barrier Reef [1]



Rocky and Nelly bays at Magnetic Island. © Rohana Rogan-Darvill 2020

7.1 Background

The Region is protected and managed through partnerships between national, state and local government agencies, First Nations peoples, industry bodies and community members. A wide range of activities occur in the Region and the Catchment that may have direct or indirect impacts on the Reef. Understanding how effectively these activities and other influences are managed, and how well they protect the Region's ecosystem and heritage values, is crucial. It assists in understanding risk of threats and resilience and informing future management decisions to strengthen and improve the outlook for the Reef.

Protection and management of the Region involves partnerships among many

Five independent consultants specialising in protected area management, monitoring and evaluation, public policy and governance assessed the effectiveness of existing protection and management arrangements for the Region's ecosystem, its heritage value and, where relevant, the Catchment.[11] As for previous Outlook Reports, this assessment considers the effectiveness of all management actions undertaken by government agencies, industry bodies and other stakeholders to protect and manage the Region. Specifically, it compares management effectiveness over time and emphasises strengths and gaps across various management topics (Section 7.1.2). This report is available on the Reef Authority website (www2.gbrmpa.gov.au).

7.1.1 Roles and responsibilities

Protection and management responsibilities within the Region

The Australian and Queensland governments have statutory responsibilities for the protection and management of the Region in their respective jurisdictions (Figure 7.1). Australian Government legislation protects the Reef and Australia's world and national heritage under specific constitutional powers. The Queensland Government is primarily responsible for the regulation of natural resource management, environment protection and land use planning.

The Reef Authority manages the Great Barrier Reef Marine Park in accordance with the *Great Barrier Reef Marine Park Act 1975* (Cth) (Marine Park Act). The main object of this legislation is to provide for the long-term protection and conservation of the environment, biodiversity and heritage values of the Region. The Australian and Queensland governments work in partnership, as formalised in the *Great Barrier Reef Intergovernmental Agreement 2015* [1300], on many matters within the Marine Park, the adjacent Queensland Great Barrier Reef Coast Marine Park and Queensland Island National Parks. The Reef 2050 Plan provides an overarching strategic direction and framework for the Australian and Queensland governments to work with partners to protect and manage the Reef (Box 7.1).[2]

Australian and Queensland governments share management responsibilities in the Region

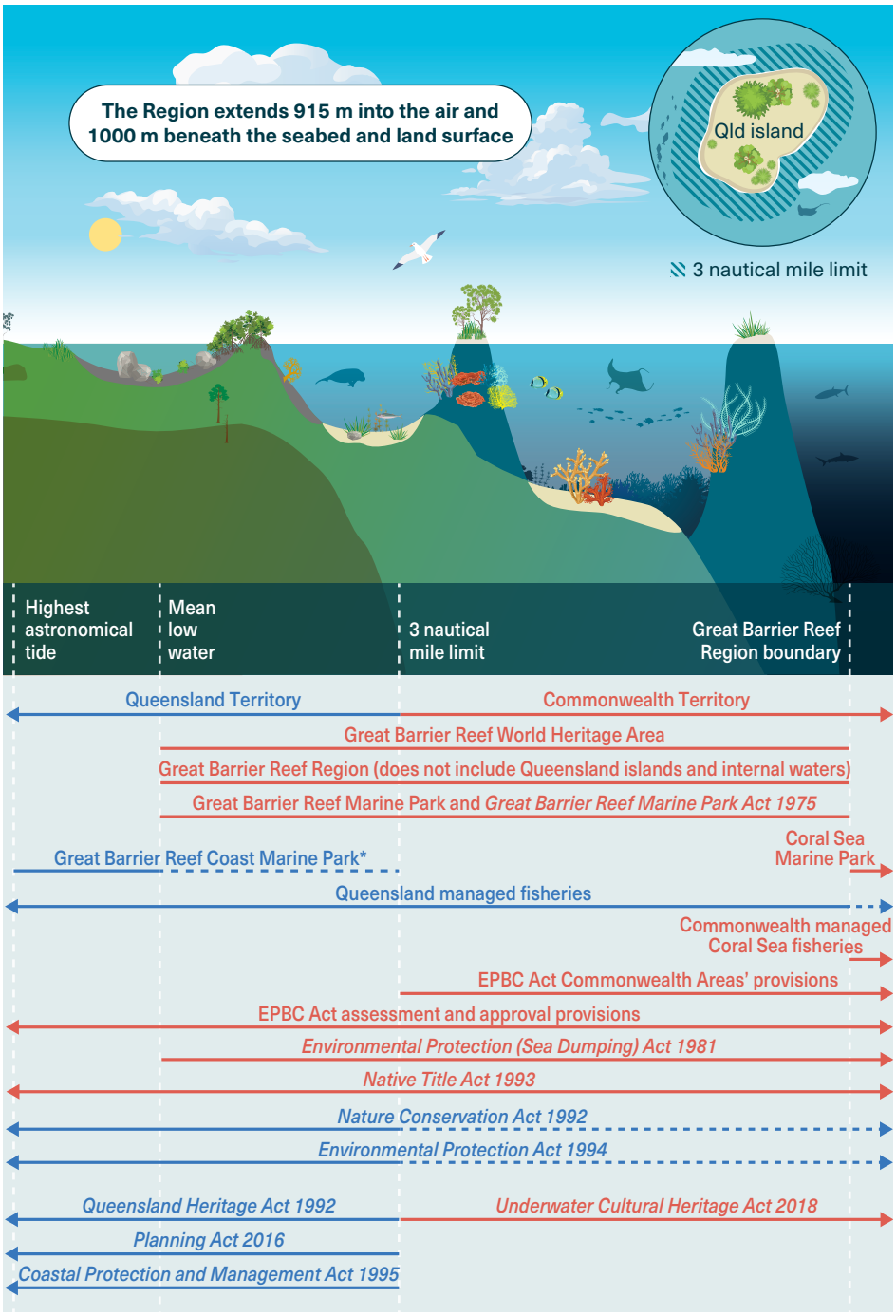


Figure 7.1 **Jurisdictional boundaries and a subset of relevant key legislation**

This diagram depicts some relevant legislation within the Region. The Commonwealth and the State of Queensland have jurisdiction over various parts of the Region (red and blue lines, respectively). A Commonwealth and Queensland intergovernmental agreement ensures integrated field management of the Great Barrier Reef Marine Park and the abutting Great Barrier Reef Coast Marine Park through joint management of marine parks and island national parks. The Queensland territory extends from the mainland to the three nautical mile limit. The Queensland territory includes Queensland-owned islands that lie within the Region, as well as the three nautical mile area surrounding Queensland-owned islands within the twelve nautical mile limit of the mainland (inset image).* Asterisk indicates that the boundary for the Great Barrier Reef Coast Marine Park may be high water or highest astronomical tide depending on location — pursuant to the Marine Parks (Declaration) Regulation 2006. The dotted lines indicate the possible extent of the relevant legislation or jurisdiction (for example depending on species or fishery). The Queensland Government regulates fisheries management with the Region. The assessment and approval provisions of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) apply throughout the Region. However, its Commonwealth reserve provisions only apply in the Coral Sea Marine Park.

BOX 7.1

Reef 2050 Long-Term Sustainability Plan 2021–2025

The Reef 2050 Plan is the Australian and Queensland governments' overarching framework for protecting and managing the Great Barrier Reef by delivering coordinated local, national and global action in key areas. The Reef 2050 Plan includes 20 objectives across elements of the Reef's habitats, species, Indigenous heritage and human dimensions. These objectives guide delivery of the Plan's vision and outcome of *Healthy Reef, Healthy People.*

Collective effort is a central concept of the Plan, recognising that achieving its ambitions will depend on strong collaboration and lasting partnerships. Governments, industry, land managers, scientists, Traditional Owners and the community all have a role to play in helping to protect and sustain the Reef. The Plan provides a strategic framework for action and is intended to guide governments, key sectors and individuals on actions they can take to contribute to improving the Reef's future.

Protection and management responsibilities outside the Region

Some threats to the Region's ecosystem (natural heritage values) and heritage values (Indigenous, historic and other) arise beyond its boundaries. All levels of government (Australian, Queensland and local) have interrelated regulatory responsibilities to manage these threats, which include those associated with climate change, coastal development, and land-based runoff from the Catchment.

The Australian Government is responsible, both nationally and internationally, for environment and heritage protection of the World Heritage Area. Actions that have, or are likely to have, a significant impact on matters of national environmental significance, regardless of whether they are undertaken in or outside the Region, are regulated by the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act).

The Queensland government, through the *Planning Act 2016* (Qld) (Planning Act), *Coastal Protection and Management Act 1995* (Qld) and *Nature Conservation Act 1992* (Qld), is responsible for natural resource management and land use for Queensland protected areas, such as islands, coast and hinterland.

Partners in management

Various partners directly participate in protection and management activities within the Region and the adjacent Catchment (Table 7.1). These partnerships spread across terrestrial and marine environments and include government agencies, First Nations people — who maintain strong connections with Land and Sea Country — industry bodies and the community.

The Reef Authority is supported by two Reef Advisory Committees (Indigenous and tourism), which are sub-committees of the Marine Park Authority Board, and 12 Local Marine Advisory Committees.

Table 7.1 Partners in the management of the Region

Australian Government	The **Department of the Climate Change, Energy, Environment and Water** is responsible for negotiating and implementing multilateral environmental agreements and policies. This department implements the EPBC Act, coordinates reporting on the state of the World Heritage Area, and implements Australia's domestic climate change and energy policies and international climate change negotiations.
	The **Great Barrier Reef Marine Park Authority** is the primary agency dedicated to protection of the Region and is responsible for managing the Marine Park and contributing to reporting on the state of the World Heritage Area.
	Australian Maritime Safety Authority is responsible for maritime safety including environmental considerations and search and rescue.
	Parks Australia manages the adjacent Coral Sea Marine Park.
	The **Department of Defence** is responsible for the management of defence activities within the Region.
	The **Department of Agriculture, Forestry and Fisheries** has responsibility for biosecurity matters within Commonwealth waters.
Queensland Government	The **Department of Environment, Science and Innovation** (DESI) is the lead Queensland agency on environmental management matters in intertidal areas, Queensland internal waters and the Catchment. DESI also has powers delegated under the *Underwater Cultural Heritage Act 2018* (Cth) to protect underwater cultural heritage.
	The **Queensland Parks and Wildlife Service** is responsible for day-to-day joint field management of the Marine Parks and Islands with the Reef Authority.
	Department of Transport and Main Roads oversees management of Queensland ports.
	Maritime Safety Queensland is responsible for maritime safety within Queensland, the protection of Queensland's waterways and the people who use them.
	Department of Agriculture and Fisheries and **Queensland Boating and Fisheries Patrol** manage and enforce fisheries, biosecurity matters and transport legislation.
	Department of Energy and Climate is responsible for implementing Queensland's Climate Change and Energy policy and programs.
	Department of State Development and Infrastructure is responsible for economic development and liveable communities in Queensland.
	Department of Housing, Local Government, Planning and Public Works is responsible for homelessness policy and services, building policy, asset management and local government.
	Department of Resources is responsible for native title, land tenure and vegetation management outside protected areas.
Partners	**Traditional Owners** continue to protect cultural and heritage values, conserve biodiversity and enhance the resilience of their Land and Sea Country. They have a role in co-design, co-governance, co-management and co-delivery.
	Researchers and **research institutions** provide training, public outreach and scientific evidence to inform policy reform, improved governance and adaptive management through formal and informal channels.
	Local governments, industry groups (for example, ports and shipping), **regional natural resource management bodies, advisory committees** and the community are involved in actions to minimise impacts, address threats and improve outcomes for the Region.

7.1.2 Focus of management

Management of the Region focuses on 14 broad management topics across three areas:
Managing direct use

- Commercial marine tourism
- Defence activities
- Fishing
- Ports
- Recreation (not including fishing)
- Research activities
- Shipping
- Traditional use of marine resources

Managing external factors

- Climate change
- Coastal development
- Land-based runoff

Managing to protect the Region's values

- Biodiversity values
- Heritage values
- Community benefits of the environment

These topics form the basis of the assessment of management effectiveness. Three additional management approaches are examined:

- Environmental regulation
- Engagement
- Knowledge, integration and innovation



Fourteen topics form the basis of the management effectiveness assessment

7.1.3 Scale and complexity

The 14 management topics included in the assessment vary in scale and complexity (Table 7.2). The assessment of effectiveness for each management topic was not weighted to consider these differences in scale and complexity. Interrelationships between management topics often create cumulative impacts, which are the interaction of effects between one or more impacts and pressures over time (past, present and future). These cumulative impacts add to the challenge of managing the Region. This complexity is referred to in the risks chapter (Chapter 9) and addressed in the long-term outlook chapter (Chapter 10).



The management topics vary in scale and complexity

Table 7.2 Scale and complexity of management topics

Management topic	Scale	Complexity		
		Social	Biophysical	Jurisdictional
Managing direct use				
Commercial marine tourism	Region-wide but variable in intensity	Major	Moderate	Moderate
Defence activities	Limited in area and duration	Minor	Minor	Minor
Fishing	Region-wide but variable in intensity	Major	Major	Moderate
Ports	Concentrated around ports	Major	Moderate	Major
Recreation (not including fishing)	Region-wide but variable in intensity	Major	Moderate	Moderate
Research activities	Region-wide but limited in intensity	Minor	Moderate	Minor
Shipping	Concentrated around shipping lanes	Moderate	Moderate	Moderate
Traditional use of marine resources	Region-wide but variable in intensity	Major	Moderate	Moderate
Managing external factors				
Climate change	Region-wide	Major	Major	Major
Coastal development	Region-wide, but limited to Catchment areas and mainly inshore waters	Major	Major	Major
Land-based runoff	Catchment and mainly inshore waters	Major	Major	Major
Managing to protect the Region's values				
Biodiversity values	Region-wide	Moderate	Major	Moderate
Heritage values	Region-wide	Major	Moderate	Moderate
Community benefits of the environment	Region-wide	Major	Moderate	Minor

7.1.4 Management approaches and tools

Three main management approaches are used to protect and manage the Region's values:

Environmental regulation

Management tools such as zoning plans, regulations, management plans, permissions and licences, and compliance actions (audits, education, infringement notices and prosecutions) are used to establish and enforce the environmental standards necessary to protect and manage the Region.

Engagement

Government management agencies work with a range of partners and stakeholders to strengthen knowledge, and to ensure fit-for-purpose management and influence actions, such as stewardship, that will help improve the outlook for the Region. The partners include First Nations peoples, local government, industry, researchers and the community.

Knowledge, integration and innovation

The best available science, traditional ecological knowledge and information from Reef industries and the wider community forms the basis for effective management. This is supplemented by results from ongoing management.

Each of the approaches is explicitly assessed in Section 7.4. Many management tools are used to address a multitude of topics and each topic is addressed by a combination of tools (Table 7.3). The effectiveness of all relevant tools has been assessed for each management topic.

Three main management approaches are used to protect and manage the Region's values

Table 7.3 Management tools used to address the broad management topics

Management tools	Direct uses								External factors			Values		
	Commercial marine tourism	Defence activities	Fishing	Ports	Recreation (not including fishing)	Research activities	Shipping	Traditional use of marine resources	Climate change	Coastal development	Land-based runoff	Biodiversity values	Heritage values	Community benefits of the environment
Acts and regulations	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Zoning plans	●	●	●	●	●	●	●	●		●	●	●	●	●
Management plans	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Permits and licences	●	●	●	●	●	●	●			●	●	●	●	●
Traditional Owner agreements				●		●		●				●	●	●
Compliance actions	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Interventions										●	●	●	●	●
Site infrastructure	●		●	●	●	●	●					●	●	●
Fees and charges	●		●	●		●	●			●	●			
Policy	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Partnerships	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Stewardship and best practice	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Education and community awareness	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Research and monitoring	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Reporting	●	●	●	●	●	●	●	●	●	●	●	●	●	●

7.2 Assessing protection and management measures

To enable an independent assessment of existing measures to protect and manage the Region's ecosystem (natural heritage value) and heritage values (Indigenous, historic, and other), the Reef Authority engaged a team of external assessors through an open tender process. The assessors brought their expertise in the assessment of protected area management effectiveness, public policy and governance, and protected area management, to examine evidence for each of the 14 management topics. The full report,[11] including justification to inform grades, is summarised in Sections 7.3 to 7.5. These sections were verified by the independent assessors to ensure they are a transparent and accurate reflection of their findings.



Independent assessors examined the effectiveness of measures

7.2.1 Scope

The scope and methods used in the assessment were consistent with the Outlook Reports in 2009,[3] 2014[4] and 2019.[5] Management activities of all relevant Australian and Queensland government agencies, and other partners and stakeholders, that contribute to the protection and management of the Region were considered. As such, the scope was broader than an examination of the management responsibilities of the Reef Authority.



Actions of all relevant parties responsible for protection and management of the Region were considered

The assessment examined management activities within the Region, and in areas external to the Region, that influence the Region's ecosystem and heritage values. For external factors, such as climate change, the assessment primarily considered management activities specifically to protect and manage the Region. It also broadly considered climate change initiatives at state, national and global levels that are relevant to the values of the Region.



Management activities both inside and outside of the Region are examined

7.2.2 Assessment method

The International Union for the Conservation of Nature and Natural Resources' (IUCN) framework for assessing management effectiveness of protected areas[1966] was applied in the assessment. This framework is based on a management cycle in which management is continuously evaluated and refined (Figure 7.2).



Figure 7.2 **Framework for assessing management effectiveness of protected areas**
Effective management is a closed loop where issues are considered, plans are made, resources are expanded, processes are followed and products and services are delivered, all leading to outcomes that address the issues.[1966]

The assessment was based on the six elements of the management framework:

- Understanding context
- Planning
- Financial, staffing and information inputs
- Management systems, processes and governance
- Delivery of outputs
- Achievement of outcomes

The independent assessment addresses the six elements of the management cycle

These six elements of the IUCN framework were examined for each of the 14 management topics (Section 7.1.2). The independent assessors considered evidence, including that provided by managing agencies, against 49 indicators (Appendix 5). To determine the effectiveness for a specific management topic, ratings for the indicators within each topic were added and scaled to provide a total score. These scores were then associated with a grade ranging from effective to ineffective.

The independent assessors provided a summary of effectiveness for three broad management approaches:

- Environmental regulation
- Engagement and knowledge
- Integration and innovation

7.2.3 Information used

Information relevant to assessing performance against each of the indicators was assembled by both Australian and Queensland government agencies and provided to the independent assessors. The assessors sought extra information from relevant research papers, workshops with managing agencies, semi-structured interviews with 21 topic experts, and other source documents where appropriate. The assessment was based on available documents and advice provided before the end of October 2023. Where necessary, information was updated after October 2023 with the consent of the independent assessors, but only where new information involved a substantial change in management.

A small number of errors were detected in the 2019 assessment, the grade and trend assessment presented here is based on the corrected 2019 results.[11]



Many different sources of evidence informed the independent assessment

7.3 Assessment of existing protection and management measures

The following assessment of existing measures to protect and manage the Region's ecosystem and heritage values is a summary of an independent analysis of the 14 broad management topics by five expert assessors.[11]

Managing direct use

7.3.1 Commercial marine tourism

The commercial marine tourism industry plays a significant role in showcasing the Reef's natural and cultural values, enhancing visitor experiences and assisting in managing and protecting the Region's values. This industry's use of the Region is jointly managed by Australian and Queensland government agencies and a range of partners and stakeholders.

A comprehensive suite of management tools is in place to regulate the industry, associated activities and their impacts. Most tourism (86 per cent in 2022) occurs in three key areas (Cairns, Port Douglas and the Whitsundays) that amount to about seven per cent of the Marine Park.[1967] About 90 per cent of the Region, therefore, has low commercial marine tourism visitation and low-level related impacts, such as physical damage to reefs and island vegetation, pollution, wildlife disturbance, reduced amenity and loss of cultural values. The threats associated with commercial marine tourism (Section 5.2.3) are being reduced through improved management that incorporates zoning plans, regulations, policies, plans of management, guidelines and strategies, such as the *Tourism Management Action Strategy,*[1187] and education.



Tourists heading out from Cairns for a day of snorkelling on the Reef. © Chloe Schauble 2023

The commercial marine tourism industry is a key partner in Reef management. Stakeholder engagement[1968] in planning and governance incorporates mainly informing (for example, through targeted education and stewardship programs), consulting (for example, through Local Marine Advisory Committees) and involving (for example, through Reef Guardians and the High Standard Tourism Program). There are now more than 120 Master Reef Guides, who deliver up-to-date scientific and management information about the Reef and its values to domestic and international visitors. High Standard Tourism Operators voluntarily operate to a higher standard than is required by legislation and are independently certified and monitored. These operators ensure an ecologically sustainable and high-quality experience for visitors. The number of High Standard Tourism Operators has increased from 19 in 2004, to 69 in 2017, and 72 in 2023.

Programs such as Eye on the Reef and Master Reef Guides allow operators to build capacity within their staff while providing an assessment of the reefs they visit. The Eye on the Reef program enables anyone who visits the Reef to collect information about reef health, marine animals and incidents. The program has seen increases in the number of reef health surveys conducted by tourism staff and by visitors (through a product offered on trips) and received by the Reef Authority. Additionally, some commercial marine tourism operators undertake in-water actions such as reef restoration, crown-of-thorns starfish and *Drupella* control, sightings, compliance reports and the presentation of World Heritage values to domestic and international visitors. These partnerships offer opportunities for interactions that build understanding of the Reef's values.

Commercial marine tourism was heavily impacted during the COVID-19 pandemic as the industry experienced a decrease in visitor numbers, shortages in skilled staff and increased operational costs. Annual visitation decreased about 41 per cent from the average of the previous seven years, and although numbers are increasing (47 per cent from 2020 to 2022), it is expected to take several years before a return to pre-pandemic numbers. As a result, the Australian Government contributed significant funds to support the industry through the Tourism Industry Activation and Reef Protection Initiative (2021–2023). The subsequent Tourism Reef Protection Initiative builds on existing programs to engage marine tourism operators to June 2024, with 26 operators selected

to deliver these services. In 2023, the industry continues to experience difficulties in attracting, training and retaining staff, due to issues such as a shortage of available housing for staff.



Tourism operators generally maintain high standards across the Region. © Matt Curnock 2021

Outputs relating to the commercial marine tourism industry are largely on track and will help to improve some Reef values. The complex joint management arrangements between the Reef Authority and Queensland Parks and Wildlife Service, are working relatively well but could be improved through streamlining, alignment and updating of policies.

A gap within the industry is the limited number of Indigenous Reef tourism operators and their lack of visibility.[1969] There are challenges in ensuring effective consultation, engagement and benefit sharing arrangements with Traditional Owner groups, especially within Traditional Use of Marine Resources Agreement areas and where there are Native Title determinations; ensuring effective incorporation of Indigenous heritage values in tourism offerings, as appropriate; and developing a strong Indigenous tourism advocacy organisation to promote and market Indigenous tourism on the Reef. Dated policies that require reviewing to ensure they meet future needs, developing shared skill sets among relevant partners and effective consultation, engagement and benefit sharing arrangements with Traditional Owner groups are additional ongoing challenges.

The Reef Authority *Tourism Management Action Strategy* (Tourism Strategy) was introduced in 2021 and aims to deliver sustainable tourism outcomes. It includes actions to address some of the gaps identified above.[1187] The Tourism Strategy will guide the review, simplification, deregulation and rationalisation of tourism policies and other management tools under the *Policy and Planning Strategic Roadmap*. Its implementation is ongoing and should provide opportunities for improved infrastructure, processes to support tourist numbers and behaviours, and governance arrangements, including effective consultation with Traditional Owners.

Outcomes are difficult to determine, particularly in relation to the economic sustainability of the commercial marine tourism industry into the future. This will depend on international competitiveness, the level of market demand and the availability of well-

trained staff. All of which are contingent on a healthy and sustainable Reef environment — something that is under threat from multiple and cumulative impacts.

Well-resourced planning and management systems are in place to support sustainable tourism outcomes

Overall, the impact of the commercial marine tourism industry on the Reef is restricted in extent, low in severity and there are well-resourced planning and management systems in place to support sustainable tourism outcomes. The threat of climate change, however, represents the main threat to the industry as it will likely impact the quality of the nature-based Reef experience, enjoyment of visitors, visitor numbers and the social and economic sustainability of the industry.

7.3.2 Defence activities

Activities undertaken by the Australian Department of Defence in the Region continue to be managed effectively, reflecting the maturity of the Defence management system and relationship between Defence and the Reef Authority.

The Department of Defence manages defence activities in the Region with input from other government agencies. For major exercises involving allied forces, such as Talisman Sabre, they collaborate with agencies including the Reef Authority, the Queensland Department of Environment, Science and Innovation (through the Queensland Parks and Wildlife Service) and the Australian Department of Climate Change Energy, the Environment and Water. Traditional Owners and Indigenous Land Use Agreement holders, as well as regional communities for Training Areas such as the Shoalwater Bay Training Area, are also consulted. Defence also oversees areas such as Shoalwater Bay, Cowley Beach and Halifax Training Areas, and HMAS Cairns that are partly within the boundaries of the Region, as well as the Townsville Field Training Area, RAAF Townsville, and the Ross Island and Lavarack Barracks, which are adjacent to the Region.

The *Strategic Environmental Assessment of Defence Activities in the Great Barrier Reef World Heritage Area* (Strategic Environmental Assessment) provides contextual understanding of the environmental risk of defence activities in the Region.[1970] The ongoing management of environmental risks at Defence sites is carried out using an internal planning and management system. This system is mature and includes both a nationwide management framework and domain-specific environmental management plans together with site- and activity-specific instruments. In accordance with the strategic environmental assessment, environmental risks of defence activities in the Region are managed through this national-scale system. There is a Region-specific *Great Barrier Reef and Coral Sea Planning Handbook* to complement the suite of tools. The management effectiveness grade for planning has decreased, reflecting the uncertainty around implementation of recommendations to improve stakeholder engagement that were identified in a 2014 evaluation.[1971]

Defence activities are self-regulated albeit subject to environmental commitments under the EPBC Act and other legislation. Department of Defence continues to demonstrate a strong commitment to this self-regulation and adopts best-practice standards. Resourcing and in-house expertise are adequate within Defence to address requirements of environmental management. Defence also has a Memorandum of Understanding with the Reef Authority that provides the managers of the Reef an advisory role to decisions on activities within the Region, bringing an additional level of oversight. In 2023, the memorandum was being updated to include a commitment to revisiting the current strategic environmental assessment, which will provide updated planning considerations

for the Region. The management effectiveness grade for inputs has decreased and this is attributed to a recognition of knowledge gaps around offshore Indigenous heritage information available to decision-making.



Director Enabling Support Ms Jessica Wood and Senior Environmental Officer Colonel Mick Goodyer from Headquarters Joint Operations Command, monitor an amphibious beach landing in Bowen, Queensland, during Exercise Talisman Sabre 2021. © Department of Defence 2021

Defence uses a range of measures, such as Environmental Assessment Reports, Standing Orders and management plans, to manage environmental impacts associated with day-to-day activities within Training Areas. Gaps remain, however, in the understanding of the effects of cumulative impacts in Training Areas and relationships to processes offsite. Delivery of outputs under the planning and management system is high as a result of strong delivery focus within Defence and strong resourcing. Outputs include the ongoing development of reports, such as Environmental Assessment Reports and Environmental Clearance Certificates, monitoring of training areas and the delivery of the PFAS (per- and poly-fluoroalkyl substances) Investigation and Management program. Within the catchment, specific PFAS Management Area Plans have been developed for each confirmed site, informed by human health and ecological risk assessments. Subsequently, Defence achieves effective outcomes within the scope of its activities within the Region, reflecting the more limited spatial scope of defence activities across the Region and the strong level of control Defence has over impacting activities.

Activities undertaken by the Department of Defence continue to be managed effectively

Historical contamination (PFAS and unexploded ordnance) remains a priority for the Department of Defence across Training Areas and other sites. Challenges for Defence remain in comprehensively addressing such legacy issues, especially for unexploded ordnance, and ensuring self-regulation and the adoption of best-practice standards remain relevant to and appropriate for the Region.

7.3.3 Fishing

Fishing, both recreationally and commercially, is the main extractive use that occurs in the Region and is jointly managed by Australian and Queensland governments. Viable commercial and recreational fishing depends on a healthy ecosystem.

The main management tool for commercial and recreational fishing is the *Fisheries Act 1994* (Qld) (Fisheries Act) and associated fisheries regulations. Commercial fisheries are regulated primarily through a combination of licences and associated quota allocations, management plans and strategies, as well as zoning and permits for harvest fishers (Box 7.2). The setting of quotas and rules on fishing activities is informed by a range of fishery and species-based assessments, including ecological risk assessments, stock assessments and harvest strategies. Additionally, for fisheries involved with overseas export of product, assessments are required under the EPBC Act. Controls for commercial fisheries are both: inputs based, aiming to control fishing effort, gear and location, together with reporting requirements; and output based, with many fisheries having individual transferrable quotas for species or prescribed commercial catch limits. Recreational fisheries are managed spatially through the *Great Barrier Reef Marine Park Zoning Plan 2003* (Zoning Plan)[1183] and regulated through output controls such as bag and size limits and restrictions on the types and number of fishing apparatus used. Commercial fisheries are differentiated based on their equipment and or target species. These controls are also informed through fishery or species-based assessments.

The Australian and Queensland governments have interrelated roles and responsibilities and managers across relevant agencies have a good understanding of values, impacts and threats to the Region related to fishing. The Queensland Department of Agriculture and Fisheries focuses on sustainable catch loads, the Reef Authority focuses on direct-use impacts to the Reef ecosystem, and the Department of Climate Change, Energy, the Environment and Water focuses on protected species and the environmental performance of fisheries. Each agency's focus reduces potential overlap between agencies and jurisdictions. However, it creates potential inconsistencies in the management of fishing activities where there are 3 different regulatory interests.



Significant reform is being implemented through the *Queensland Sustainable Fisheries Strategy*

Significant management reform for fishing is being implemented through the *Queensland Sustainable Fisheries Strategy 2017–2027*[1251] (the Fisheries Strategy), which aims to significantly improve fisheries management. The focus is on improved assessment of fish stocks and ecological risks to inform adaptive management of quotas and rules, and a commitment to achieving 60 per cent biomass retention for each fishery by 2027. Stock assessments, harvest strategies and ecological risk assessments are now in place for most fisheries in Queensland (Box 5.2). Additionally, funding for management of fishing has increased and has supported assessments and compliance.

Through fishery working groups, the Fisheries Strategy has also provided renewed forums for stakeholder engagement. However, there are lags in the achievement of the outcomes, reflecting biological timeframes for recovery of fish stocks. The Queensland Boating and Fisheries Patrol and the Reef Joint Field Management Program carry out a comprehensive compliance program. This program has strengthened and increased in maturity in the direct management of fishing in the Region. Vessel tracking systems have been mandatory on commercial vessels since 2020 and have improved enforcement management. This reduces the risk of non-compliance associated with commercial fishing in no-take areas within the Marine Park. Recreational fishing in these protected zones continues

to be a common offence in the Marine Park but is being addressed through enhanced compliance action by the Reef Joint Field Management Program.

Outcomes for fishing remain only partially effective in 2023

Despite the high levels of investment in fisheries, outcomes for fishing remain only partially effective. In part, this reflects the biological timeframes needed for recovery of fish stocks and consequential lag time for achievement of outcomes under the Fisheries Strategy. Additionally, in implementing the Fisheries Strategy, understanding of risks associated with fishing activities in the Region has increased including greater knowledge of the status of some fish stocks. For example, 2021 stock assessments identified the Spanish mackerel as severely depleted when previously it had been identified as sustainable (Section 5.4.1). The timeline of the Fisheries Strategy is 2017 to 2027, with overall achievement of its outcomes intended to continue over coming years.

Gaps remain in the understanding of potential impacts of climate change on the distribution of targeted fish species. There are also broader knowledge gaps related to day-to-day interactions of fisheries with bycatch and non-target species, some marine habitats and ecological processes, although this has improved with increased use of ecological risk assessments.

BOX 7.2

Benefits of Partially Protected Zones in the Great Barrier Reef Marine Park

In 2004, the Great Barrier Reef Marine Park was rezoned to increase protection of values within the Region.[1183] The *Great Barrier Reef Marine Park Zoning Plan 2003* divided the Marine Park into areas ranging in their level of protection, from allowing ecologically sustainable use and extraction, to high levels of protection such as no-take zones where extractive activities are not allowed and no-entry zones where even visitation is not allowed. No-take and no-entry zones account for 33 per cent of the Marine Park and are generally free from extractive activities such as fishing.[1183] The ecological benefits of no-take and no-entry zones have been extensively documented.[1948,1972] They include higher biomass of fish species and enhanced resilience of coral reef communities to disturbances such as coral bleaching and outbreaks of crown-of-thorns starfish inside no-take zones, compared to zones open to fishing.[1973,1974]

Conservation Park Zones account for 1.5 per cent of the total area of the Marine Park. These zones are considered Partially Protected Areas because limited extractive use such as limited line fishing and spearfishing are often allowed.[1183] While Conservation Park Zones are a recognised marine resource management tool, comparatively little is known about their effectiveness compared to no-take Marine National Park Zones.[1975] Recent studies have demonstrated that Partially Protected Areas can provide an added layer of protection for targeted coral reef fishes and support greater biomass of targeted fishes compared to less regulated Habitat Protection Zones.[836,1975] Special Management Areas that overlay Conservation Park Zones and prohibit spearfishing can provide similar levels of protection as Marine National Park Zones, by protecting fishing stocks.[1976] Therefore, Partially Protected Areas are a useful spatial management tool for the conservation of target fish species while also providing opportunities for reasonable use and enjoyment of the Marine Park.

Challenges remain regarding the need for improved understanding of impacts on and protection of species of conservation concern. The introduction of independent data validation on commercial vessels will help to address these challenges (Box 5.3). Under the Reef 2050 Plan,[2] there is a suite of actions to trial, develop and implement robust systems of independent data validation in high-risk commercial fisheries. These actions include independent verification of levels of interaction with species of conservation concern. The actions are in the early stages of implementation, including trialling of technology, with full implementation expected before 2029. Furthermore, the protection of these and other non-target species will also be supported through the implementation of actions associated with the Reef gillnet fishing phase out occurring from 2023 to 2027.

7.3.4 Ports

The ports management topic encompasses all aspects of the development, operation and maintenance of ports, with the exception of shipping and ship movements. There are 12 ports within or adjacent to the Reef that affect the Region's ecosystem and heritage values (Section 5.7).

Management of ports is primarily led by individual port authorities that are Queensland Government-owned corporations, with oversight by the Queensland Department of Transport and Main Roads. The management and planning arrangements for ports cross a range of key management issues, consisting of: master plans (for priority ports) and land use plans; long-term maintenance dredging management plans and associated frameworks; *Queensland Coastal Contingency Action Plan*;[1977] port procedures; marine biosecurity arrangements (including ballast water exchange requirements); and permit requirements associated with specific activities.

Within individual port areas, port authorities are responsible for the management of vessel loading/unloading and movements and the development and maintenance of port infrastructure, including dredging and placement of dredged material. These activities carry with them a range of environmental risks associated with threats such as marine pollution and debris, light pollution, underwater noise and vibration, habitat loss, water quality changes. General biosecurity obligations, including the risk management of marine pest introduction to coastal waters, is carried out by the Queensland Department of Agriculture and Fisheries.



Port authorities provide a high degree of environmental management

Port authorities are typically well resourced and provide a high degree of environmental management and monitoring effort within their areas. There is also a good working relationship between port authorities and key regulators. These include the Queensland Department of Transport and Main Roads, which has a leading role in benchmarking port planning and dredging management, and the Reef Authority, which has an interest in dredging and placement activities that occur in the Marine Park. While the Reef Authority often does not have direct jurisdiction within most port areas, as most are excluded from the Marine Park, ongoing engagement has been formalised through a Memorandum of Understanding with the Queensland Ports Association and the membership of the Reef Authority on various port technical advisory and consultative committees.

Port authorities and agencies continue to implement the significant reforms that occurred from 2014 under the *Maintenance Dredging Strategy for Great Barrier Reef World Heritage Area Ports,*[1408] *Sustainable Ports Development Act 2015* (Qld) and *Dredging and*

Dredge Spoil Material Disposal Policy.[1413] These reforms are embedded into the planning process for ports and have led to improvements in management inputs and outputs. Since 2019, management and planning frameworks for dredging, at sea placement and port development are mostly implemented as standard practice and align with international best practice.

The control of marine pests being introduced to Australia is managed primarily through the use of ballast water controls and vessel inspections and is well developed. However, since 2019, there is enhanced recognition of risks associated with marine biosecurity within ports, such as marine pests already established in coastal waters, as well as underwater noise. This has prompted policy development in these areas, but this is ongoing. Formal engagement and support to local waterway partnerships to improve the holistic management of catchment-related issues, including sediment contribution into port areas, has also commenced.

Challenges for ports over the coming years include addressing concerns for marine pests and underwater noise, implementing management actions in relation to vessel strikes, together with managing potential jurisdictional conflicts associated with multiple levels of permitting for maritime developments.

7.3.5 Recreation (not including fishing)

Recreation is defined as an independent visit for enjoyment that is not part of a commercial operation [1368] and includes both local and international tourists. Responsibility for management of recreational use is spread across numerous Australian and Queensland government agencies, including the Reef Authority, Queensland Parks and Wildlife Service, Maritime Safety Queensland, and Queensland Boating and Fishing Patrol (Department of Agriculture and Fishing).

Recreation is managed through the *Recreation Management Strategy for the Great Barrier Reef Marine Park* (the Recreation Management Strategy).[1368] It is nested under a suite of management tools including the Marine Park Act, regulations, zoning plan and plans of management. Specific plans of management have been developed for areas of high recreational use (the Whitsundays, Hinchinbrook and Cairns) and a new plan of management for the southern section of the Reef is being developed. As of 2022, to decrease the risk to the ecosystem, 59 per cent of no-anchoring areas within the Marine Park were legislated (enforceable under law).

Recreation is generally considered well managed and poses low risk to the Reef.[5,1978] However, a critical gap remains in systematic monitoring to understand and manage for the changing nature and scale of recreational use in the Region. Since 2019, several projects have been established to develop monitoring frameworks and may provide information on human dimensions of the Reef,[1399] including recreation. These include mapping patterns of vessel activity and establishing monitoring frameworks for sustainable use and benefits of the Reef, stewardship efforts on the Reef, and governance of the Reef. An extended System of *Environmental Economic Accounting — Ecosystem Accounting* framework is newly available to help Reef managers to understand ecosystem services and benefits, including as relevant to recreational use.[1323]



It is important to understand changing patterns in recreational use

Funding is currently dedicated to developing these frameworks and testing the methods, though long-term investment in is not secured so their ongoing implementation and data collection is uncertain. If implemented and funded, these projects may fill a critical monitoring gap and help managers monitor, understand, identify and respond to changes in recreational use, for instance, in types of use, spatial patterns, user motivations, infrastructure developments.



Marine Parks vessel in the Region amongst other users. © Commonwealth of Australia (Reef Authority), photographer: Johnny Gaskell 2021

Financial input into management of recreation has increased since 2019. Funding is targeted at filling knowledge gaps and on the expansion, maintenance and evaluation of public moorings, including assessing their effectiveness in reef protection and preventing anchor damage. A whole-of-program increase has recently occurred within the Reef Joint Field Management Program, with significant investment towards compliance activities. Stakeholder engagement remains strong with Reef Authority and Queensland Parks and Wildlife Service staff in regional offices engaging with recreational users, particularly through Local Marine Advisory Committees and engagement with the Reef Guardian programs.

Despite the lack of systematic monitoring, recreational use of the Reef is understood to have grown and is projected to continue to change (Section 5.5.1). As such, regular reviews of management plans, such as the Recreation Management Strategy[1368] and plans of management, are necessary to ensure they remain fit-for-purpose and commensurate to potential changing risks.

7.3.6 Research activities

This evaluation of effectiveness of management focuses on the direct management of research activities that occur within the Region. Alignment of research into decision-making and management agency interactions with research providers are also considered, but to a lesser extent.

Research conducted on the Reef is a source of ongoing knowledge upon which to base future management policies and decisions. Most research activities occur at the four major research stations on Lizard, Orpheus, One Tree and Heron islands.

Researchers who undertake research in the Region, such as collection of specimens, *in situ* experiments and installation of research equipment, require permits and licences from managing agencies. The Reef Authority, Queensland Parks and Wildlife Service and Queensland Department of Agriculture and Fisheries have lead roles in managing research activities. These activities are managed through zoning plans, legislation, policy and the marine parks permissions system. Joint accreditation of research institutions by the Reef Authority and Queensland Parks and Wildlife Service enables low-risk research to occur in some locations without the need for specific permits.[5]

The role of citizen science has increased in intensity over this period of review. Citizen science programs are increasingly aiming to support decision-making by Reef managers. Key programs to help facilitate this include Eye on the Reef and The Great Reef Census. One notable use of data from citizen science programs is in the Crown-of-thorns Starfish Control Program which uses data to inform culling efforts.



An initial trial of prototype cloud brightening equipment, near Broadhurst Reef, Reef Restoration and Adaptation Program © Commonwealth of Australia (Reef Authority) 2021. Photographer: Rohana Rogan-Darvill

Most impacts associated with research are understood and are considered low risk and well managed. The Reef Authority, in partnership with the Queensland Department of Environment, Science and Innovation, has been actively adapting the planning system for research in response to the emerging field of intervention and adaptation research.

In 2020, the managing agencies published a policy on Great Barrier Reef interventions (Box 7.3). This is a vital first step in planning for and managing research efforts into novel intervention and adaptation approaches, such as those being conducted by the Reef Restoration and Adaptation Program. These interventions vary in their associated risk. In 2023, research on interventions was largely focused on initial small-scale trials with low complexity. The objective of these programs is to develop a suite of interventions that will build the resilience of the Reef. To accomplish this goal, the interventions will grow in size and complexity with early efforts to manage risk effectively becoming increasingly important. While key biophysical information gaps remain in relation to feasibility, potential impacts and anticipated future benefits of some of these interventions, the policy represents a positive step toward managing research efforts in the face of future uncertainty. The policy is complemented by guidelines that address the emergence of research into interventions on the Reef.

BOX 7.3

Managing rehabilitation and adaptation interventions in the Region

Mitigating human-induced climate change through effective global emissions reduction is the most urgent and critical need for the Reef's future, but there is a growing need for active and targeted interventions to support the resilience of the Reef's ecosystems in the face of current and future threats.[2,1387,1397] Existing management and interventions, such as Marine Park zoning, permissions system, compliance, crown-of-thorns starfish control, and fisheries and catchment management, remain critical to supporting the health of the Reef but these alone may no longer be sufficient.[1387]

In 2020, the Reef Authority and Queensland Department of Environment, Science and Innovation implemented the *Policy on Great Barrier Reef Interventions* (Intervention Policy). This policy supports the research and development of novel innovations that could directly support ecosystem recovery to build resilience and achieve conservation benefits. The Intervention Policy seeks to provide adaptive, robust and enabling decision-making guidance for the development, testing and implementation of a suite of interventions. The methods proposed for the Reef vary in their associated ecosystem, social, cultural and economic risks. Some of the interventions are novel within the marine environment and are associated with varying degrees of scientific uncertainty. To mitigate the risks, small-scale *in situ* pilot trials are encouraged to understand which methods might be feasible, cost-effective at large scale and lead to the greatest conservation benefits.

Interventions can pose a complex decision-making landscape where Reef managers must consider current risks associated with applied research and development trials, the potential conservation benefits for the future, and the risks of inaction. Decisions must include assessment balancing the enabling of innovation while minimising risks from failures in this emerging area of science, technology and governance.

In some cases, independent groups can support intervention research programs to identify and assess risks, such as the Reef Restoration and Adaptation Program's Intervention Risk Review Group. This is an independent, interdisciplinary expert group established to consider matters related to, and provide guidance and advice on, the assessment and management of intervention risk for the Reef Restoration and Adaptation Program activities.

Research is generally not considered to have a large or detrimental impact on the Reef ecosystem. However, there is a lack of understanding regarding the cumulative impacts of research activities. Specifically, there is limited understanding of cumulative impacts in relation to extractive research efforts. There is the potential for risk of lasting harm from the cumulative impact of research on reefs surrounding the four major research stations where most research takes place. While recognising the knowledge gap, some researchers suggest that damage to these reefs is likely to be outweighed by benefits from the outcomes of the research.



A knowledge gap exists around cumulative impacts of research

Permitting for research in the Marine Park has also seen some notable improvements since 2019. Through streamlining permits and improvements to the Reef Management System and Permits Online system researchers and education programs can now submit their permit activity reports (such as take of specimens, equipment installation) through an online database that is searchable by the Reef Authority. Uncertainty remains about the adequacy of current Marine Park permission systems in keeping pace with novel intervention and adaptation approaches. Additionally, there is a need for greater baseline information to inform permitting and research decisions, including on cumulative impacts.



Stereo photogrammetry survey by reef tourism industry collaborating with Reef Restoration and Adaptation Program scientists at Moore Reef. © Matt Curnock 2023

Applied research and monitoring is key to assessing and advising on the condition (and trend in condition) of the values and threats arising from broader environmental and anthropogenic stressors. Numerous science strategies, research partnerships and funding streams are in place to support and influence research priorities so that outcomes can be applied to and integrated into management. While the Reef Authority and Queensland government agencies are not primarily research organisations, they have sound working relationships with the scientific community. Examples include memorandums of understanding with universities and relationships with science organisations, such as CSIRO and the Australian Institute of Marine Science, and museums, such as the Australian Museum which operates the Lizard Island Research Station. These relationships allow managing agencies to help focus research on key management issues for the Region and to better distribute findings via cross-organisation training and meetings. Where possible, these relationships also help facilitate review of research management practices to minimise any adverse impacts of research activities. The development of the Data Management System for the Reef 2050 Monitoring and Reporting Program is intended to harvest data from multiple sources to form a common ‘data lake’ with managed access. This system is designed to facilitate easier access for managers to Reef research outputs with a focus on monitoring and modelling.

7.3.7 Shipping

Shipping relates to the movement of commercial vessels within the Region. It includes travel to, from, and between the Region's ports and transiting shipping channels, but not activities associated with ship movements within port areas (Section 7.3.4). A ship is a vessel greater than 50 metres in length. Commercial ships sailing within the Region include bulk carriers, container carriers, vehicle carriers, general cargo ships, tankers, cruise ships and larger superyachts.

Shipping is well regulated and effectively managed

Shipping is well regulated and effectively managed, reflecting the maturity of the planning system. A major focus of shipping controls is on the reduction of the potential for incidents and the rapid response on those that do occur to reduce their impact. Shipping generally is well regulated in the Region, with a governing framework established under the *North-East Shipping Management Plan*[1979] and pollution response framework under the *Queensland Coastal Contingency Action Plan.*[1977] The use of Marine Orders provides day-to-day measures to support management and allow for rapid adoption of arrangements from international levels, such as the International Maritime Organization's Convention for Safety of Life at Sea, or to respond to particular emerging areas.

Vessels use several major shipping routes through the Region. The entire Region is part of the Great Barrier Reef and Torres Strait Vessel Traffic Service (Reef VTS) and subject to a range of pilotage requirements. Under the *North-East Shipping Management Plan*, there is a strong working relationship between the Australian Maritime Safety Authority, Maritime Safety Queensland and the Reef Authority, with support from port authorities.[1979] The plan provides an effective framework that is periodically reviewed to reprioritise management actions for continuous improvement in the sector. A key change since 2019 is the use of exhaust gas cleaning systems to reduce sulphur fuel emissions as part of a transition towards lower emissions in international shipping. These scrubbers require discharge of sulphur compounds into the marine environment. Although assessments have been undertaken on the risks of these discharges, they were not specific to the context of the Reef (Section 5.8.3) and the sensitivities of and impacts on Reef habitats remain unknown.



Ship being towed into port. © Commonwealth of Australia (Reef Authority)

Various shipping incidents occurred during the reporting period. However, these primarily related to factors outside of the control of managing agencies, for instance, loss of propulsion or crewing conditions, and responses have been effective in mitigating risk. Where incidents result in marine pollution, resourcing and coordination of the response is well established within the Australian Maritime Safety Authority and Maritime Safety Queensland. This includes arrangements under the *Queensland Coastal Contingency Action Plan.*[1977]

Challenges remain for management of shipping in relation to recognised gaps in the understanding of, and response to, vessel strike and underwater noise risks in shipping areas. The ongoing implementation of actions associated with the *National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna*[1980] has not yet been integrated into planning and management arrangements. Similarly, policy development for underwater noise is underway but not yet implemented.

Since the introduction of Reef VTS, there has been a significant reduction in ship groundings and vessel incidents and low levels of environmental impacts across shipping channels. Outcomes for shipping remain effective, but challenges remain in ensuring secure funding for effective habitat remediation efforts following an incident.

7.3.8 Traditional use of marine resources

The traditional use of marine resources (traditional use) is undertaken by First Nations peoples, who are the Traditional Owners and Custodians of the Reef and its Catchment. As recognised in the *Native Title Act 1993* (Cth), they hold inherent rights, interests and obligations to protect and care for their Country as they have done for longer than 60,000 years (Chapter 4). More than 70 Traditional Owner groups have knowledge and connection to the Reef and practice traditional activities that include fishing, collecting, hunting or harvesting, and looking after cultural and heritage places.[1981]



Partnerships with Traditional Owners are key to protecting and managing Country. © Queensland Government 2022

One of the most effective formal approaches in managing traditional use is the establishment of Traditional Use of Marine Resources Agreements. These are statutory agreements under the *Great Barrier Reef Marine Park Regulations 2019* (Cth) and are

recognised in the *Great Barrier Reef Marine Park Zoning Plan 2003* (Cth). They are a unique partnership agreement that recognises and supports the native title rights and interests of the Traditional Owner groups, who hold an inherent spiritual connection to the Reef. Agreements such as the Traditional Use of Marine Resources Agreements and Indigenous Land Use Agreements promote sustainable use of key species and ecosystems by incorporating cultural lore and contemporary science. Groups may self-manage and impose restrictions on take of certain species, such as dugongs and green turtles, through the agreements. The agreements also provide mechanisms and support for other activities conducted by Traditional Owner groups, including monitoring, education, as well as community and compliance activities within their Sea Country.



Traditional Use of Marine Resources Agreements have assisted the management of Sea Country

Ten Traditional Use of Marine Resources Agreements and one Indigenous Land Use Agreement are currently in place, covering 46 per cent of the Region's coastline (an increase from 25 per cent in 2019). Another Indigenous Land Use Agreement lies offshore from the mainland coast. The Reef Authority has commenced new partnerships to develop four new Traditional Owner-led agreements and a new Plan of Management for the Southern region of the Marine Park is being co-designed with four Traditional Owner groups.

The Reef planning system [11] is trying to better understand Indigenous knowledges, processes and institutions and to make better connections with state-based planning. However, Indigenous knowledge systems have not yet been effectively incorporated into decision-making.[1982] Numerous plans and strategies identify actions to keep Indigenous heritage, including traditional use, strong, safe and healthy such as the *Aboriginal and Torres Strait Islander Heritage Strategy*. The planning and governance systems for the Reef [11] are closely intertwined in addressing traditional use. The *Reef 2050 Traditional Owner Implementation Plan*[1120] (Box 10.2) provides support to better understand and agree on a range of governance concepts, including co-management, co-governance and clarification of Traditional Owner rights and interests.



Indigenous knowledge systems are yet to be effectively incorporated into decision-making

Engagement of Traditional Owners on matters relating to managing traditional use is typically through informing, consulting and involving. Traditional Owners are informed through targeted education and stewardship programs. Consultation, such as providing input into plans and policies, occurs primarily through forums such as the Reef Authority's Indigenous Reef Advisory Committee and Marine Park Board, the Reef Advisory Committee for the Reef 2050 Plan, and Local Marine Advisory Committees. Engagement also involves Indigenous rangers and other Traditional Owners working with their own and wider communities to address traditional use and to form and maintain partnerships.

Improvements in the governance system and engagement are being made to better focus on engagement through collaboration and empowerment. The *Gurra Gurra Framework 2020–2026*[1182] supports the Queensland Department of Environment, Science and Innovation to reframe relationships with Traditional Owners by placing Country and people at the centre of policy, programs and service delivery. The Framework aims to enable co-governance and co-stewardship, respect community-led decision-making processes and timeframes, and explore new ways of working through co-design and co-delivery, though progress has been limited.

Sea Country values mapping has been undertaken in some accredited marine resource agreement regions to improve understanding of the cultural values specific to Traditional Owner Sea Country. These include with Mandubarra[76] and Woppaburra[78] groups, and further mapping is underway with other Traditional Owner groups. Another benefit of the Traditional Use of Marine Resources Agreements program is the improved knowledge sharing and training. The Traditional Use of Marine Resources Agreements program's mentoring and 'buddy' system between established and developing areas has been a significant capacity builder for saltwater Traditional Owners.

Traditional Owner groups are managing their Sea Country through Indigenous ranger programs supported by the Australian and Queensland governments. These programs give the opportunity for rangers to guide on-Country management and uphold compliance across the Region. Management of the COVID-19 pandemic limited Traditional Owners' ability to access Sea Country due to limited boats and resources to conduct protection and rehabilitation activities. It also limited access to remote communities which delayed some program activities.



Indigenous rangers collecting data at Stephens Island © Mandubarra Aboriginal Land and Sea Incorporated 2024

Traditional Owners are engaged in a range of monitoring projects and report on the condition of their Sea Country. For example, the Traditional Owner Technical Working Group was formed in 2020 as part of the Reef Trust Partnership Integrated Monitoring and Reporting Program. The working group guides the implementation of the *Strong Peoples — Strong Country framework.*[1103] Certain Traditional Owner groups will develop indicators and test ways to monitor and report on condition and trend of Indigenous heritage. Based on available information, traditional use of marine resources is thought to have a minor and localised impact on the Reef's values when compared to the impacts from multiple interacting threats relating to climate change, extreme weather events, marine debris, land-based runoff and others.

Overall, the establishment of Traditional Use of Marine Resources Agreements has assisted in the management of Sea Country. This includes an improved understanding of agreement areas and enhanced management of marine resources through incorporation of traditional knowledge and practice. There are also benefits to Traditional Owners through employment and training. The Traditional Use of Marine Resources Agreements program has supported Aboriginal and Torres Strait Islander peoples to return to Country and deliver a range of field management activities.

Ongoing opportunities for Traditional Owners to access and manage Sea Country are limited due to a lack of suitable boats and limited resources to conduct protection and rehabilitation activities. There are also differences in capacity between areas that have agreements in place and those that do not, which has implications for passing on traditional knowledges, practices and culture and accessing Country.

Future challenges for management of traditional use of marine resources include: developing Indigenous-led plans and customary management approaches and policies to address customary use of biological resources; developing access and benefit sharing arrangements aligned with local customary laws or lores, capacity and management aspirations; strengthening available tools; enhancing equity, in particular the engagement of women in decision-making; and, enhancing regional governance models that include Traditional Owners.

The focus on partnering with Traditional Owners requires a commitment by the managing agencies to training that facilitates greater trust with Traditional Owners and enhances their governance capacities. Resourcing to improve linkages among Traditional Use of Marine Resources Agreements groups and with other structures and decision-making groups will enhance capacity but remains a challenge. The facilitation of further well-designed collaborative agreements requires retention of adequate staff with appropriate skill sets within the Reef Authority. This is currently affected by broader market demands in employment of staff with specialised skills.

Managing external factors

7.3.9 Climate change

Climate change is considered the greatest threat to the values of the Region,[5] and the ecological impacts of climate change are expected to have cascading social and economic consequences. Urgent global action is critical to deliver on international commitments to limit temperatures to 1.5 degrees Celsius of warming, or as close as possible, to minimise impacts to the Reef.[1097,1100] Management and policy responses related to climate change fall into two broad categories: mitigation and adaptation. Mitigation policies aim to limit the extend of global warming and climate change. Adaptation policies aim to assist existing ecosystems and communities to adjust to the expected regional and local impacts of climate change.



Rooftop solar panels. © Nick O'Carroll 2024

The effectiveness of global actions to mitigate climate change will be the primary determinant to climate impacts on the Reef. Abating the deterioration of the Reef's ecosystem and heritage values demands significant global action to reduce greenhouse gas emissions to limit future global warming and associated changes to the global climate and regional weather patterns. The Paris Agreement, under the United Nations Framework Convention on Climate Change, provides the international framework under which actions to mitigate global climate change impacts are occurring. The Paris Agreement sets an ambitious target to keep global temperature increase to well below 2 degrees Celsius and pursue efforts to keep warming below 1.5 degrees Celsius above pre-industrial levels.

The Australian Government has the primary responsibility for addressing climate change mitigation, nationally. In 2022, Australia submitted an updated Nationally Determined Contribution with increased emission reduction targets for 2030 of 43 per cent below 2005 levels, and a target of net zero by 2050. This represents a 15 per cent increase on its previous 2030 target. These targets are now enshrined in legislation following the *Climate Change Act 2022* (Cth), which operates as 'umbrella' legislation to implement Australia's net-zero commitments and codifies Australia's net 2030 and 2050 greenhouse gas emissions reductions targets under the Paris Agreement. Under the *Queensland Climate Action Plan*, the Queensland Government set a 50 per cent renewable energy target by 2030, a 30 per cent emission reduction below 2005 levels by 2035, increasing to a 75 per cent emission reduction below 2005 levels by 2030 and net zero emissions by 2050. In April 2024, the *Clean Economy Jobs Act 2024* (Qld) was passed to legislate these emissions reduction targets.

Emissions reductions targets are now enshrined in the *Climate Change Act 2022* (Cth) and the *Clean Economy Jobs Act 2024* (Qld)

Under the Paris Agreement, countries are not required to measure, report and commit to reducing greenhouse gas emissions that occur outside their own borders (for example, excludes the overseas use of fossil fuels exported from Australia). In 2022, overseas emissions that originated from the use of Australian exported coal and gas were estimated to be more than double the amount generated by the Australian economy.[1983] Detailed analysis of this aspect of global climate policy was not in scope for the management effectiveness assessment.

Australia is leading the International Partnership for Blue Carbon, which is an initiative that seeks to protect, sustainably manage and restore global coastal blue carbon ecosystems and this contributes to climate change mitigation.

The Reef *Authority's Position Statement on Climate Change* (2024) [1100] clearly states that climate change is the greatest threat to the Reef, and only the strongest and fastest global action to decrease greenhouse gas emissions will reduce the risks and limit impacts to the Reef. The Reef Authority has limited jurisdictional responsibility for directly addressing the drivers of climate change, such as the mitigation of global greenhouse gas emissions. Even with strong global action to reduce emissions, the impacts of climate will continue to increase over coming decades due to past emissions.

Considerable efforts are being made under the Reef 2050 Plan to reduce the impacts of other pressures to help reefs cope with or recover from disturbances due to the impacts of climate. The updated Reef 2050 Plan introduced a work area dedicated to addressing climate change with specific goals and strategic actions outlined for climate change mitigation, emissions reductions and climate change adaptation.

The *Great Barrier Reef Blueprint for Resilience* (2018)[1387] had a key initiative titled 'Accelerating actions to address global climate change', that aimed to see the Reef and coral reefs globally as a focus of policy discourse, with programs to reduce carbon emissions, and with Reef communities and industries demonstrating leadership in emission reduction efforts and climate change adaptation. A complementary initiative was 'Fostering partnerships for local action and innovation', which aimed to see individuals, industries and communities who are aware of the challenges facing the Reef, participate in efforts to protect it, and inspire intergenerational change. This is evident within the Reef Guardian Councils through their operations and engagement with the community. In early 2024, the *Reef Blueprint 2030 — Great Barrier Reef Blueprint for Climate Resilience and Adaptation* (Reef Blueprint 2030) was published with updated strategic goals that aim to drive how the Reef Authority adapts its management under a changing climate.[1984]

The Queensland Government recognises the threats climate change poses to the values of the Reef through the *Queensland Climate Adaptation Strategy*.[1985] As part of its climate change response, it is partnering with the Local Government Association of Queensland to work with local governments to plan for and better manage climate risks and build resilience. This helps to ensure that climate risks are considered in planning and development decisions across Queensland, and that local governments are well positioned to support climate action within their local communities.

The values of the Reef relevant to climate change are well known by managers. The Reef Authority's *Position Statement on Climate Change* (2019)[1986] includes description of the values of the Reef and the impact that climate change has on these values. However, progress in understanding the direct, indirect and cumulative impacts of climate change on the Reef has slowed considerably over the past 10 years since the cessation of the Climate Change Group within the Reef Authority. In early 2024, an updated position statement on climate change was published by the Reef Authority.[1100]



A mix of mitigation, restoration, adaptation, and resilience measures is needed

Overall, the Reef has a complex governance system that was established when there was very limited understanding of the impacts of climate change and it may not be agile enough to adapt to these rapidly evolving impacts. Committed warming due to historical emissions means that climate change mitigation alone will not be sufficient sustain coral reefs under a climate-changed future.[1987] Solutions for the Reef must involve a mix of mitigation, restoration, adaptation, and resilience measures.[1987] Other key challenges related to the management of climate change impacts on the Reef include a lack of knowledge and understanding of how climate change will impact the Reef across multiple timeframes and emission scenarios, the efficacy of marine and terrestrial interventions under high emission scenarios, and trade-offs between different interventions.

7.3.10 Coastal development

Coastal development relates to land-based physical development and land use change that occurs in catchments adjacent to the Reef. It includes management of activities undertaken within the Catchment that affect the Region. The management of ports in, and adjacent to, the Region is part of this broad topic. However, it has been considered separately in Section 7.3.4. Similarly, the management of land-based runoff is considered in Section 7.3.11.

Coastal development activities are managed within a multi-level governance system where multiple stakeholders and decision-makers converge to make decisions that

influence on-ground outcomes. The Planning Act and associated legislation aim to establish an integrated, coordinated and accountable system of land use planning, development assessment and related matters, preserving ecological sustainability as a core principle of planning in Queensland. The *Queensland State Planning Policy* provides a policy framework for planning outcomes across Queensland by requiring that state interests are delivered through local government planning schemes and regional plans that guide development in each local government area. The state development assessment provisions guide Queensland assessment of development applications that are likely to affect state interests, including consideration of coastal protection as a state interest.



Coastal development activities are managed within a multi-level governance system

Planning systems that address coastal development are well developed. However, non-statutory planning related to coastal development, such as regional natural resource planning, lack the resourcing needed to achieve their full potential. The ongoing reforms to the EPBC Act have led to a renewed focus on regional planning. The aim is to reduce cumulative impacts on threatened species and ecological communities in areas of High Environmental Value.

Lack of consistency across jurisdictions and conflicts between planning frameworks are recognised weaknesses in the current planning system in relation to coastal development. For example, conflicts between planning frameworks have affected the delivery of water quality improvement actions. Jurisdictional limits of responsibility across territories have created administrative complexity and constrained the ability for managers to address threats and manage outcomes. Poor linkages between major programs and key management agencies, for instance, the Queensland Wetland Program and the Queensland Department of Resources and Department of Regional Development, Manufacturing and Water, are also a recognised limitation of the current planning system. This has increased uncertainty in achieving effective outcomes.

The values and stakeholders relevant to coastal development are known by managers. For example, the Reef Authority Actor Network Mapping project maps existing actors within a network that connects the Reef Authority to the organisations and institutions they engage with for research and management practice. The Reef Guardian Councils' program is a collaborative stewardship arrangement between 19 coastal local governments within the Reef catchments and the Reef Authority. Its vision is, 'A local government alliance to reduce land-based impacts on the Reef through collaboration, education and targeted action'. Each of the 19 Reef Guardian Councils address coastal development through their *Reef Guardian Council Action Plans 2020–2024*. These action plans generally lack integration with the key local government statutory planning processes and instruments that govern land use and development decisions.



Integration and coordination between land- and marine-based planning is a significant challenge

Effective integration and coordination between land-based and marine-based planning matters within the planning and governance system for coastal development is a significant challenge. The lack of knowledge relating to the cumulative effects of climate change is also a significant challenge for coastal development. These challenges are both exacerbated by a disconnect between priorities and agendas among management agencies and this can constrain the integration of risk assessments into different governance domains.

7.3.11 Land-based runoff

Land-based runoff, particularly from agricultural land uses, has long been identified as a major contributor to poor ecosystem condition in the Reef.[2,4,1098,1988] With the Reef's combined catchments covering approximately 424,000 square kilometres, management of land-based runoff is highly complex and requires cooperation and integration among diverse management agencies.

Management of land-based runoff requires actors at all scales, from intergovernmental bodies and national governments to individual landowners, to engage and enact programs on their lands. Effective joint management arrangements are in place between Australian and Queensland governments through the Reef 2050 Plan, including the underlying *Reef 2050 Water Quality Improvement Plan 2017–2022,*[1825] which directly addresses improving water quality to conserve Reef ecosystems. The managing agencies, industry and the community, use the Water Quality Improvement Plan to guide their collaborative efforts to improve the quality of water flowing to the Reef.

Planning systems for land-based runoff have continued to expand since 2019. These include the introduction of the strengthened Reef Protection Regulations (Qld) and setting end-of-basin load water quality objectives (Reef Water Quality Objectives) for all Reef catchments. The Reef Protection regulations were made in close consultation with key stakeholders including the agricultural sector, industrial stakeholders, local councils, conservation groups, natural resource management (NRM) bodies, individual producers and the public. The regulations require landowners to achieve minimum standards for practices on grazing land and banana and sugarcane farms to minimise fine sediment and nutrient discharges to water that flows to the Reef. The regulations were rolled out over a five-year period based on water quality priorities and to allow agricultural industry time to adapt to the new requirements. This staged approach, while necessary, means that programs are still in their infancy and efficacy is currently hard to measure. Despite an extensive consultation process there remains a degree of dissatisfaction among the agricultural sectors. This may be because efforts focused on consultation and knowledge sharing, compared with more involved engagement efforts to collaborate with and empower farmers. Additional efforts may be worthwhile.

Despite their unpopularity,[11] these regulations are considered to provide a sophisticated and scientific approach to managing agricultural runoff and complement existing voluntary programs and market-based measures.[1989] The Reef Water Quality Objectives provide clear baselines for end of catchment levels of anthropogenic dissolved inorganic nitrogen and anthropogenic fine sediments for all the major natural resource management regions within the Catchment. However, these minimum standards are insufficient on their own to reach stated water quality targets.[1990]



Reef Protection regulations complement voluntary programs and market-based measures

Ongoing support for implemented voluntary and market-based programs is necessary to help encourage landowners to obtain, keep and expand on best-practice management of their land. The Water Quality Improvement Plan includes a target of 90 per cent of agricultural land within priority areas in the Catchment following best management practices by 2025.[1883,1991] Key industry programs, such as Smartcane, Banana Best Management Practice and Hort 0, and GRASS, continue to operate as a key intermediary between industry and regulatory actors to support farmers in meeting the new requirements. Fine sediment and particulate nutrient targets can be met for most regions if best-practice management is fully implemented in priority areas. In contrast, the

dissolved inorganic nitrogen target can only be met for most regions if there is adoption of more innovative practices.[1990] The existing levels of best-practice initiatives are not considered sufficient to reach agreed targets.[1990]

Improving monitoring systems for anthropogenic runoff has been a priority since 2019. Specifically, there have been notable technological improvements, such as greater integration of the eReefs marine modelling system into decision-making.[1810] Knowledge gaps remain in relation to bioavailable nutrient (primarily nitrogen and phosphorus) impacts, pathways into coastal and marine ecosystems and validation of the predicted water quality benefits from improved irrigation practices and water use efficiency. Understanding these and the way in which on-ground practices impact upon the Reef may also be less well understood by landowners,[1992,1993] although efforts to address this have progressed since 2019. Partnerships between government and industry, for example Best Management Programs and associated support tools NutriCalc™ and Nutrition EDGE courses for grazing, continue to provide education and support for farmers. Research entities have helped to increase the accessibility of information to farmers through initiatives such as the 1622-WQ app, which provides farmers with local water quality data to help see 'the link between their practices and water quality outcomes'.[1993,1994]

Monitoring of water quality outcomes are reported via the Paddock to Reef Program[1995] and the Reef Water Quality Report Card. These report cards provide an interactive guide for managers into the state of the Reef as well as key insights into the programs that have been active in the different catchments. Trends based on outputs from these report cards up to 2020 indicate that 2025 targets are unlikely to be met based upon current improvement trajectories. There is some uncertainty in relation to how changes in regulation may be impacting on trajectories towards 2025 goals. This is primarily due to delays in data and reporting, and ongoing review of land management targets. More broadly, Regional Report Cards produced by the five regional report card partnerships are released annually and report to local communities on condition from freshwater to marine zones.[1996]

Despite reductions in pollutant loads, 2025 water quality goals are unlikely to be met

Despite significant financial investment into improving water quality in the Catchment, funding is considered insufficient to achieve the 2025 water quality targets for the Reef.[11] Nutrient management may be considered achievable, with an estimated cost of $390 million.[1997] However, it was estimated that up to $8.21 billion may be required to deliver sufficient reductions in sediment and dissolved inorganic nitrogen. This relates primarily to the cost of remediating sediment in the Fitzroy region, which was estimated to cost $6.46 billion alone. In 2024, contributions to achieving these objectives are less than half, indicating that financial resourcing is insufficient to meet the 2025 water quality targets.

Improvements have occurred in the management of land-based runoff along with a general reduction in pollutant loads since 2019. However, it is not expected that the 2025 water quality targets will be met. The impact of the shift from a predominantly self-governed system for industry-led best practice management to one regulated by government legislation coupled with voluntary, validated agricultural certification systems is hard to determine yet, due to its staged implementation approach. This top-down governance may lead to less than equitable relationships between groups, limiting the ability for true collaboration [1998,1999] and, without intent, may frame the type of collaboration that takes place.[1998,2000] This has led some landholders to feel that the relationship with regulatory bodies is often punitive in nature and negatively impacts on their desire to

participate. Research into how to navigate the challenges of uptake within the top-down governance approach is ongoing.[1942,1943,1944,1945,1946,1947]

This limitation is well understood by Reef management agencies and substantial effort has been expended in projects that aim to involve the whole community in a place-based approach to deliver outcomes for Reef and community alike. As more regulatory initiatives are rolled out, it remains more important than ever to maintain and expand on these types of collaborative projects to ensure continued engagement with on the on-ground stakeholders.

Managing to protect the Region's values

7.3.12 Biodiversity values

Biodiversity is a critical component of the Reef's outstanding universal value and natural heritage value. Protection of biodiversity values is at the centre of planning and management actions undertaken by managers within the Region.



Protection of biodiversity values is at the centre of planning and management actions

The Reef continues to be exposed to cumulative stressors and consequential impacts. Over the reporting period, the Reef experienced two mass coral bleaching events (2020 and 2022), and one severe cyclone (cyclone Trevor in March 2019). The cumulative impact of coral bleaching events, severe cyclones, poor water quality, crown-of-thorns starfish outbreaks and other stressors, such as unsustainable fishing practices (for example, gill nets), marine debris and changes to coastal ecosystems are not well understood, although descriptive qualitative models and spatial mapping tools are starting to address these gaps.[1697]

The planning and governance systems for the Reef are complex, span terrestrial and marine environments, engage diverse stakeholder groups, and are based on coordinated planning and decision-making processes. Marine spatial planning for the Reef implements ecosystem-based management, focused on integrated, multi-objective marine plans. These incorporate zoning, enable traditional use of marine resources, support local economies, address impacts, support research and more. Terrestrial spatial land use planning in the regional context focuses on catchment-based planning for natural resource management and traditional land use planning at the local government level. There have been challenges in integration and effective implementation, resourcing and monitoring.

The *Intergovernmental Agreement for the Reef* sets a framework for joint coordination of planning and management across jurisdictions and incorporates complementary zoning, joint permitting, plans of management, joint policy and consistent management of the Reef Joint Field Management Program, fisheries and the Reef 2050 Plan. The Reef 2050 Plan is the overarching plan addressing most of the key elements required for effective management of biodiversity values. However, given cumulative impacts of climate change and other stressors, the Reef 2050 Plan and its associated plans and strategies lack clear pathways to mitigate significant negative impacts from climate change.[1097]

The Zoning Plan primarily aims to protect biodiversity. It provides spatial control of use as well as, to a lesser extent, access within the Marine Park. For the most part, complementary arrangements are in place in adjacent areas under Queensland

jurisdiction. The Zoning Plan relies on effective permitting arrangements and enforcement for successful implementation. Enforcement has improved with the extension of vessel tracking across the commercial fishing fleet, better targeting of compliance actions based on risk assessment that gives priority to impacts on protected species, and enhanced compliance monitoring technology.



Monitoring and protecting key nesting sites for vulnerable species, such as green sea turtles, are management priorities for the Reef Joint Field Management Program. © Queensland Government 2022

Actions that have, or are likely to have, a significant impact on matters of national environmental significance, including the Marine Park and the World Heritage Area, whether undertaken in or outside the Region, are regulated under the EPBC Act. The 2020 independent review of the EPBC Act notes that compliance and enforcement of provisions under the EPBC Act approvals (that are made outside of the Marine Park) are ineffective, with significant impacts on the ability to protect biodiversity values. This may include illegal discharge or inappropriate management of coastal development activities. In general, for activities that require a Marine Parks permit, there are extensive compliance and enforcement programs under the Marine Park Act, Fisheries Act and other legislation.

Relationships are strongest between the Reef Authority and the Australian and Queensland governments. Engagement in relation to biodiversity values often involves stakeholders being informed and consulted rather than empowered to fully engage in decision-making. Greater efforts have been made to engage with Traditional Owners since 2019. There are strong and growing connections between decision-making, research and a range of actors, such as through the Reef 2050 Integrated Monitoring and Reporting Program (RIMReP). However, a broader range of stakeholders could be engaged in decision-making, including farmers, fishers, mining companies, energy providers, property developers and individual citizens.[2001]

More than 90 monitoring programs for biodiversity values operate within the Region. Current monitoring represents about 40 per cent of the environmental regimes of the Reef[1697] and confidence around condition status is limited for some species and ecosystem processes because of a lack of long-term data over a broad area.[2002] Significant improvements have been made in the design and updating of monitoring programs through the Reef 2050 Integrated Monitoring and Reporting Program. The focus has been on addressing priority monitoring gaps, Reef-wide decision support-systems and developing new strategies to access information. There are also improvements

in information sharing, for example the Reef Knowledge System provides accessible up-to-date information about the Reef to guide management decisions.

Since 2019, there has been significant investment in Reef programs, updating of relevant plans, expanded monitoring efforts, prioritisation of research and improvements to governance arrangements, such as expansion of Traditional Use of Marine Resource Agreements. Partnerships are expanding, leading to significant improvements in engagement with Traditional Owners. This includes the incorporation of Indigenous knowledges and moves towards co-management through Traditional Use of Marine Resource Agreements and other mechanisms.

While important advances have been made since 2019, the challenges facing the Reef are increasing in scale and complexity. Despite a suite of planning documents, significant inputs and a comprehensive range of outputs, outcomes for biodiversity are assessed as partially effective and in decline. The downward trend in outcomes relates to poor protection of values, poor reduction of the major risks and threats to the Reef and poor environmental and economic sustainability in relation to use of the Reef. Widespread emission of greenhouse gases continues to impact the Reef, although recent improved emissions reductions targets (national and state levels) are a positive step forward. It is unclear whether the current plans, actions and investments will be sufficient to protect biodiversity in the face of significant cumulative threats, primarily related to the impacts of climate change.



The challenges facing the Reef are increasing in scale and complexity

The stressors on the Reef indicate that the current governance system may be inadequate to improve biodiversity outcomes.[2001,2003,2004,2005] The system 'is not built with the agility required to adapt to rapidly evolving climate impacts',[2006] reflecting a need for more substantial institutional redesign or rethinking of principles and values underpinning governance goals.[2007] Work programs supporting the Reef (at least 58) [2008] are not currently considered to be at the required scale, coherence or responsiveness to the emerging threats to biodiversity. The Reef 2050 Integrated Monitoring and Reporting Program identified Reef governance as a critical monitoring gap[2009] and a governance monitoring program is under development to identify indicators to assess governance effectiveness in relation to Reef 2050 Plan objectives.[2]

Key challenges remain, including: identifying realistic values and outcomes for the Reef under a climate-changed future and the likelihood of ongoing ecosystem function decline; managing for coral resilience and understanding how multiple stressors affect different demographic processes and reef recovery; engaging in co-management and co-governance arrangements with Traditional Owners to manage biodiversity; and enhancing communication among all stakeholders, including researchers, farmers and the community.

7.3.13 Heritage values

The topic of heritage values assessed here encompasses Indigenous, historic (including Commonwealth heritage), and other heritage values (Chapter 4). Traditional use of marine resources, which is a part of Indigenous heritage, is considered in Section 7.3.8. The Region's natural heritage values (a major element of world and national heritage value) are considered in the assessment of management to protect biodiversity values (Section 7.3.12).

Planning for historic heritage operates at multiple scales. At the national level the EPBC Act provides for significant historic heritage to be listed on World Heritage, National Heritage or Commonwealth Heritage lists. The *Underwater Cultural Heritage Act 2018* (Cth) provides blanket protection for all wholly or partially submerged ship and aircraft wrecks 75 years or older. At the state level, historic heritage is protected by inclusion in state heritage registers and planning schemes are required to consider heritage. At the regional and local level, registers for places of local importance are created and administered by local governments, and heritage can be included in local statutory planning instruments with heritage-specific provisions such as codes and overlays.

Commonwealth listed and priority historic heritage sites are well protected, maintained and monitored. The Reef Authority and the Queensland Parks and Wildlife Service coordinate various aspects of their work and approaches in relation to heritage through the Reef Joint Field Management Program using the framework set out in the Intergovernmental Agreement and the Reef 2050 Plan. The Reef Joint Field Management Program focuses on the implementation and field delivery of agreements, mentoring, training and empowering of Land and Sea Rangers and Indigenous Compliance Officers. It delivers compliance and maintenance services to historic heritage structures and sites, and is responsible for protecting Indigenous and historic heritage values on island national parks and Commonwealth islands, including story places and other locations of ceremonial and spiritual significance.



A Meriam Nation Custodian working with Reef Joint Field Management Program rangers on red-tailed tropicbird research at Raine Island. © Queensland Government 2023

Joint marine parks permits are assessed on matching criteria and a cultural referral process aims to ensure potential impacts to cultural heritage are considered in permit assessments and decisions, though this does not cover Queensland islands. Special management areas continue to protect two Catalina aeroplane wrecks. Many places and objects of historic heritage significance, however, remain unlisted and vulnerable to impacts, with the planning system struggling to provide adequate protection.[10]

Planning has an important role in assisting Traditional Owners to secure a future that acknowledges their complex and continuing relationships with Land and Sea Country. The Reef planning system for Indigenous heritage matters operates at several scales and comprises complex layers of legislation, plans (strategic, zoning, management), strategies, agreements (Traditional Use of Marine Resource Agreements, Indigenous Land Use Agreements) and conventions relating to heritage.

Planning helps secure a future that recognises Traditional Owners' deep relationships with the Reef

There has been increased recognition of Indigenous heritage in the management of the Region. Indigenous heritage is one of the four themes in the overarching objectives of the Reef 2050 Plan. Under these objectives, it has a focus on acknowledging Traditional Owners' aspirations for protecting the Reef and its cultural heritage and it aims for increased participation, voice and capacity in governance processes. The *Reef 2050 Traditional Owner Implementation Plan*[1120] provides an operational platform to strategically coordinate and advance the delivery of actions to achieve Traditional Owner aspirations in relation to heritage matters (Box 10.2). It provides support to further understand and agree on a range of governance concepts, including co-management, co-governance and clarification of Traditional Owner rights and interests. In November 2023, a principles-based 'Agreement to Partner' was signed by the Reef 2050 Traditional Owner Steering Group, and the Australian and Queensland governments, to give effect to the rights, interests, and aspirations of Traditional Owners for the Reef in delivering the *Reef 2050 Traditional Owner Implementation Plan*.

The 2021 First Nations Heritage Protection Alliance is working to reform protections that preserve cultural treasures for future generations and co-design partnerships with the Alliance communities to reform cultural heritage laws. This includes the review and restructure of processes, procedure and protocols for First Nations cultural heritage protections. The Reef Authority's *Reef Blueprint 2030* includes a key strategic goal to co-manage Sea Country with Traditional Owners.

'Agreement to Partner' is a key step in progressing Traditional Owner aspirations for the Reef

The *2019 Aboriginal and Torres Strait Islander Heritage Strategy*[1102] provides a five-year strategy to improve the protection of Indigenous heritage within the Region. In 2020, the *Toolkit for safeguarding Indigenous heritage and knowledge,*[2010] which recognises the inherent rights of Indigenous people, was created. Initiatives such as Traditional Use of Marine Resource Agreements and Indigenous Land and Sea Ranger programs assist Traditional Owners to access their Sea Country and to pass on knowledge from the Elders to the younger generations (Box 7.4).



Discussing habitat management for Land and Sea Country. © Mandubarra Aboriginal Land and Sea Incorporated 2024

BOX 7.4

Indigenous Ranger Programs — building a legacy to care for Land and Sea Country

Established and emerging Indigenous ranger groups across the Great Barrier Reef use specialised traditional practices and cultural knowledge, along with western methods, to manage and care for their Land and Sea Country. The Lama Lama Rangers program is considered a best-practice Traditional Owner-led and -managed program.

Grant McIvor is a Lama Lama Traditional Owner and former ranger. He has been returning to Lama Lama Country where his children, parents, grandfather and extended family live and where his sister is a senior Lama Lama Ranger, carrying on the well-established biodiversity preservation and research programs developed over decades. Working on your Country brings wide-ranging benefits.

"Longer-term employment, training, sustainability of Sea and Land Country and the connection between wellbeing of people and Country is evident through the Lama Lama Ranger group. I am happy to see young mob there doing good work for Country, and our Elders are happy to see the younger generation back on Country."

— Grant McIvor, Lama Lama Traditional Owner

Indigenous ranger employment pathways are also having positive impacts on other First Nations communities like Wujal Wujal, home of the Kuku Yalanji, Kuku Nyungul and Jalunji Traditional Owners. The Dabu Jajikal Elders have worked tirelessly to build momentum in their community.

"We want a program for future generations. We want to take them to Sea Country. We want to protect the Reef, protect seagrasses for the turtle and dugong populations and see our children caring for Country."

— Chris Patterson, CEO of Dabu Jajikal Aboriginal Corporation

Further south, Manduburra junior rangers are starting the journey of becoming Sea Country Custodians. It is being woven into their identity from a young age. They are on Country with their families, and it has become a way of life for some young mob. Rohann Sultana, Manduburra Traditional Use of Marine Resources Agreement junior ranger coordinator, wants their junior ranger program to evolve.

"The most important thing for us is having our kids back on Country and being part of that custodial relationship. By the time they are teenagers it is more natural for them to be on Country, understanding it, recognising what it needs, than watching a screen."

— Rohann Sultana, Manduburra Traditional Owner and Traditional Use of Marine Resources Agreement junior ranger coordinator

Connections are being made across Land and Sea Countries so best-practice species monitoring and land management programs can continually improve. This model for capacity building emphasises knowledge sharing and the establishment of partnerships to enhance community capability, health and wellbeing — for Country and Traditional Owners.

Source: Caring for Sea Country — Traditional Owner Stories from the Great Barrier Reef[1] 7.3.14.

The Queensland Parks and Wildlife Service's *Values-Based Planning Framework* also recognises Indigenous cultural values as a significant focus of protected area planning. The Permissions Cultural Heritage Referral project is improving the Reef Authority's ability to include Traditional Owner cultural knowledge in Marine Park permit decisions.

Since 2019, significant improvements have been made to documentation, monitoring and reporting frameworks for Indigenous heritage values and knowledge sharing among key players. The *Strong People — Strong Country* framework supports the establishment of indicators to monitor Indigenous heritage under the Reef 2050 Integrated Monitoring and Reporting Program and will support the understanding of progress towards the Reef 2050 Plan. Sea Country Values Mapping projects facilitate planning or product development including identification of saltwater heritage values and sites, threats to cultural heritage values, cultural landscapes, and cultural species. These are built on traditional lore, customs and cultural authority governance systems led by saltwater Traditional Owner groups (Section 8.5.2). A Data Management System for the Reef 2050 Integrated Monitoring and Reporting Program is being developed for improved information management, and the Reef Authority has a Cultural Knowledge Management System. These types of information systems assist Traditional Owners to share and or store culturally sensitive and other information, where appropriate. The 2020 *Toolkit for safeguarding Indigenous heritage and knowledge* recognises the rights of Indigenous people to protect and manage their heritage and respects their rights in traditional knowledge and traditional cultural expression.

Outcomes for Heritage were assessed as partly effective and in decline. Challenges to the management of heritage values include:

- delivering a Reef-wide engagement approach to incorporate Traditional Owners through genuine partnerships and co-governance arrangements
- enhancing the provision of on-ground management capacity and opportunities for Traditional Owners to protect and rehabilitate heritage
- better application of relevant international and national principles relating to heritage across all areas of Reef planning and management
- enhancing and integrating information on and monitoring of historic heritage (such as shipwrecks, plane wrecks and other relics)
- improving digital spatial data and tools, information and data management, and data sharing arrangements to assist assessments of heritage
- reviewing and updating relevant legislation to strengthen outcomes, including expanding protection of sites of heritage value
- improving the integration of heritage matters into local government planning mechanisms, across agencies and across terrestrial and marine planning systems
- education and awareness programs to minimise risk to heritage.

7.3.14 Community benefits of the environment

Community benefits of the environment encompass the socio-economic and socio-cultural attributes of the Reef. Many of these are values based and include benefits such as employment, income, understanding, appreciation, enjoyment, personal connection, health benefits and access to Reef resources.

Community benefits are supported under the Marine Park Act 1975. They are also addressed in many of the policy and decision-making guidelines for the Reef. For example, the Reef 2050 Plan aims to develop a shared understanding of the community benefits derived from the Reef and provides principles for decision-making including basing decisions on best available science and community knowledge.

In recognition that some of the most significant threats to the Reef come from outside the Region (climate change, land-based runoff), managing agencies have increased efforts to understand, work with and influence the broader community. This is done through, for example, regional report card partnerships, Local Marine Advisory Committees, educational and virtual outreach programs, and the Great Barrier Reef Aquarium.



Members of the public reading information about the Whitsundays. © Queensland Government. Photographer: Victor Heurtas 2022

Since 2019, significant work has been undertaken by managers to better understand community benefits across the Region and to incorporate this knowledge into planning, policy and assessment processes. The primary monitoring program for this is the Social and Economic Long-Term Monitoring Program (SELTMP) that gathers long-term data about Reef users, communities and industries, and their changing relationship with the Reef over time. This program provides information, such as on human use and dependency, wellbeing, and cultural context, to ensure management decisions reflect the needs of the people who interact with the Reef.

Recent work has improved understanding of community benefits across the Region

To supplement this, the Sustainable Use and Benefits Monitoring Project (SEABORNE) considers who uses the Reef, for what purpose and benefit, and how human use impacts the Reef's ecological, social and economic values. The Integrated Reef Stewardship

Monitoring Project (PROTECT) monitors how individuals and community organisations engage in Reef stewardship and explores the causal links between stewardship activities and desired Reef outcomes. While there has been significant investment in developing systematic monitoring programs to track trends over time for community benefits, full implementation does not have secure, ongoing resourcing.

Monitoring community benefits through the lens of climate change is a key challenge. The exact form of these impacts on community benefits is still largely unknown, particularly under high emission scenarios where there are significant gaps in existing knowledge regarding disruptions to the Reef and the cascading impacts on socio-ecological systems and community benefits.

7.4 Assessment of management approaches

The purpose of this section is to assess the three broad management approaches outlined in Section 7.1.4: environmental regulation; engagement; and knowledge, integration and innovation. These findings are based on assessments of each approach against all management topics (Section 7.3).

7.4.1 Environmental regulation

Protection and management of the Region includes statutory instruments such as Acts and regulations, zoning plans, plans of management, permits, fees and charges, and compliance and enforcement programs. Various non-statutory mechanisms such as policies, strategies, position statements, guidelines and management plans are in place. The Reef 2050 Plan is an overarching plan for the Region.

There has been significant regulatory reform since 2019

Since 2019, there has been regulatory reform through the introduction of the Reef protection regulations and the *Climate Change Act 2022* (Cth) together with ongoing adjustments to specific fisheries using tools under the *Fisheries Act 1994* (Qld) and regulations. These reforms are intended to address some of the key threats to the Reef including poor water quality, climate change and unsustainable fishing practices. On top of this work, some of the regulatory mechanisms need review and updating to enhance effective and adaptive management. For example, a statutory review of Reef protection regulations was completed early in 2024.



The Region is managed through a joint partnership between Commonwealth and State agencies.
© Queensland Government. Photographer: Victor Huertas 2023

In 2020, the findings of an independent review of the EPBC Act identified that, while benefits were achieved, the focus on matters of national environmental significance and adoption of a project-by-project consideration of environmental outcomes meant the holistic outcomes for environment and heritage cannot be attained. This undermines the ability to address system-wide threats to natural environments. Conversely, the separate listing of the Marine Park as a matter of national environmental significance contributed to more clear and adequate environmental assessment outcomes for the Region. A reform agenda based on the review findings is currently being implemented. The *Nature Positive Plan: better for the environment, better for business*[2011] will develop new National Environmental Standards for the long-term protection and conservation of environment and heritage matters, and will require achievement of net benefit for new projects assessed under the EPBC Act.

There are largely effective joint management arrangements in place to minimise jurisdictional overlap between the Australian and Queensland governments in relation to Marine Park permitting, field presence and compliance activities. An improvement in monitoring and responding to compliance matters is attributed to funding allocated to the Reef Joint Field Management Program in 2018. However, inconsistencies in regulation across Australian and Queensland government jurisdictions have potential to arise because of differences in regulatory focus (Section 7.3.3).

The Zoning Plan provides spatial management for activities that can occur 'as of right' without a permission and activities that are prohibited in certain zones. Zones with higher protection have positive outcomes for the conservation of fish species.[1975] However, zoning must be supported by implementation of other tools such as an effective permission system and site-specific plans of management[1972] such as those in place for Whitsundays, Cairns, Hinchinbrook and Shoalwater Bay. The Zoning Plan does not influence external factors (such as climate change and land-based runoff) but it does increase ecosystem resilience.[1099,2012]

Compliance systems are increasingly sophisticated, especially for tracking vessels and their activities. There is no current mandatory requirement for independent data validation on commercial fishing vessels, which limits compliance monitoring, especially for impacts to species of conservation concern. The ability to monitor compliance of recreational fishing and sewage pump-out on recreational vessels is similarly limited because of a lack of mandatory reporting systems.

The process of developing and reviewing of statutory and non-statutory instruments would benefit from greater adaptability and responsiveness to emerging evidence, particularly in the face of climate change.[2008]

7.4.2 Engagement

The Great Barrier Reef Intergovernmental Agreement and Reef 2050 Plan framework is one of a range of other agreements between agencies that form the basis of effective partnerships and collaboration between the Australian and Queensland governments and associated agencies. This is evidenced by the effective engagement within the Reef Joint Field Management Program and joint permission system for the Great Barrier Reef Marine Park and Great Barrier Reef Coast Marine Park.

The key stakeholders for the Reef are diverse and generally well known to managers and the Reef Authority's Actor Network Mapping project is improving the identification of other relevant Reef actors. While engagement and relationships are strongest between the Reef Authority and the Australian and Queensland governments, external institutions such as the World Heritage Centre and IUCN have had a significant impact on policy, inputs, planning and management of the Reef.

Effective stakeholder engagement can occur across a spectrum.[1968] For the Region, engagement is most often focused on 'informing' (for example, education and stewardship programs, Great Barrier Reef Aquarium, Reef Knowledge System), 'consulting' (for example, Reef Authority Board, Advisory Committees and Local Marine Advisory Committees, information collection) and 'involving' stakeholders (for example Reef Joint Field Management Program partners, trained community volunteers, Indigenous rangers, Master Reef Guides, High Standard Tourism Program, Reef Guardians, Eye on the Reef participants).

Effective stakeholder engagement can occur across a spectrum

There is less evidence of the 'collaborating' and 'empowering' types of engagement [11] that fully encompasses co-design, co-development and co-delivery, including free, prior and informed consent from Traditional Custodians.[2006] However, during the reporting period increased efforts have been made in several areas. Firstly, there have been policy commitments to co-management with First Nations peoples by the Reef Authority [1181] and Queensland Department of Environment, Science and Innovation.[1182] Secondly, there is greater engagement by Traditional Owners in management and on-Country work, especially through the expanded Traditional Use of Marine Resources Agreement program. Other improvements include: the incorporation of Values Based Mapping; the employment and training of Indigenous Rangers; and strengthened communications between managers and Indigenous peoples. There are strong and growing connections between research, decision-making and a range of actors, including through the Reef Authority Actor Network Mapping project, National Environmental Science Program and Reef 2050 Integrated Monitoring and Reporting Program.



A Wuthathi Custodian and Reef Joint Field Management Program ranger at Raine Island in the Region's remote north. © Queensland Government 2023

Partnerships have increased in number and diversity and are underpinned by increasingly complex arrangements, including the nesting of partnerships, particularly in relation to land-based issues such as Natural Resource Management arrangements with regional bodies, local governments and non-government organisations. Investment and brokerage have diversified through initiatives like the Reef Trust Partnership Grant Agreement, where

the Great Barrier Reef Foundation and Queensland Government operate as investors and program managers. The various types of partnerships include:

- knowledge-based reporting, such as the Outlook Report and the Reef Knowledge System
- integrated delivery partnerships, such as the Reef Joint Field Management program, Reef Guardians program and those formalised through a memorandum of understanding (such as between the Reef Authority and Department of Defence and between the Australian Maritime Safety Authority and Maritime Safety Queensland)
- policy and planning partnerships underpinned by the Great Barrier Reef Intergovernmental Agreement
- working with Traditional Owners.

Opportunities exist to continue to expand and tailor engagement across relevant stakeholder communities. Remaining challenges include: resourcing of effective engagement and partnering with Traditional Owners; ensuring the most effective engagement of all Reef Advisory Committees in planning and decision-making; developing greater cross-sectoral and cross-scale collaboration and partnerships; and, data management and collaboration coordination.

7.4.3 Knowledge, innovation and integration

Knowledge, research and monitoring are critical in this time of rapid change as a means to address diverse impacts on the Reef from multiple and cumulative stressors. Adaptability and flexibility are needed given the range of possible scenarios related to the predicted impacts of climate change and other threats. There are substantive knowledge gaps for biodiversity in relation to ecosystem function and processes, population recruitment, various species and habitats. Cumulative impacts are challenging to quantify, assess and manage and are little understood in the Region but through descriptive qualitative models[1697] and spatial mapping tools they are beginning to be better understood.



Knowledge, research and monitoring are critical in times of rapid change

Continual revision of research management tools such as the *Science and Knowledge Needs for Management,* [1386] the *Scientific Consensus Statement* [1991] and the National Environmental Science Program, help to communicate and drive research outcomes that can underpin effective decision-making. In 2021 the *Priority Monitoring Gaps Prospectus: Reef 2050 Integrated Monitoring and Reporting Program* [2009] identified 11 priority monitoring gaps to track managing agency progress against the objectives of the Reef 2050 Plan. The Reef Trust Partnership has invested in filling these priority gaps and their integrated application to decision-making.

Monitoring of Reef governance systems is in its infancy. The Reef 2050 Integrated Monitoring and Reporting Program identified governance was a critical monitoring gap and as a result indicators are being developed to better monitor and assess governance effectiveness. This work is funded by the Reef Trust Partnership and is expected to improve understanding of what constitutes governance and how it can enhance decision-making.

Key partnerships such as those among the Reef Authority, CSIRO, the Australian Institute of Marine Science and universities, and less formalised citizen science programs such

as the Eye on the Reef program, will continue to play important roles in addressing knowledge gaps. The Reef 2050 Integrated Monitoring and Reporting Program encompasses a broad suite of ecological and human dimensions monitoring programs and projects that provide information on the condition and trends of values. It also supports critical improvements in data integration, accessibility and use, to aid adaptive management of the Reef.

Various Reef rehabilitation projects are in place. There are about 19 in-water coral reef restoration projects since 2017 and coral restoration and adaptation is a growing field of research, including the Reef Restoration and Adaptation Program which launched in 2020. Challenges remain in understanding the feasibility and cost-effectiveness of scaling up many of the proposed interventions and in assessing socio-economic impacts.[32]



A rehabilitation project using metal frames and coral fragments. © Matt Curnock 2022

The key challenges for research and monitoring of the Region include: integrating a wide range of diverse knowledge sets across multiple sectors, in particular traditional knowledges; monitoring of Traditional Owner reef use and wellbeing; consolidating data from Reef-related projects; presenting data in an easily accessible format and expanding monitoring and modelling in response to a climate-changed future to support decision-making.

Reporting and evaluation are carried out through various tools. The Outlook Report, published every five years, provides a regular and comprehensive basis for evaluating and reporting on the condition and management of the Region. The findings of the Outlook Report inform the review process for the Reef 2050 Plan — the overarching strategy for Reef management. The Reef 2050 Plan includes clear monitoring and reporting requirements, and the Reef 2050 Integrated Monitoring and Reporting Program provides support for an improved integrated framework for reporting on Reef health and management actions under the plan. Indicators for Reef health are set under the *Reef 2050 Objectives and Goals 2021–2025*[2013] and relate to coral reef habitats, seagrass, natural wetlands, islands and a range of important fauna (e.g. protected species, seabirds, bioculturally important fish and invertebrate species). Implementation of the Reef 2050 Integrated Monitoring and Reporting Program is ongoing in the current reporting period.

Reef Trust investments are delivered by various partners, who report on project performance every six months through the online monitoring, evaluation, reporting and improvement tool (MERIT). Part of the Queensland Government's investment into the Queensland Reef Water Quality Program supports the Paddock to Reef Program.[1995] The Paddock to Reef program publishes Reef Water Quality Report Cards that provide an evaluation of water quality management outcomes within the Reef, though there can be a lag time of a few years between data collection and reporting. Regional Report Cards are released annually and report on conditions from freshwater to marine zones.[1996] Condition (and trend in condition) of some Reef ecosystems are evaluated and reported annually through the Marine Monitoring Program[579] (inshore water quality, coral and seagrass health) and the Long-term Monitoring Program[386] (offshore reef health).

Key challenges include incorporating a wide range of diverse knowledge sets across multiple sectors, particularly Traditional Knowledge[2006] and effectively communicating findings to all stakeholders, especially the public.



Raine Island in the north of the Region. © Queensland Government 2023

7.5 Assessment summary — Existing protection and management

Paragraph 54(3)(f) of the *Great Barrier Reef Marine Park Act 1975* (Cth) requires '*... an assessment of the existing measures to protect and manage the ecosystem ...*' within the Great Barrier Reef Region.

Paragraph 176(3)(d) of the *Great Barrier Reef Marine Park Regulations 2019* (Cth) requires '*... an assessment of the existing measures to protect and manage the heritage values ...*' of the Great Barrier Reef Region.

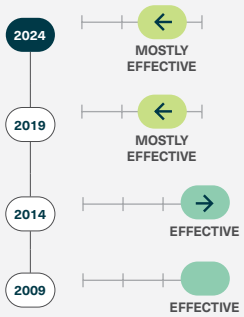
The assessment was undertaken by independent, expert assessors based on the six elements of the management framework:

- understanding of context
- planning
- financial, staffing and information inputs
- management systems and processes
- delivery of outputs
- achievement of outcomes.

These elements are assessed across the 14 management topics (Section 7.1).

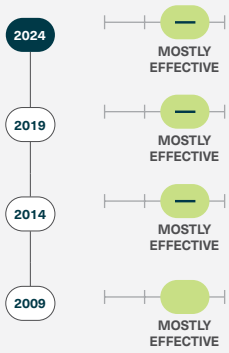
7.5.1 Understanding of context

Grading statements — Understanding of context		Trend since previous report
	**Effective:** Understanding of values, threats, regional and global influences and stakeholders is good for most management topics.	→ Improved — Stable ← Deteriorated ··· No consistent trend
	**Mostly effective:** Understanding of values, threats, regional and global influences and stakeholders is generally good but there is some variability across management topics or components.	
	**Partially effective:** Understanding of values, threats, regional and global influences and stakeholders is only fair for most management topics.	
	**Ineffective:** Without urgent and effective additional management intervention, the values are likely to deteriorate rapidly with the loss of most values in the longer term.	

Criterion summary	Grade and trend
Understanding of context: Context was the strongest element in the management effectiveness framework. Managers generally had a good and improving understanding of the values relevant to each management topic (although this was weakest for heritage and coastal development), national and international influences, and key stakeholders. While condition and trends for each topic were generally known, threats and their impacts were less well known. Specifically, the cumulative and consequential impacts of threats were generally poorly understood across most management topics.	

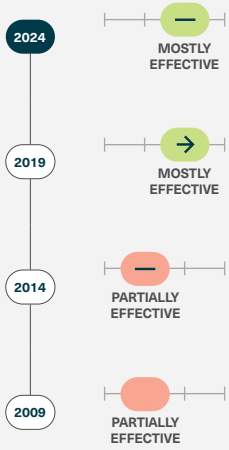
7.5.2 Planning

Grading statements — Planning		Trend since previous report
	**Effective:** Effective planning systems that engage stakeholders are in place for all or most significant issues. There is adequate policy to manage issues that are consistent across jurisdictions.	→ Improved — Stable ← Deteriorated ··· No consistent trend
	**Mostly effective:** Effective planning systems that engage stakeholders are in place for many significant issues. Policy and consistency across jurisdictions are generally satisfactory.	
	**Partially effective:** Planning systems that engage stakeholders are deficient for a number of significant issues. Policy and consistency across jurisdictions are a problem for some issues.	
	**Ineffective:** Planning systems that engage stakeholders are deficient for many significant issues. Policy and consistency across jurisdictions are a problem for some issues.	

Criterion summary	Grade and trend
Planning: Planning performed well in relation to overall management effectiveness with no topics being graded as ineffective or partly effective. Reef planning is spatially complex, spanning marine and terrestrial environments and requires effective coordination of actors and systems. Management topic-specific legislation, plans and policies apply across multiple spatial scales (international to local) and sectors. The Reef 2050 Plan is the overarching plan addressing most of the key elements required for effective Reef management and the Intergovernmental Agreement sets the framework for joint coordination of planning and management. Strengths of planning include certainty around where activity can occur (Zoning Plan), setting clear actions and planning consistency across jurisdictions (Reef 2050 Plan).	

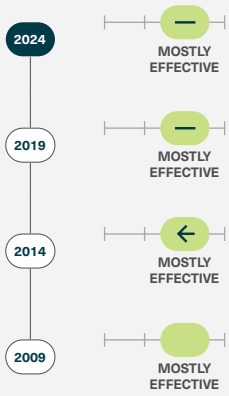
7.5.3 Financial, staffing and information inputs

Grading statements — Financial, staffing and information inputs		Trend since previous report
	**Effective:** Financial and staffing resources are largely adequate to meet management needs. Biophysical, socio-economic and Traditional Owner knowledge is available to inform management decision-making.	→ Improved — Stable ← Deteriorated ··· No consistent trend
	**Mostly effective:** Financial and staffing resources are mostly adequate to meet management needs. Biophysical, socio-economic and Traditional Owner knowledge is mostly available to inform management decision-making although there may be deficiencies in some areas.	
	**Partially effective:** Financial and staffing resources are unable to meet management needs in some important management topics. Biophysical, socio-economic and Traditional Owner knowledge is variably available to inform management decision-making and there are significant deficiencies in some areas.	
	**Ineffective:** Financial and staffing resources are unable to meet management needs in many management topics. Biophysical, socio-economic and Traditional Owner knowledge to support decision-making is frequently deficient in some areas.	

Criterion summary	Grade and trend
Financial, staffing and information inputs: Inputs for most topics were graded as mostly effective, with four topics rated as partially effective (climate change, coastal development, heritage and community benefits). Funding in general, has increased across most topics with improvements in the funding for water quality improvement, Reef management and conservation, Reef restoration and adaptation, and strengthening partnerships and stewardship. Innovative funding strategies are being developed (for example the Reef Recovery 2030 fundraising campaign by the Reef Trust Partnership). The adequacy of human resourcing within all managing organisations was the weakest of all topics and was partly impacted by COVID-19. Data inputs overall are effective, although there are gaps in Indigenous heritage and historic heritage information. Provisioning of adequate data sharing platforms was also identified as a key deficit particularly for research efforts. Non-government involvement was also mostly effective reflecting the strong level of community engagement and interest in the Reef.	

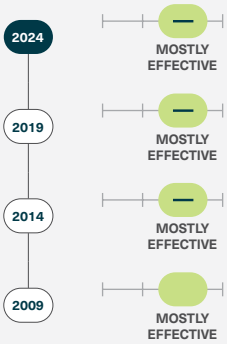
7.5.4 Management systems, processes and governance

Grading statements —Management systems, processes and governance		Trend since previous report
	**Effective:** The majority of management processes are appropriate and effective in addressing the management of the various management topics.	→ Improved — Stable ← Deteriorated ··· No consistent trend
	**Mostly effective:** The majority of management processes are appropriate and effective in addressing management although there are deficiencies in relation to a small number of management topics or processes.	
	**Partially effective:** A minority of critical management processes show significant deficiencies across most management topics.	
	**Ineffective:** A majority of management processes show significant deficiencies across most management topics.	

Criterion summary	Grade and trend
Management systems, processes and governance: Processes for many topics remained stable since 2019 but there were declining trends for community benefits, coastal development, land-based runoff and research. Strengths were identified in relation to engagement with stakeholders and the integration of biophysical and socio-economic information into decision-making. Weaknesses relate to the integration of Indigenous and heritage information, consideration of cumulative and consequential impacts, and limitations in governance systems (such as gaps in effective engagement of local governments and other key actors, coordination among jurisdictions and siloed approaches). Declines in governance effectiveness reflect the scale and complexity of matters that need to be addressed as part of Reef management and point to the need for more substantial institutional redesign or rethinking of principles and values underpinning governance goals.	

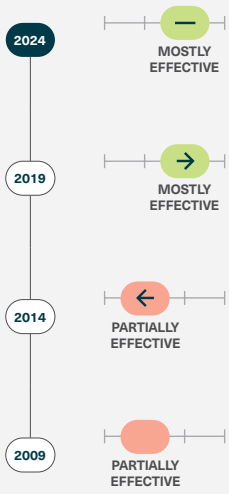
7.5.5 Delivery of outputs

Grading statements — Delivery of outputs		Trend since previous report
	**Effective:** Management programs are mostly progressing in accordance with planned programs and are achieving their desired objectives. Managing agency and community knowledge base is improving.	→ Improved — Stable ← Deteriorated ··· No consistent trend
	**Mostly effective:** Management programs are mostly progressing in accordance with planned programs and are achieving their desired objectives but there are problems in some management topics. Managing agency and community knowledge base is generally improving.	
	**Partially effective:** Many management programs are not progressing in accordance with planned programs (significant delays or incomplete actions) or actions undertaken are not achieving objectives. The knowledge base is only growing slowly.	
	**Ineffective:** Most management programs are not progressing in accordance with planned programs (significant delays or incomplete actions) or actions undertaken are not achieving objectives. The knowledge base is only growing slowly.	

Criterion summary	Grade and trend
Delivery of outputs: Outputs remained stable for the majority of topics. Upward grade changes, such as that for climate change, reflect the improvement in the planning system. Declines across research, traditional use of marine resources and land-based runoff are a result of resourcing issues during the period of COVID-19 restrictions, which impacted the outputs that could be delivered. While the delivery of outputs was generally strong, especially in terms of delivering products and related actions, there were weaknesses in achievement of results against objectives. This in part reflects the absence of clear objectives for some management topics or misalignment of outputs with expected objectives.	

7.5.6 Achievements of outcomes

Grading statements — Achievement of outcomes		Trend since previous report
	**Effective:** Desired outcomes are mostly being achieved, Reef values are being protected and threats are being abated for most management topics. Use of the Great Barrier Reef is largely environmentally and economically sustainable with good community engagement, understanding and enjoyment.	→ Improved — Stable ← Deteriorated ··· No consistent trend
	**Mostly effective:** Desired outcomes are being achieved in many management topics, values are being protected and threats are being abated for many of the management topics. Use of the Great Barrier Reef is largely environmentally and economically sustainable with good community engagement, understanding and enjoyment.	
	**Partially effective:** Desired outcomes, protection of values and abatement of threats are not being achieved at desirable levels in some critical management topics with likely eventual flow-on effects across the Great Barrier Reef. Critical aspects of the use of the Great Barrier Reef are not environmentally or economically sustainable.	
	**Ineffective:** Desired outcomes, protection of values and abatement of threats are not being achieved at desirable levels in most of the management topics, including critical areas with likely eventual flow-on effects across the Great Barrier Reef. Critical aspects of the use of the Great Barrier Reef are not environmentally or economically sustainable.	

Criterion summary	Grade and trend
Achievement of outcomes: The achievement of outcomes was the weakest of all elements of the management effectiveness framework. However, results were highly variable across the management topics with most direct use areas performing well but external factors and overall values performing poorly. The outcomes for five topics were graded as partially effective for biodiversity, coastal development, fishing, heritage and land-based runoff. The management outcomes for climate change were graded as ineffective. The relatively poor achievement of outcomes partly reflects a range of external influences on the Reef (such as bleaching events and climate change stressors) but also reflects an increasing understanding of the extent of existing impacts. Outcomes for climate change and biodiversity were poor across a number of indicators, including the protection of values, reduction of threats, and environmental, economic and social sustainability. Poor outcomes for heritage reflect the poor and deteriorating condition of many Indigenous heritage values and many historic heritage sites, especially underwater cultural heritage. However, there was evidence of effective partnerships across most of the management topics.	

7.6 Overall summary of existing protection and management

Effective management of the Region is a complex task, given the range of threats and their variation across space and time. The management effectiveness assessment[11] focused on the six elements of the management framework: context, planning, inputs, processes, outputs and outcomes. It addressed 14 broad management topics and considered the activities of relevant Australian and Queensland government agencies and other contributing partners.

The assessment found the Region continues to be well managed, with more than 80 per cent of elements across the management topics considered effective or mostly effective (Table 7.4). Context was the strongest element, reflecting managers' knowledge and understanding of Reef values, national and international influences, and relevant government and non-government actors across the overall system. Overall, the weakest elements were processes and outcomes. Notable management improvements since 2019 include the enhanced funding and planning initiatives through the Reef 2050 Plan[2] and *Queensland Sustainable Fisheries Strategy 2017–2027*.[1251]



Reef 2050 Plan and Queensland Sustainable Fisheries Strategy have led to notable improvements.

For some aspects of management, declines in effectiveness have occurred since 2019. The challenges posed by climate change in relation to existing planning and governance systems are growing, as is recognition of other impacting processes. The declines often relate to emerging recognition of gaps in the understanding of impacts and their associated coverage in planning systems and programs, as well as extended lag time in achieving key outputs and outcomes. Further gaps relate to governance, the setting of relevant standards and targets for benchmarking, achieving environmental and economic sustainability for the Region, and the integration of Indigenous knowledge into decision-making.

Direct use of the Region is generally well managed, likely due to the lower complexity involved, relative to external factors, and the maturity of management systems. For fishing, achievement of outcomes remains partially effective, which reflects the lag time needed to achieve outcomes under the *Queensland Sustainable Fisheries Strategy 2017–2027*,[1251] and better understanding of the status of some fish stocks and risks associated with fishing activities in the Region.

Overall, management to protect the Region's biodiversity, heritage and community benefit values is mostly effective. Inputs to management of heritage and community benefits, however, have not improved from partially effective, and achievement of heritage and biodiversity outcomes has been trending downward since 2019.



Management is considered weakest for climate change and coastal development

Management is considered weakest for climate change and coastal development, both external factors influencing the Region. Nevertheless, climate change has seen the most improvement in management effectiveness since 2019, including enhanced management of climate change risks and advances in climate change policy at national, state and local levels. Notable policy advances include the introduction of the *Climate Change Act 2022*

(Cth) and the inclusion of a specific work area under the Reef 2050 Plan that articulates clear goals and strategic actions towards achieving emission reduction targets. Despite this progress in policy, the management of the Reef regarding climate change remains subject to significant challenges. Land-based runoff is another external factor which, while largely well managed, has seen declines across planning, inputs, processes and outputs, and the achievement of outcomes remains partially effective.

Achievement of outcomes has declined across six management topics. This highlights weaknesses in relation to protection of Reef values and reduction of threats to these values, and this may indicate a level of 'drift' in the governance system.[2004] For instance, issues related to: centralised and siloed decision-making in some areas; long time frames from policy changes to delivery and implementation; and, declining system flexibility and alignment with ancillary organisations and policies, including international policy, especially in relation to climate change.

Many threats to the Reef are being addressed in meaningful and positive ways

While the challenges involved in managing a large and diverse system are significant, many threats to the Reef are being addressed in meaningful and positive ways. Managers are using research to inform planning and management, extensive on-ground work has been undertaken since 2019, and partnerships have increased in number and diversity and are underpinned by increasingly complex arrangements. Opportunities to improve resourcing of effective engagement and partnering with Traditional Owners and develop greater cross-sectoral and cross-scale data management, coordination and collaboration will be important in the near future.

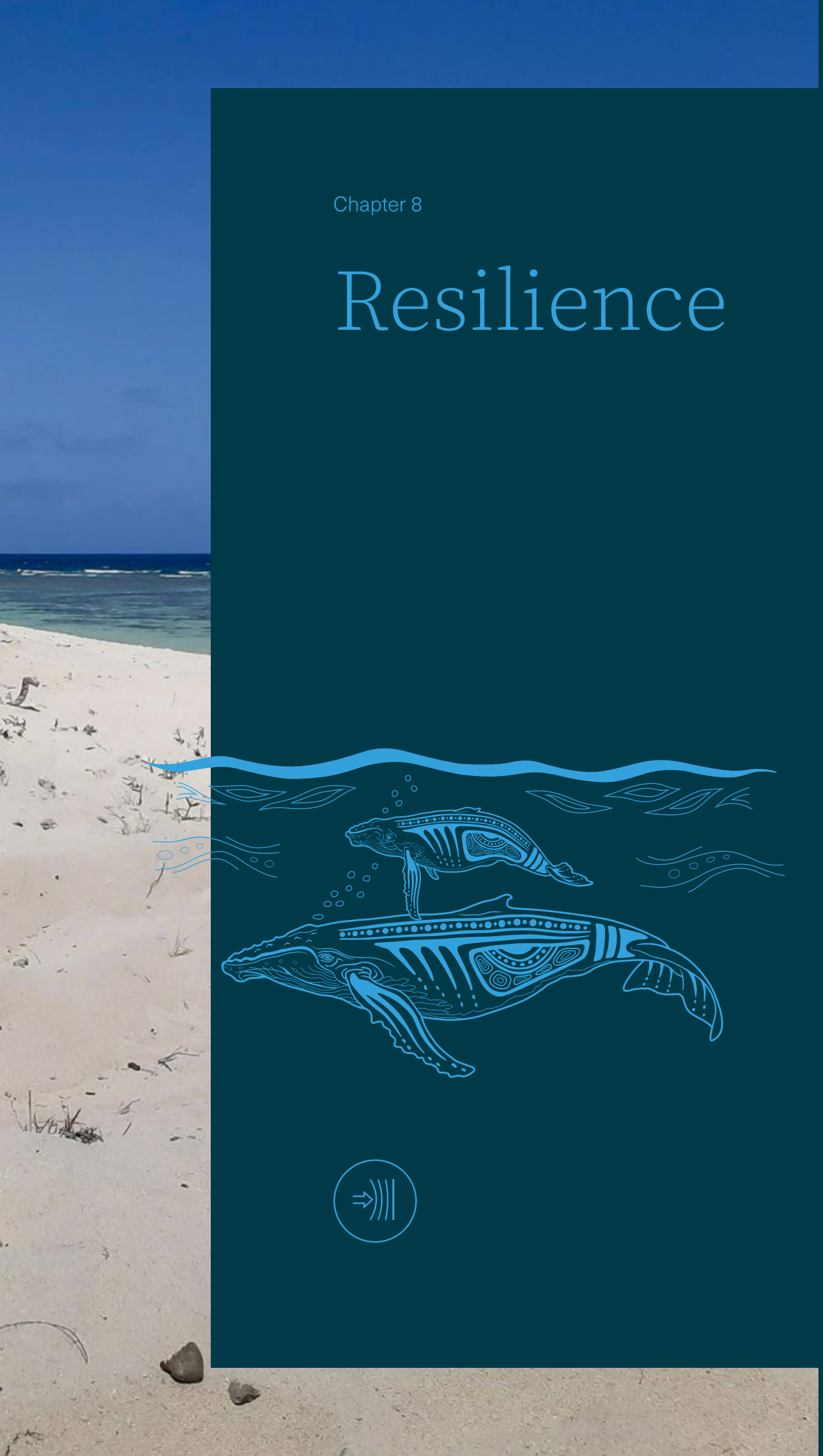
Table 7.4 **Summary of assessment results for each topic in relation to the elements of context, planning, inputs, processes, outputs and outcomes**

Grading statements		Trend since previous report
	**Effective:** The grading statements for each of the assessment criteria are provided in Sections 7.5.1 to 7.5.6.	→ Improved, grade changed ↗ Improved, within same grade — Stable ↙ Deteriorated, within same grade ← Deteriorated, grade changed *Trend arrows in this table are more specific than those in other assessment tables within the Outlook Report as they show whether sufficient change has occurred to result in a change in grade.*
	**Mostly effective:** The grading statements for each of the assessment criteria are provided in Sections 7.5.1 to 7.5.6.	
	**Partially effective:** The grading statements for each of the assessment criteria are provided in Sections 7.5.1 to 7.5.6	
	**Ineffective:** The grading statements for each of the assessment criteria are provided in Sections 7.5.1 to 7.5.6	

	Topic	Context	Planning	Inputs	Processes	Outputs	Outcomes
Managing direct use of the Region	Commercial marine tourism	EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	EFFECTIVE	MOSTLY EFFECTIVE
	Defence activities	EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	EFFECTIVE	EFFECTIVE	EFFECTIVE
	Fishing	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	PARTIALLY EFFECTIVE
	Ports	EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	EFFECTIVE
	Recreation	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE
	Research activities	EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	EFFECTIVE
	Shipping	EFFECTIVE	EFFECTIVE	MOSTLY EFFECTIVE	EFFECTIVE	MOSTLY EFFECTIVE	EFFECTIVE
	Traditional use of marine resources	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE
Managing external factors influencing the Region	Climate change	PARTIALLY EFFECTIVE	MOSTLY EFFECTIVE	PARTIALLY EFFECTIVE	PARTIALLY EFFECTIVE	PARTIALLY EFFECTIVE	INEFFECTIVE
	Coastal development	PARTIALLY EFFECTIVE	MOSTLY EFFECTIVE	PARTIALLY EFFECTIVE	PARTIALLY EFFECTIVE	MOSTLY EFFECTIVE	PARTIALLY EFFECTIVE
	Land-based runoff	EFFECTIVE	EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	PARTIALLY EFFECTIVE
Managing to protect the Region's values	Biodiversity values	EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	PARTIALLY EFFECTIVE
	Heritage values	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	PARTIALLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	PARTIALLY EFFECTIVE
	Community benefits of the environment	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	PARTIALLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE	MOSTLY EFFECTIVE



Loggerrhead turtle at Wreck Island: the satellite tag tracks movements across the Region and internationally
© Emily Webster 2019



Chapter 8

Resilience

Resilience

‘an assessment of the current resilience of the ecosystem ...’ within the Great Barrier Reef Region, s 54(3)(e) of the *Great Barrier Reef Marine Park Act 1975* (Cth).

‘an assessment of the current resilience of the heritage values ...’ within the Great Barrier Reef Region, s 176 (3)(e) of the *Great Barrier Reef Marine Park Regulations 2019* (Cth).



Nooks and crannies among coral growing on a reef at the Cod Hole. © Commonwealth of Australia (Reef Authority). Photographer: Johnny Gaskell 2023

The Mandubarra people are a clan of the Mamu-speaking people and Custodians of Mandubarra Land and Sea Country. For Mandubarra Traditional Owners like Mel Ball and Rohann Sultana, their connections extend from jabun (the coast) out across wajali (the sea). Mel and Rohann hold a deep commitment to their Sea Country, their ancestors, and future generations.

The practice of cultural lore, one of many mapped Mandubarra cultural values, is a central tenet of the protection of threatened species for Mandubarra traditional Custodians.

"Turtles are our totem, but it also comes back to turtle rehabilitation. The last few years there hasn't been any hatchling or nesting, so Uncle James has used turtles' totemic value to be a way of offering protection for them."

— Mel Ball, Mandubarra Traditional Owner

Ongoing bajgal (sea turtle), dugong and seagrass monitoring serves a dual purpose: increasing sea turtle numbers and, once established, *"to then allow us, in the future, to return to our traditional practices and culture to pass down,"* says Mel.

"I feel like us being able to work on Country and to be based on Country, it's important for value sharing into our community, we have respect for what we hold culturally, and the more people know about what is happening on Country, the healthier country is, the healthier people are, and the more they want to care for Country."

— Rohann Sultan, Mandubarra Traditional Owner

Central to the Mandubarra Traditional Use of Marine Resources Agreement and the work of the Mandubarra Land and Sea Rangers, is reinvigorating community connection back to their traditions on Sea Country (Section 8.5.2).

"I grew up with my Mum being a ranger. When we're going onto places we didn't know had history for us, and when you compare how healthy land and sea was a couple of generations ago, we want to protect and preserve, and the more present we are there, it's more likely that people and country are healthy."

— Mel Ball

Conservation programs on Country envelop the community and have revived intergenerational cultural knowledge sharing. Mandubarra have several species protection programs; sea turtle rehabilitation is one of them.

Source: Caring for Sea Country — Traditional Owner Stories from the Great Barrier Reef [1]



Barnard Island Group, Mandubarra Sea Country © Google Earth | Airbus 2024

8.1 Background

The *Great Barrier Reef Marine Park Authority Act 1975* (Cth) defines ecosystem-based management as an integrated approach to managing an ecosystem and matters affecting that ecosystem in which the main objective is to maintain ecological processes, biodiversity and functioning biological communities. These latter concepts are also important in the concept of social–ecological resilience (Figure 8.1), which is defined as the capacity of a system to absorb disturbance and reorganise while retaining essentially the same identity, structure, function, and feedback systems.[2014] The Region is a social–ecological system in which people, species and habitats are interlinked. Therefore, resilient human and ecological communities are critical for the system's long-term sustainability.[2015]

Resilient human and ecological communities are critical for the system's long-term sustainability

Resilience is not about maintaining a single state, rather, it is a multi-dimensional dynamic process. A resilient system is an ever-changing system that has capacity to both adapt to change and to return to healthy states after a disturbance or impact. It is able to resist and/or recover from abrupt changes, or adapt to gradual ones, while maintaining its key components — i.e. its **identity**, including values and integrity; its **structure**, including communities and biodiversity; and its **function**, including social and ecological processes (Figure 8.1 and case study 8.5.1).[1387,1397,2014] The likelihood of a system maintaining its key components and not crossing an undesirable threshold is sometimes referred to as robustness.[2016]

Resilience-based management is defined as 'using knowledge of current and future drivers influencing ecosystem function to prioritise, implement, and adapt management actions that sustain ecosystems and human well-being'.[1099] Both ecosystem- and resilience-based management are adaptive, focusing on maintaining connections across the social–ecological systems and managing the drivers affecting the systems. Resilience-based management additionally acknowledges that humans are capable of driving change in both social and ecological spaces, emphasising consideration of resilience to future impacts.[1099] Given ongoing cumulative pressures and climate change trajectories, it is crucial to apply resilience-based Reef management in practice — by adopting additional measures to support system resistance, adaptation and recovery, and incorporating uncertainty and unpredictability. These measures are in addition to ecosystem-based management measures designed to protect values and mitigate risk.[1387]

Effective management can strengthen a social-ecological system's resilience. However, it can be complex to develop tangible resilience-based management goals and translate these into meaningful management actions. While there has been increasing guidance,[1099,2016,2017,2018] managers need to understand their particular social–ecological system well enough to develop location-specific tangible goals, including by defining their system's thresholds, scales, cycles, feedback processes and domains (see also case studies 8.3.1 and 8.3.2).[2019] Ultimately, resilience is about having the capacities to live with complexity, uncertainty and change, abrupt or incremental, and to continue to develop with ever-changing environments.[2020]

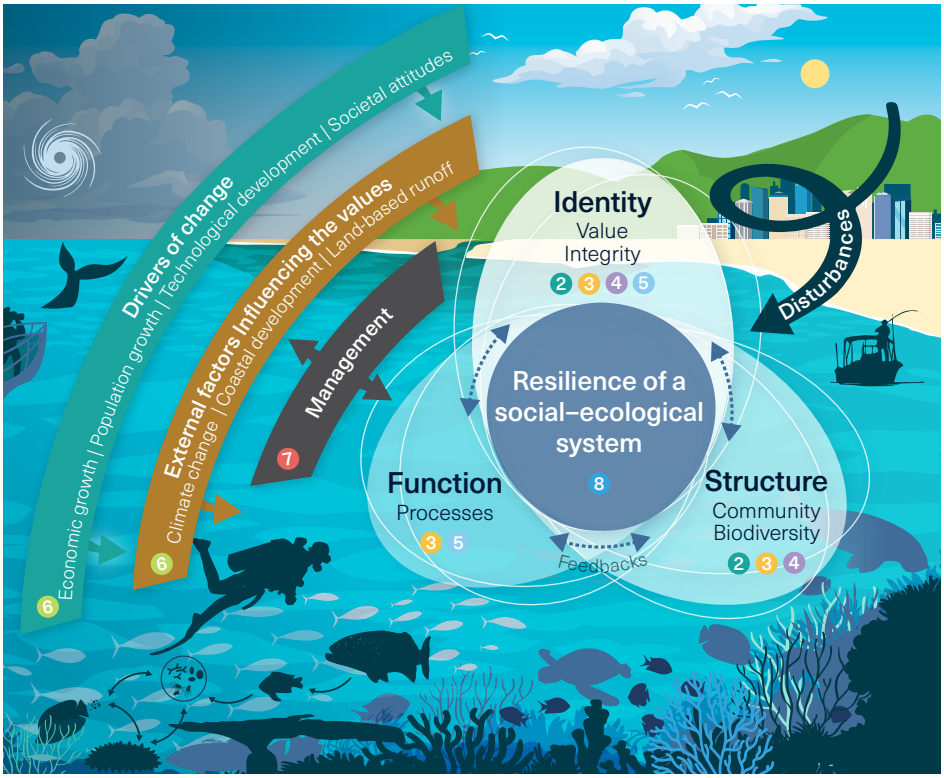


Figure 8.1 **The resilience components of a social–ecological system**

A resilient social–ecological system will retain its **identity**, values, and integrity by absorbing and/or resisting disturbances, reorganising and/or recovering its community and biodiversity **structures**, and maintaining and/or adapting key **functions** and processes. The system is depicted in different configurations, showing its capacity to change through time while the core resilience components retain their integrity. These core components can be considered at multiple spatial and temporal scales, linked by feedback processes (dashed blue lines). The system's identity is both an emergent property of its structure and function and a definition of its values and boundaries. Resilience includes an ability to resist and/or recover from abrupt changes and to adapt to gradual ones, all of which occur within a broader environmental and social space and can be quantified with metrics such as thresholds and domains of attraction. In addition to its natural disturbance regime, the system is subject to external factors that can directly threaten its integrity. These factors are influenced by broadscale drivers of change. Resilience-based management recognises the dynamic nature of complex systems and can be adaptively targeted at different resilience components or influencing factors (e.g. case study 8.5.1). Numbered circles on the diagram link to relevant chapters in this Outlook Report.

8.2 Ecosystem resilience

A resilient social–ecological system will retain its identity by absorbing disturbances, reorganising, and maintaining its functions and processes (Figure 8.1).[2019] Determining how resilient a system is before a disturbance occurs is difficult, particularly where chronic drivers, like climate-driven ocean warming, have caused shifts and, in some instances, long-term changes to the Reef ecosystem.[59,2021,2022] Identifying the social–ecological elements that create resilience in this complex Reef system improves our ability to mitigate threats and assist with recovery.

Resilient systems retain identity by absorbing disturbances, reorganising, and maintaining functions and processes

Managing for resilience must also account for the timeframes expected for detecting recovery after disturbances. The Region's biodiversity — its ecosystems and populations

of species — will have a recovery timeframe from a few years to decades,[2023,2024] so assessing ecosystem condition shortly after disturbances might not convey the full scale of potential recovery. That is because the processes known to support recovery also operate over different timescales. For example, recruitment can be year-round or occur in annual or biannual pulses in different reef species,[2025,2026] while reef building will operate at a timescale of decades to millennia.[901,2027] The biotic and abiotic factors that influence the recovery trajectory of coral reef ecosystems varies across the Reef. Each subsystem and population exists in a distinct community state, making recovery trajectories highly variable and difficult to predict. As a result, identifying key indicators of resilience remains challenging and yet crucial for the success of resilience-based management.

Climate change impacts are predicted to intensify over the coming decades, causing severe and possibly irreversible changes to the Reef's ecosystems (Section 6.3). The impacts will not be uniform. They will likely be worse in some areas than others, such as inshore reefs and seagrass meadows that are already living close to their threshold of tolerance to cumulative disturbances. These habitats have been exposed to chronic impacts from sedimentation and nutrient pollution and may be close to the point where their ability to resist further thermal stress is surpassed.[1884,2028] For these reasons, minimising future increases in impacts by continued and evolving use of a resilience-based management approach will become increasingly important.

8.3 Case studies of recovery and decline in the ecosystem

The capacity to recover after disturbance is a critical attribute of a resilient system. In this chapter, signs of ecosystem resilience are examined through a series of case studies that assess recovery of natural heritage values after disturbance. These case studies were selected because they represent a range of species, habitats and processes and many have long-term datasets. Most of these case studies have been assessed in previous Outlook Reports, although some changes have occurred (Appendix 2).

The capacity to recover after disturbance is a critical attribute of a resilient system

The series of case studies illustrate the extent to which some natural heritage values of the ecosystem have recovered or declined following disturbance. The aspects of resilience focused on in each case study are:

- the extent to which some key habitats and species have responded after human and natural disturbances — coral reefs, seagrass meadows and the black teatfish (a sea cucumber)
- the extent to which populations of some representative species involved in key ecological processes have responded after human and natural disturbances — urban coast dugongs (herbivory) and coral trout (predation)
- the effectiveness of specific management actions to address declines in particular species — loggerhead turtles and humpback whales.

8.3.1 Coral reef habitats

Coral reefs are among Earth's most diverse, complex, productive, and geologically persistent ecosystems, [2029] but the stability of reef communities varies greatly across temporal and spatial scales.[2030] Species composition appears to be more stable over centuries and millennia than it is over days to decades.[2030,2031] At these shorter ecological timescales, reef communities often represent transient states, shaped by the dynamic interplay of ecological interactions and physical disturbances.[2032] Disturbance can be a key enabler of high biodiversity in coral reef communities, but the relationship between disturbance and coral reef communities is more complex than is often recognised.[2033] There is increasing evidence that human-driven environmental changes are pushing coral reefs towards states that are less biologically and functionally diverse, including in the context of past changes over thousands and millions of years.[2031,2034]

Coral reef ecosystem functioning is underpinned by interactions among numerous organisms and four key ecological processes: habitat creation and loss, photosynthetically derived biomass production, trophic structuring and nutrient cycling.[805] Habitat is created by calcium carbonate production and removed by bioerosion. Biomass from photosynthesis is produced through primary production and assimilated through herbivory. Trophic structure is developed through different levels of carnivory and maintained by growth of prey. Nutrients are introduced, retained and re-integrated through the system. Chapter 3 includes descriptions of the Reef's ecological and chemical processes. Together these processes combine with reef-specific biodiversity and community composition to define a reef's identity (Figure 8.1) and, correspondingly, its thresholds, scales, cycles, feedback processes, and domains of attraction.[2019] How these relationships are maintained are key aspects of the resilience of coral reef habitats. Domains of attraction is a term for describing conditions conducive to return of a system to a reference state after perturbation and is relevant to robustness.[2016]



Reefscape at John Brewer Reef. © Ryan Ramasamy 2022

Management

The multiple well-established and effective management tools available to protect the Region's coral reef habitats can be grouped under three approaches: environmental regulation and legislation; engagement with reef users; and integration of evidence-based knowledge into resilience-based management approaches (Section 7.4).

Relevant legislation includes the *Great Barrier Reef Marine Park Act 1975* (Cth) (Marine Park Act) as the primary legislation related to the Marine Park, and the *Great Barrier*

Reef Marine Park Regulations 2019 (Cth), the *Great Barrier Reef Marine Park Zoning Plan 2003* (Cth) and the complementary Queensland zoning plan, and several plans of management.[1175,1176,1178,2035] Special management areas are designed to manage access and use of a specific area in addition to zoning. The Reef Authority develops and implements policies that give effect to the agency's responsibilities, functions and powers outlined in the Marine Park Act and is responsible for granting permissions for activities in the Marine Park.

The Reef Authority, Queensland Government agencies and other Australian Government agencies work together to conduct management activities in the Region. Conducting compliance actions is a key feature of this work. Such actions include educating Reef users and assisting self-regulation; aircraft, vessel, and land-based surveillance; tracking remote vessels; and auditing of activities that require a permit. On-ground interventions, such as the effective Crown-of-thorns Starfish Control Program (Box 8.1), can contribute to the resilience of coral-reef habitats in the Region.

Traditional Owner agreements, such as through the accreditation of a Traditional Use of Marine Resources Agreement, are an example of a pathway to co-management to enhance the effectiveness of the Marine Park management. More broadly, engagement with Reef users often focuses on promoting stewardship, both directly by supporting partners and stakeholders (Section 8.5.1) and indirectly, through education and by encouraging partners and stakeholders to engage with and promote stewardship actions themselves.

Effective adaptive management decisions should be based on the best available evidence-based science, traditional knowledge, and information from the wider community through citizen science programs such as Eye on the Reef. In addition to foundational management programs, new initiatives are being explored to support resilience in coral reef habitats through the Reef Restoration and Adaptation Program (Box 5.4). Tools to support decision-making are being developed within the Reef 2050 Integrated Monitoring and Reporting Program (Box 10.1). An adaptive management approach must also support continual improvement, including evolution of policy and strategic management documents, such as the *Great Barrier Reef Blueprint for Climate Resilience and Adaptation* (Blueprint 2030).[1984]

BOX 8.1

Crown-of-thorns starfish as native coral predators on the Reef

Crown-of-thorns starfish are native coral predators on the Reef and at low densities, coral growth can outpace the rate of predation. However, starfish populations periodically erupt, causing widespread coral mortality that compounds the impacts of cyclones, coral bleaching, flood events and coral diseases (Section 3.6.2). Outbreak waves initiate on reefs in the northern Reef and progressively extend southward over a period of 10 to 15 years.[2036] More localised outbreaks initiate independently in the southern Reef.

The Crown-of-thorns Starfish Control Program (Control Program) aims to protect coral across a network of high-value reefs by suppressing starfish numbers to sustainable levels. It has become a core management action to enhance the Reef's resilience under a changing climate. There is now strong evidence that the Control Program is effectively reducing the severity of outbreaks and protecting coral across

entire reefs and regions.[187] Sustained and timely culling can effectively suppress outbreaks to the point where coral growth greatly exceeds losses from predation (Figure 8.2).[187]

Importantly, these protected coral communities continue to replenish local and downstream reefs with coral larvae, supporting the recovery and adaptation of the Region's reefs after major disturbance events. The Control Program delivers crown-of-thorns starfish suppression and coral protection outcomes across hundreds of reefs and augments the benefits of zoning plans and other management actions to enhance the resilience of the Reef and the industries that rely on it.

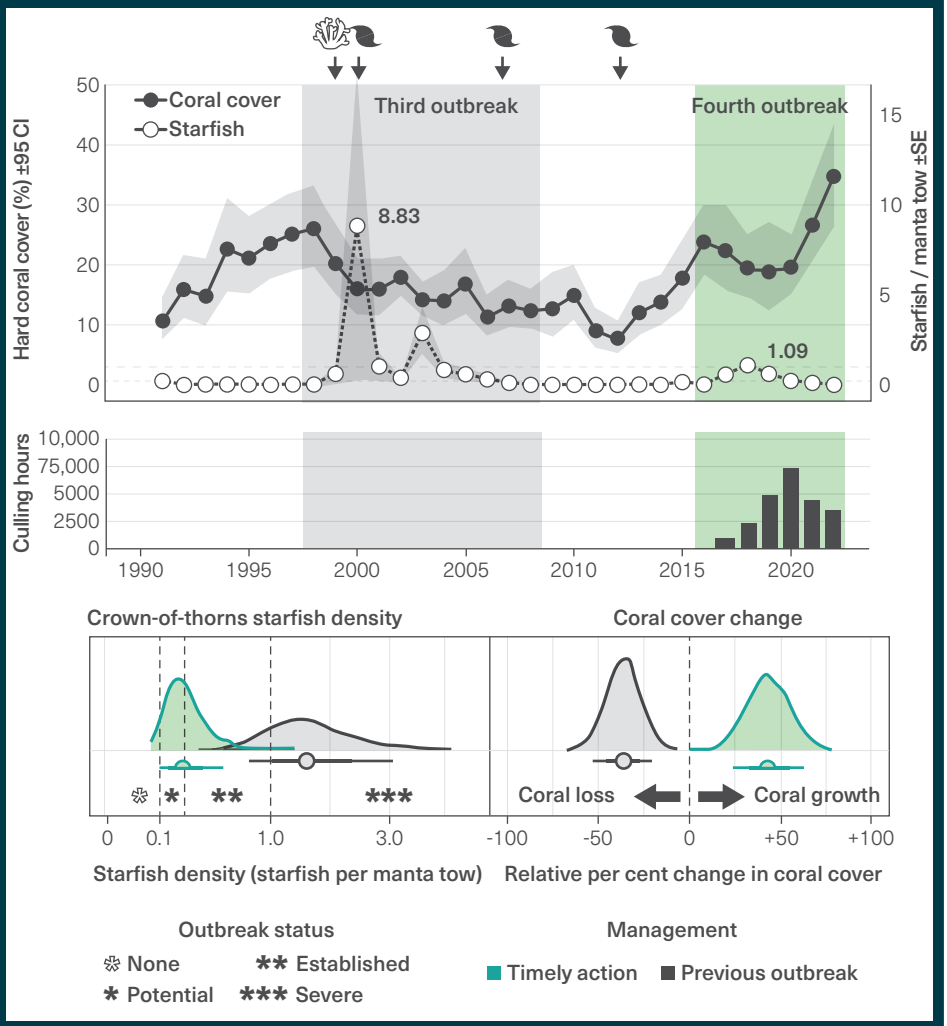


Figure 8.2 **Example of the effect of crown-of-thorns starfish control effort near Townsville, Great Barrier Reef Marine Park**

This panel compares outcomes during the previous (1998 to 2008) and current (2016 to present) crown-of-thorns starfish outbreak wave. Top panel: Estimates for coral cover (in percentage) and starfish densities (number of crown-of-thorns starfish per manta tow) from manta tow surveys conducted by the Australian Institute of Marine Science from 1992 to 2022. Culling effort (hours) shown below. Bottom panel: Posterior probability distributions comparing the starfish density and coral cover outcomes during the previous and current starfish outbreak waves. The findings illustrate the suppression of crown-of-thorns starfish and coral protection outcomes achieved with timely and sustained control effort during the current outbreak, relative to the higher starfish density and significant coral loss observed in the absence of starfish control during the previous outbreak. Source: Matthews *et al.* (2024).[187]

Only the strongest and fastest possible actions to decrease global greenhouse gas emissions will reduce the risks from and limit the impacts of climate change on coral reef habitats. Effective global action on climate change will greatly increase the effectiveness and positive impact of existing management actions in the Catchment and the Region.

Evidence for recovery or decline

Over the past decade (to the end of 2023), the largest ecological impact on the Reef has been four mass coral bleaching events linked to global warming and the El Niño–Southern Oscillation, two of which occurred in the past 5 years.[311,2037] A sixth widespread bleaching event was detected in early 2024.[167] The Reef has continued to be affected by cumulative pressures arising from the chronic effects of declining water quality[1734] and major large-scale disturbances, such as cyclones and periods of elevated sea temperatures (Figure 8.3), and crown-of-thorns starfish outbreaks.[1888,2038,2039]

The existence of large-scale variability in the exposure of the Region's coral reef habitats to stress and their ability to support recovery after acute disturbances,[161] highlights the existence of systemic resilience.[2040] Reassembly of the coral community, even in novel compositions, is the basis of a dynamic and resilient system.[2019] However, the strength of the system's resilience is less certain — how much more disturbance can the Reef's ecosystem absorb without significantly shifting its identity away from being a coral reef system. The recovery window between disturbances is expected to shrink in the near future because of the intensification and increased frequency of anthropogenic impacts.[573,2041]

In recent years, recovery of coral reef habitats, reported as increases in hard coral cover, has been detected on some inshore reefs[185] and documented for many offshore reefs across the Region.[161] Coral cover on inshore reefs remains relatively low where chronic environmental pressures are likely exacerbating the effects of acute disturbances and limiting the potential for recovery of coral reef communities.[158,185,2028] Coral cover on many shallow offshore reef slopes has reached its highest levels since the beginning of monitoring.[161] Increases in coral cover are driven primarily by fast-growing species, such as branching and tabular *Acropora*,[161] which are also sensitive to disturbances.

The use of coral cover as the primary indicator of resilience is not ideal[174,573] as it misses crucial information about recruitment, colony size, biodiversity and community composition.[174,2045,2046] These components underpin the function and resilience of coral reef habitats. Increases in coral cover may mask 'recovery debts' when the ecosystem fails to reassemble to a similar configuration of species and functions.[174] The extent and size of this deficit may be determined by how the functions of resistant or rapidly recovering species compare to the original set of functions before impact and degradation.[2045]

Lizard Island (Jiigurru) in the northern part of the Reef, 270 kilometres northeast of Cairns, has felt the effects of several large-scale disturbances in the last decade. These include cyclones Ita (2014) and Nathan (2015)[1643] and thermally induced coral bleaching in 2016, 2017 and 2020.[311,1604,2039,2047] Ocean acidification also poses an ongoing threat.[2048] The response of the coral reef habitats at Lizard Island to these disturbances demonstrates the complexity of resilience and recovery processes at a local scale.

In April 2014, cyclone Ita crossed the island from the north as a category 4 cyclone. Reefs on the north of the island were severely affected, and coral cover declined by 85 per cent at North Reef, though there was little detectable change elsewhere around Lizard Island.[1643] The fish community showed similar substantial site-specific abundance changes and species-level turnover.[372]

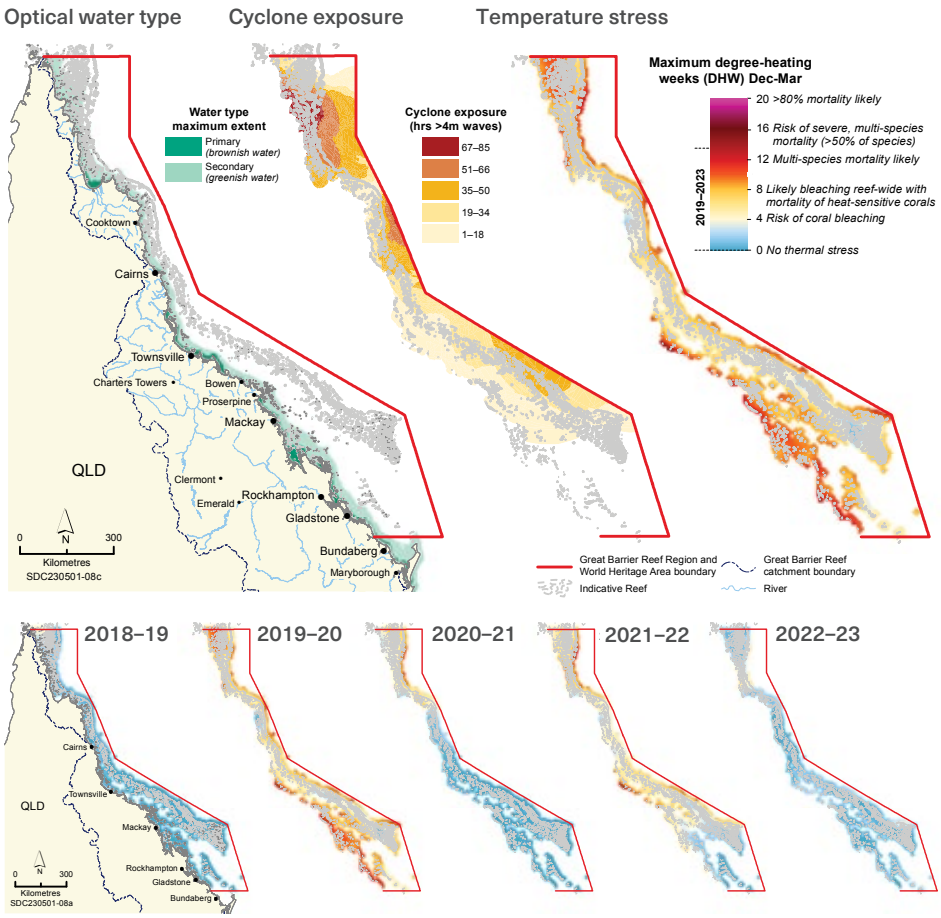


Figure 8.3 **Multiple disturbances affecting the Great Barrier Reef, 2018–19 to 2022–23, December to March**

The top panel series shows exposure for three important stressors across the entire period: left, maximum extent of primary and secondary water types; middle, total accumulated exposure to cyclone-generated waves exceeding 4 metres in height; and right, thermal stress as maximum degree heating weeks reached between 01 December to 31 March for the 2018–19 to 2022–23 summers. Maximum degree heating weeks reached for individual summers are shown along the bottom. Although widespread coral bleaching occurred across the Region in 2019–20 and 2021–22, most reefs did not experience heat stress sufficient to cause severe, multi-species mortality. A degree heating week is a measure of accumulated heat stress since 01 December above a physiological temperature stress threshold relevant to corals (1 degree Celsius above the maximum monthly mean). Source: Water type data from TropWater at James Cook University[2042] and 4 metre wave modelling data from the Australian Institute of Marine Science.[2043] Degree heating weeks (DWH) data from the US National Oceanic and Atmospheric Administration (NOAA) is a Coral Reef Watch analysis of maximum accumulated thermal stress (DHW) for the bleaching season, December–March.[2044]

In March 2015, cyclone Nathan crossed Lizard Island as a category 4 cyclone and affected reefs through waves generated from the south. In contrast to cyclone Ita, south-facing reefs suffered major declines in coral cover by up to 90 per cent at Trimodal Reef between South and Palfrey islands.[1643,1700] No further change in coral cover was detected at North Reef. Loss of coral cover was accompanied by reduction in abundances of branching coral (*Acropora, Pocillopora, and Stylophora*), but massive[2049] corals (such as *Porites*) were relatively unaffected.[1700] Some coral species also experienced sublethal effects such as a reduced reproductive capacity, probably due to energy being diverted towards processes such as injury repair.[1700] Some individuals of large surgeon fish were affected as their coral shelter was lost in cyclone-affected areas.[2050] At the island scale, the decline in cover was particularly notable as it approximately halved. However, impacts from back-to-back cyclones were patchy compared to the more uniform loss of cover and species diversity following the subsequent bleaching events in 2016 and 2017.

In April 2016, the largest mass bleaching event on record affected the Reef. Estimates of bleaching and loss of coral cover on northern reefs were more than 50 per cent in many locations[311] and around 80 per cent for Lizard Island.[1643,2039] Coral communities experienced bleaching again in 2017. This sequence of disturbances drastically changed the assemblage structure of reefs around the island compared to data from earlier in the 2000s and the mid-1990s.[1643] For example, loss of coral cover was accompanied by declines in genus and species richness with the total number of species across surveyed sites decreasing from 76 in 2011 to 49 in 2017. Only 28 of the coral species recorded in 2011 were recorded again in 2017.[1643]

Coral bleaching was widespread across surveyed sites; however, bleaching severity in adult colonies was often species-specific and habitat-dependent.[2051,2052] In general, *Acropora* corals showed a high susceptibility to thermal stress, including mortality of branching species,[1617] whereas *Porites* was often observed to have a degree of resistance to thermal bleaching. Reef-building stony corals *Porites, Pocillopora, Stylophora* and corals in the Merulinidae family experienced the least significant declines in abundance after these disturbances.[1643,2052]

In 2017, the dominant benthic taxa at Lizard Island were soft corals and species of massive *Porites* and Merulinidae. Overall, juvenile abundance did not vary significantly after 2016 bleaching; however, susceptibility to bleaching was also taxon-dependent.[53,2052] There were notable increases in the relative coverage of algal turfs and other main functional groups of algae following the decrease in coral cover and species diversity from the 2016 bleaching event.[874]

Sites surveyed in 2020 showed a shift in benthic community composition towards a higher relative cover of crustose coralline algae and macroalgae, rather than returning to a higher coral cover state. In 2020, coral cover on some reefs still accounted for less than 20 per cent of total cover.[1643]

By 2021, significant increases (up to 600 per cent) in coral cover were detected in semi-exposed reefs, such as North Reef and Trimodal Reef compared to 2018. These increases were primarily associated with recruitment of *Acropora*.[874] In some sites, *Acropora* coral recruits were able to grow to coral cover levels of 25 per cent (equivalent to the average coral cover on coral reefs globally[2053]) within just 2 years (from 2020 to 2022).[174] *Acropora* corals appear to be responding with a pronounced boom-and-bust pattern, while massive *Porites* colonies, which were relatively unaffected by repeated bleaching events, exhibit a precarious degree of resilience, increasing in area but with an underlying recruitment deficit.[1072]



Massive corals tend to resist bleaching more effectively than fast-growing species. © Matt Curnock 2022

A recent study showed that more than 75 per cent of the coral species recorded at sites around Lizard Island showed persistence through time despite the local disturbance history over the last 44 years. At site-level, coral species diversity has been in a state of flux over the 2011–2020 period. Significant declines in species richness were notable from 2011 to 2017 followed by significant recoveries from 2017 to 2020.[1644] While 284 of the previously recorded species appear to have persisted, 28 species that were recorded before 2011 have not been recorded in subsequent years and may be at risk of local extinction.[1644] An additional 31 species are under threat of local range reduction as they have not been recorded at Lizard Island or at nearby reefs since 2015.

The 2016 bleaching event also led to changes in fish assemblages. Decreases in fish abundance were primarily driven by declines in coral-associated damselfishes. However, fish abundance increased at several sites, suggesting substantial spatial movements.[1650] Some changes in fish community composition across habitats seemed to be uncorrelated with coral loss.[1617,1650] For example, some populations of obligate coral-dependent fishes persisted and continued to recruit [370] despite a significant loss of coral cover and the local depletion of habitat-providing *Acropora* in 2017.[1643] Reef assemblages that were previously distinct from each other showed increasing functional and taxonomic similarities post-disturbance. There were shifts towards predominance of small-bodied, algal-farming habitat generalists.[1617] Following disturbances and subsequent reassembly of fish communities, coral settlement and recruitment success were lower where the new fish assemblages contained more herbivorous fish but a lower diversity of foraging traits.[2054]

The resilience of coral reef habitats has been demonstrated at many locations on the Reef through the ability to begin recovery during periods free from intense acute disturbances. However, increases in coral cover do not necessarily represent reassembly of the coral community nor recovery of a reef's full diversity and function. The evidence from Lizard Island strongly suggests that the four disturbances have changed coral reef community assemblages profoundly. These changes have also directly affected key reef functions, such as ecosystem primary production and net calcification.[751] *Acropora* corals appear to have made a remarkable recovery at Lizard Island since 2017.[277] However, the sensitivity of these corals to bleaching means that these reefs also experience some of the most severe declines during marine heatwaves.[1604]

Some coral reefs have shown resilience through the ability to start recovery

Deficits in the performance and functioning of assemblages recovering from cumulative disturbances suggest that the return of coral cover alone cannot ensure the reassembly of reef trait diversity, and that shortening intervals between disturbances can limit recovery among functionally important species.[2045] Therefore, it is important to consider other components of the ecosystems that will likely play a role in making benthic habitats more conducive for coral settlement and recruitment. The variation in fish biodiversity is likely to contribute to spatially uneven patterns of coral recruitment and reef recovery because of the ability of reef fish to shape the reef benthos.[2054]

Shorter recovery windows will affect the ability of reefs to maintain structure and function

Coral cover variability over the last decade has included both the lowest and highest levels recorded and may suggest the Reef has entered a period of instability in coral cover succession dynamics.[162] In terms of resilience, a distinction can be made between assemblages that regain their original composition despite recurrent disturbances and

those that maintain functional traits despite shifts in species composition (potential adaption).[2045] The functioning of future coral reefs will be intimately linked to corals and the entire benthic and fish community. Given the increasing scale, frequency and intensity of disturbances on coral reefs, it is important to evaluate the persistence in space and time of corals, benthic organisms and fish species to further understand the impact that modern climate disturbances may be having on biodiversity, reef function and resilience.[1644] Indicators to support this evaluation are under development under the *Reef 2050 Long-Term Sustainability Plan* (Reef 2050 Plan).[2055,2056]

8.3.2 Seagrass meadow habitats

The Region is home to one of the world's largest seagrass resources.[2057] Seagrasses in the Region, particularly those in coastal habitats, act as a buffer between catchment inputs and reef communities.[2058] Seagrass meadows are crucial feeding grounds for populations of large herbivores including dugongs and green sea turtles.[516] Seagrass meadows in the Region are dynamic ecosystems, and significant changes in distribution and abundance due to natural cycles are typical in some regions.[2058] These cycles are often marked with decline in abundance and diversity followed by recovery. However, coastal development and the associated increase in land-based runoff are increasing the pressures on inshore seagrass meadows and affecting the frequency of the natural cycles of seagrass loss and recovery.[145] The significant proportion of seagrass meadows found in coastal areas are regularly exposed to threats associated with declines in water quality and available light.

Low light levels associated with reduced water quality can limit the growth and recovery of coastal seagrasses, and they have likely contributed to the complete disappearance of seagrass at some sites in the Region in 2011.[690] For seagrass meadows to be able to respond to acute and chronic disturbances, seagrasses must possess the necessary combination of characteristics that allows them to respond to changes. If they cannot respond quickly enough, these systems may be permanently lost.

Resilient seagrass meadows have the capacity to resist and recover from repeated, cumulative disturbances. Resilience in seagrass meadows is affected by:

- environmental features, such as good water quality and stable climate [2059] (Figure 8.1: the system's broader environment and social space)
- ecological features, such as connectivity between ecosystems and trophic interactions [2060] and grazing pressures from large herbivores such as dugongs 1903 (Figure 8.1: the system's ecological processes)
- intrinsic characteristics of seagrass meadows, such as life history traits, species diversity and presence of seed banks [2058,2059,2061] (Figure 8.1: the system's processes, with links to community and biodiversity structure).

Monitoring the extent, frequency and intensity of acute and chronic impacts, as well as the condition and trend of seagrass meadows, is essential to inform resilience-based management responses that assist seagrass meadows to remain productive.



Monitoring seagrass flowers informs resilience measures. © Kor-jent van Dijk 2009

Management

Seagrass meadows are important foraging grounds for large herbivores of cultural significance and nursery grounds for species of fisheries interest. Therefore, these ecosystems are managed and protected by proxy under various pieces of Commonwealth and Queensland legislation. The *Fisheries Act 1994* (Qld) (Fisheries Act) protects all marine plants, including seagrasses. The *Planning Act 2016* (Qld) manages the authorisation of ecologically sustainable development that involves the removal of or damage to marine plants. Other planning and assessment Acts and Regulations are used to protect seagrass meadows from potential development impacts, such as through powers to refuse or manage particular activities, to declare protected areas, or to place conditions on discharges or runoff.[2062] These tools include the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act), the *Environment Protection* (Sea *Dumping) Act 1981* (Cth), the Marine Park Act and the *Planning Act 2016* (Qld).

The primary focus of management actions to protect seagrass is to improve water quality entering the Region by implementing the *Reef 2050 Water Quality Improvement Plan.*[1883] Progress towards the plan targets is assessed through the *Reef Water Quality Report Card*. Understanding how the health and resilience of the Reef are affected by pressures such as declines in water quality is critical for evaluating the effectiveness of management actions. Information on the condition (and trend in condition) of inshore seagrass meadows is provided by the Great Barrier Reef Marine Monitoring Program, which also informs other initiatives, including regional report cards for Natural Resource Management regions. Seagrass rehabilitation methods are being explored, but outcomes are not yet available.

Recently, a seagrass resilience metric was developed specifically to assess and monitor how resilience of inshore seagrass meadows changes in response to impacts. The metric was developed to provide a measurable and practical indicator informed by “a set of measurable biological characteristics that exemplify seagrass meadows’ resistance to

pressures and essential mechanisms for recovery" as stated in the seagrass monitoring review by the Reef 2050 Integrated Monitoring and Reporting Program.[2063] The resilience metric takes into consideration intrinsic characteristics of seagrass species shown to support the resilience of the meadow. The metric was built upon the long-term historical data on reproductive status and size of seed banks (capacity for recovery), and species functional traits that determine the meadow's capacity to resist disturbance.[150] It uses a decision tree to assign site scores for resilience across three main categories: i) low resistance sites, ii) non-reproductive but high resistance sites, and iii) reproductive and high resistance sites.[150]

Evidence for recovery or decline

In the Region, inshore seagrass meadows have been monitored regularly since 2005.[145] When monitoring started, seagrass meadows in most parts of the inshore Region were in a good state of health with abundant foundational species and seed banks. Resilience was high in most regions, and meadows were considered to be in good to very good condition. However, inshore seagrass meadows have been subjected to persistent chronic levels of stress, mainly due to increases in land-based runoff. As a result, seagrass meadows in some regions have been left in a weakened state with limited resilience and unable to recover from episodic disturbance, such as thermal stress (Figure 8.4).

In late 2008, meadows in the northern Wet Tropics and Burdekin regions remained in a good state of health with abundant seagrasses and seed banks despite being affected by category 4 cyclone Larry in 2006.[2064] In contrast, locations in the southern Mackay Whitsunday and Burnett Mary regions were in poor and moderate condition, respectively, having low abundance, reduced reproductive effort and small or absent seed banks.[2065]

The onset of La Niña in 2009 caused a steady decline in seagrass condition in the Burdekin and Wet Tropics regions, and in locations within the Fitzroy region.[2066] This decline was likely driven by the above-average discharge from the catchments into the Reef.[2067] The level of decline became substantial across all habitats and meadows, which were in a vulnerable condition leading up to 2011 when the Reef was severely affected by category 5 cyclone Yasi. Post cyclone Yasi, the abundances of inshore seagrass were the lowest recorded since monitoring started. In 2011, most monitoring sites remained classified as poor or very poor in abundance, and severe losses were reported from the Wet Tropics, Burdekin, Mackay Whitsunday and Burnett Mary regions.[2066]

By 2017, little or no recovery had occurred across most of the regions, and seagrass condition began to gradually decline.[2065] Cumulative pressures, including severe climatic events, such as heat waves, continued to undermine the resilience of inshore seagrass meadows. Frequent and repeated disturbances seemed to be maintaining lower seagrass abundance at some locations, which in turn reduced the capacity of the seagrasses to expand and produce viable seed banks.[2068] Since 2019, recovery was sustained across northern regions for a couple of years despite being affected by heatwaves in 2020 and 2022.[149] However, meadows in the southern regions of Fitzroy and Burnett Mary remain in poor condition and continue to decline, especially after the heavy floods in Burnett Mary catchments in early 2022.[149]

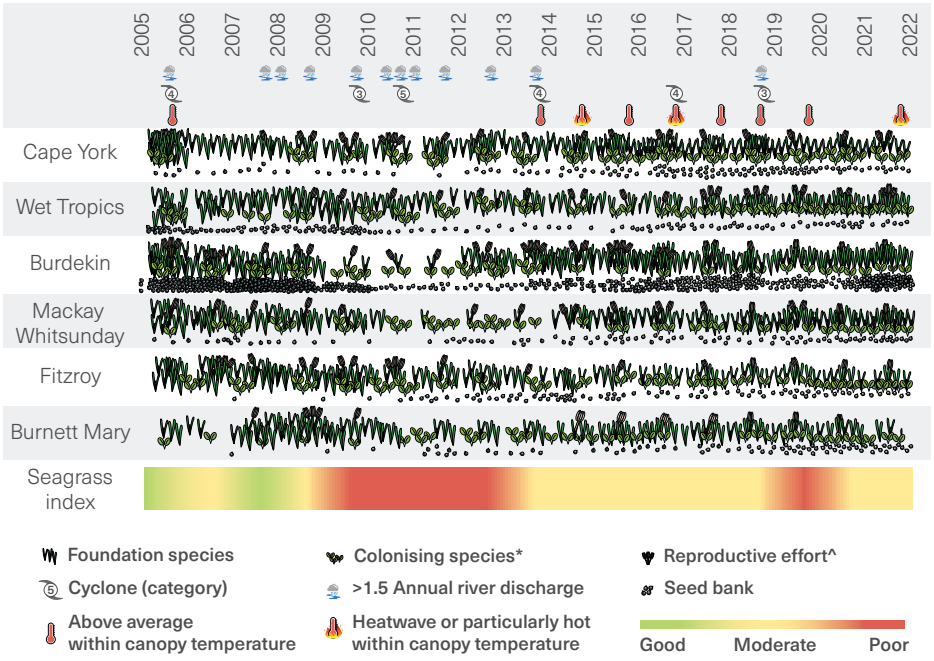


Figure 8.4 **Summary of the state of inshore seagrass for each Natural Resource Management region, 2005 to 2022**

The diagram illustrates pressures, abundance of foundation and colonising species, seed bank abundance, and reproductive effort. These factors provide information on the meadow's capacity to resist and recover from disturbance. The resilience component of the seagrass index uses a decision tree to assign site scores for resilience across three main categories from lowest to highest resilience: i) low resistance sites, ii) non-reproductive but high resistance sites, and iii) reproductive and high resistance sites. * Colonising species are represented by the genus *Halophila*; however, *Zostera* and *Halodule* species can be either colonising or foundational species depending on meadow state. ^ Reproductive effort not recorded in 2005. Source: Adapted from McKenzie *et al.* (2023).[145]

Seagrass meadows in the Burdekin region have demonstrated exceptional resilience to cumulative disturbances. Inshore seagrass meadows in the Burdekin region are primarily structured by wind-induced turbidity (resuspension) in the short term and by episodic riverine delivery of nutrients and sediment in the medium term. Disturbance from wave action, sediment movement and elevated sea surface temperatures are also dominant influences. Rainfall in the Burdekin region is often lower than in other Reef regions.[363]

Like in the rest of the Region, seagrass meadows in the Burdekin region had high proportion of foundation species, high reproductive effort, and abundant seed banks at the beginning of monitoring in 2005 (Figure 8.5). Declines in condition started in 2008 due to large flood events and continued following cyclone Yasi, hitting their lowest point in the 2010–11 monitoring year.[2066] From 2011, the seagrass rapidly recovered, and by 2013–14 seagrass abundance had nearly recovered to pre-2011 levels. Resilience was also high with high levels of foundational species and seed banks.[2069] However, recovery has varied between habitats, and seagrass abundance has progressively declined at intertidal and subtidal reef habitats since 2015. Nevertheless, overall seagrass condition remained good for four consecutive years despite two back-to-back marine heatwaves that affected the Region in 2016 and 2017. In 2017–18, coastal seagrasses increased to their highest abundance since 2001; however, this was immediately followed by large declines in 2018–19.[2068]

In 2018–19, the Burdekin region was affected by major acute events, such the high discharge event from the Burdekin River coupled with unusually large outputs from the smaller creeks and rivers discharging into Cleveland Bay in early 2019.[2068] This led to declines in seagrass abundances across the region, the largest losses occurring in reef

subtidal and coastal intertidal habitats. Sediment loads in the discharge, and wind-driven resuspension, elevated turbidity and reduced benthic light during the wet season, were a legacy from the Burdekin River floods. However, light availability quickly returned to seasonally expected levels in the dry season, during which rainfall and discharge were below average, allowing recovery at some sites.[2068]

In 2020–21, seagrass abundance recovered, and resilience increased slightly, but varied between sites. In coastal intertidal seagrass habitats, reproductive effort and seed banks increased to their highest level in 2 years [2070] but remained very low in reef intertidal and subtidal habitats. In all habitats, seed density was higher in the late wet season, indicating a possible late flowering and seed set. After a slightly cooler 2020–21 season, intertidal within-canopy temperatures increased in 2021–22 and were, on average, the warmest since monitoring was established.[145]

Burdekin region seagrass meadows have demonstrated resilience for nearly 20 years

For almost 2 decades, seagrass meadows of the Burdekin region have demonstrated high resilience, particularly through their capacity for recovery (Figure 8.5). The presence of a robust seed bank and high species diversity, which are characteristics known to confer resilience, may indicate a conditioning to acute disturbances and reflect the nature of the disturbances, which are episodic and dominated by wind events and Burdekin River flows.

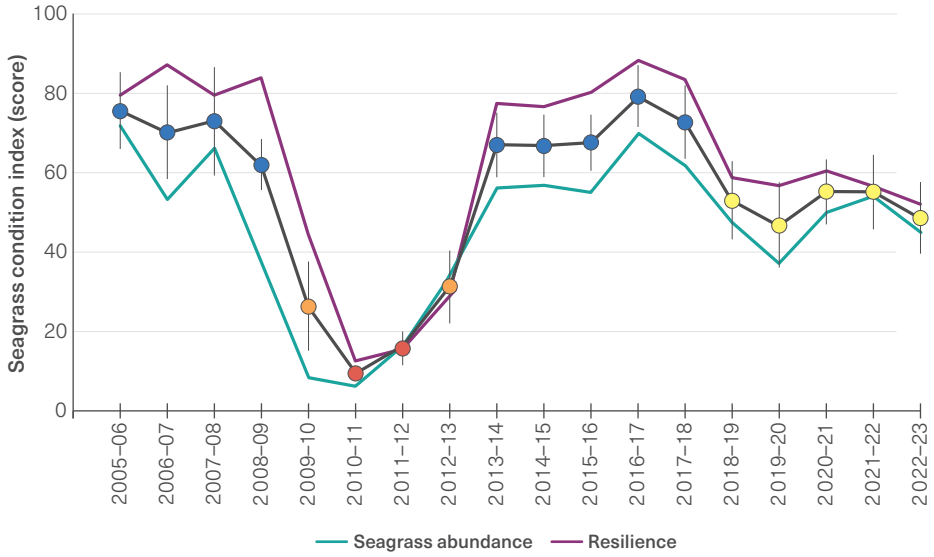


Figure 8.5 **Condition of inshore seagrass meadows for the Burdekin region, 2005–06 to 2022–23**
Black line with circles represents the seagrass condition index score. Values are scaled from 0 to 100 (no unit) and colours indicate grade. Dark blue ● = very good (81–100). Blue ● = good (61–80), Yellow ● = moderate (41–60), Orange ● = poor (21–40), Red ● = very poor (0–20). The seagrass condition index combines indicators for seagrass abundance (teal line) and resilience (purple line). Source: McKenzie *et al.* (2023).[145]



Damage to seagrass leaves likely caused by exposure to elevated water temperature. © Dieter Tracey

8.3.3 Black teatfish

Tropical sea cucumbers are harvested globally to produce the high-value product called bêche-de-mer.[326] Approximately 70 species of sea cucumbers are commercially fished, although commercial value varies greatly between species.[326,2071] The harvests are predominantly exported, mainly to China and other Asian nations for consumption and use in traditional Chinese medicines.[326] In the Region, the black teatfish sea cucumber *Holothuria whitmaei* has a high commercial value in Queensland's east coast fishery. Sea cucumbers are sedentary, and the recruitment of sea cucumber populations depends on the density of individuals at a local scale. These characteristics make teatfish vulnerable to overharvesting.

Black teatfish are vulnerable to overharvesting

In the Region, the black teatfish fishery closed in 1999 due to overharvesting causing the depletion of density and biomass of this species. On reefs north of Townsville, biomass had reduced by 75 per cent compared to estimated unfished biomass.[2072] In 2019, the black teatfish fishery reopened after industry-led surveys found the population biomass had increased.[2073] Due to the high value of sea cucumber and increasing pressure from domestic markets, harvest for the black market is a risk for this fishery.[1287]



Black teatfish on Lark Reef. © Kristen McSpadden 2023

Sea cucumber behaviour and biology have important effects on processes, such as bioturbation and bioremediation in coral reef ecosystems, inshore seagrass meadows, mangrove systems, and deeper continental habitats.[2071,2074] They also contribute to deposit-feeding as a pathway for regeneration and mineralisation of surface sediments.[2071] The management of this fishery considers the important ecological role of sea cucumbers in marine ecosystems.[1287]

Management

The Queensland Sea Cucumber Fishery (East Coast) was established in 1996, under the Fisheries Act. Currently, the commercial bêche-de-mer fishery is managed by the Queensland Department of Agriculture and Fisheries under the *Queensland Sea Cucumber Fishery Harvest Strategy: 2021–2026*.[1287] The design of the *Great Barrier Reef Marine Park Zoning Plan 2003* protects a minimum of 20 per cent of each reef bioregion from extractive activities, including those containing suitable habitat for black teatfish. The black teatfish is listed as Endangered on the International Union for Conservation of Nature Red (IUCN) List, but this species is not protected under Australian legislation.[17]

In the Region, the fishery is limited entry with only 18 commercial licences, which allows for individual transferable quotas for black teatfish. Effort restrictions are applied through rotational zones that limit access by restricting the number of days of permitted harvesting at each reef or group of reefs each year, distributing the catches spatially.[1287] The hand-harvesting method used in the fishery is highly selective, resulting in minimal risk to non-target species.[347] Recreational harvest of black teatfish is not permitted in Queensland.

Specimens being exported from Australia for commercial purposes must come from an approved commercial source, such as a fishery approved as a wildlife trade operation under the EPBC Act. Under the EPBC Act, the species can only be exported via a permit issued by the Department of Climate Change, Energy, the Environment and Water in accordance with the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES), to which Australia is a signatory. After a positive non-detriment finding by the Department, the fishery was granted a short 12-month export approval. This prompted the first stock assessments and environmental risk assessment for the Queensland fishery.[347,2075]

Evidence for recovery or decline

In 2021, the latest stock assessment for black teatfish found that population biomass was 40 to 42 per cent of the unfished biomass in 1877, which is when fishing for sea cucumber in Queensland began.[347] This model suggests that the biomass had steadily increased since 2001, but that this recovery was slower than expected.[347] The fishery was closed between 2000 and 2019 and some evidence suggests that recovery since the closure has been more limited than the stock assessment results indicate.[326,1290, 2076]

Concerns remain around the accuracy of the stock assessment models because of uncertainty around biological parameters, such as age at maturity, lifespan,[326] and fertilisation and recruitment success particularly at low densities.[1290,2076] Current information on status or trends for the stock of black teatfish in fished and unfished reefs is also a knowledge gap.[100,110,326,347]

8.3.4 Coral trout

Coral trout belong to the genus *Plectropomus* and are one of the largest and most conspicuous fishes on coral reefs of the Indo-Pacific. They are key reef predators that play an important role in the transfer of energy through the food chain and influence the composition of fish assemblages through top-down control via predation.[1331,2077] Coral trout are also highly prized food fishes that are targeted by commercial, recreational, artisanal and subsistence fisheries throughout their geographic ranges.[2078,2079] Coral trout is one of the major components of the line fishery catch in the Reef. The genus *Plectropomus* has 8 species, of which 6 occur in the Region.[2080]

Common coral trout (*Plectropomus leopardus*) is the most abundant and widespread coral trout species across most of the Region.[2081] Two closely related species, the spotted (bar-cheek) coral trout (*Plectropomus maculatus*), and the black-saddled (footballer/blue-spot) coral trout (*Plectropomus laevis*) are common on inner-shelf and outer-shelf reefs, respectively.[2081,2082] Common coral trout typically have constrained home ranges but can move considerable distances within and sometimes among reefs, particularly when transiting to and from spawning aggregation sites.[2083,2084,2085]

Common coral trout are protogynous hermaphrodites that transition from female to male throughout their development.[2078] Females reach sexual maturity at 30 to 37 centimetres total length and 2 to 3 years of age.[2086] The size and age of transition from female to male is variable but is likely to be influenced by a range of factors including population size structure, behavioural processes, and fishing intensity.[2086] In the Region, peak spawning periods extend over several days around new moons spanning the Australian summer.[2087] However, recent evidence also shows that the Reef's coral trout can spawn and produce viable offspring throughout the year.[1357] Hybridisation among several coral trout species is known to occur, including between common coral trout and spotted coral trout.[2088,2089]

Coral trout closely associate with coral reef habitat. Post-settlement juvenile coral trout are commonly found in patchy reef habitats with interspersed live coral colonies that provide them with shelter.[2090] Adult coral trout often reside under tabular corals and within reef crevices that provide shade, shelter and concealment from which they can ambush prey.[2091] Coral trout population dynamics and resilience can be strongly influenced by changes in coral cover, reef habitat complexity and prey abundance following disturbance events.[2091,2092,2093] Therefore, coral loss can increase the risk of overfishing of coral trout stocks due to sudden productivity declines.[2094] For example, on fringing reefs in the Keppel Islands group in the southern region, coral trout abundance was significantly reduced, and tracked the trajectory of declines in coral cover and prey fish abundance, following flood plume disturbances between 2009 and 2013.[2092]

A recent study has shown that physiological parameters used to assess the health of coral trout were unrelated to coral cover at sites where individual fish were captured. These results suggest that adult common coral trout may be resilient to declines in coral cover, at least over periods of 2 to 5 years following acute coral loss caused by climate-induced mass coral bleaching.[2095] Given the age at first breeding for coral trout is 2 to 3 years and that adult biomass is dominated by older age classes, the impacts of reduced coral cover on adult biomass are unlikely to manifest for at least 5 years.[2094] Additionally, past stock assessments for coral trout have not found any clear association between bleaching events and coral trout catchability. However, a previous stock assessment observed that coral loss caused by cyclones correlated with lower catchability of coral trout over the following years.[2096] A lack of relationship between coral cover and the health of individual adult coral trout likely represents the coral trout's increased access to prey resources and reduced investment in key energetic process, such as growth. These factors may increase the resilience of coral trout to habitat degradation in the short-term.[2095]

Pressures such as increases in sea temperature can directly affect fish physiology and behaviour, which can ultimately undermine the capacity of coral trout populations to acclimatise or adapt to changes in environmental conditions.[2097] Loss of coral and habitat degradation are also factors influencing coral trout biology and ecology.



Coral trout benefit from the structure provided by coral reefs. © Matt Curnock 2022

Management

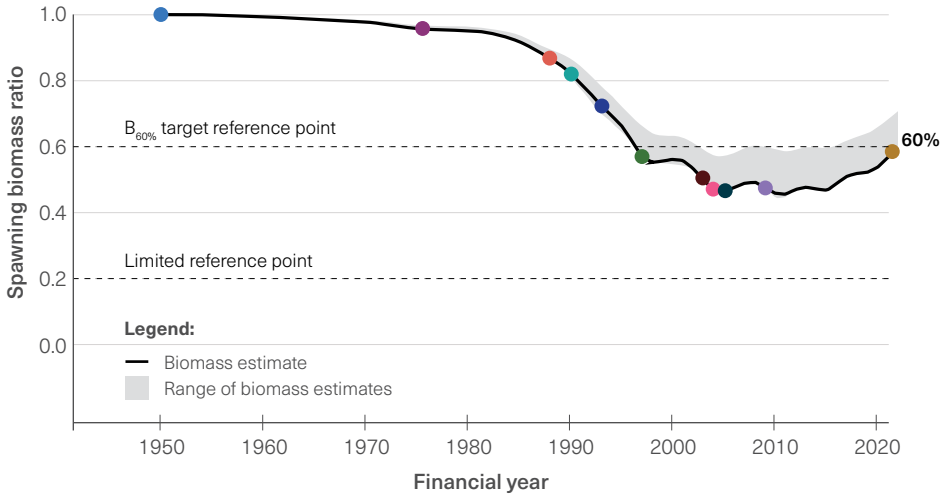
Coral trout are the primary targets of the Queensland Reef Line Fishery.[1270] The fishery makes no distinction between coral trout species, and they are collectively marketed as coral trout, but common coral trout are the primary target species.[2098] Coral trout comprise approximately 35 to 55 per cent of the commercial catch, 20 to 25 per cent of the charter catch and 15 to 20 per cent of the recreational catch of demersal reef fish from the Reef.[2099]

Coral trout are managed as a single stock using a range of fishery controls, including individual transferable quotas (ITQs) and a total allowable commerical catch (TACC) for the commercial sector, as well as a minimum length limit and a recreational in-possession (bag) limit.[2100] Annual coral trout harvest peaked at approximately 2000 tonnes in the early 2000s before the introduction of ITQs and a TACC of 1350 tonnes in 2004 and a further reduction to 1280 tonnes in 2005 (Figure 8.6).[1270] In 2022, a common coral trout stock assessment identified that total retained coral trout catch averaged 1002 tonnes between 2017 and 2021. This included 812 tonnes by the commercial sector, 68 tonnes by the charter sector, 111 tonnes by the recreational sector and 11 tonnes by First Nations (Traditional Owner) fishers.[1270]

The *Great Barrier Reef Marine Park Zoning Plan 2003* has generated significant benefits for coral trout stocks and other reef-associated species.[2101] Coral trout are more abundant, larger, older, and more fecund on Marine National Park Zone (no-take reserve) reefs than on reefs that have remained open to fishing.[58,2102] Furthermore, no-take reserves also export coral trout larvae and deliver recruitment subsidies to fished reefs, contributing to population replenishment and fishery sustainability across the Region.[2102,2103] The existing management regime that mixes Marine Park no-take zones and catch quotas is robust to regional variation in ecological dynamics, overfishing and climatic change.[656]

The Queensland Reef Line Fishery is also subject to short seasonal closures during summer new moons that apply to both commercial and recreational sectors. The closures are based on the presumption of seasonal and lunar spawning of the common

coral trout.[1270] However, a recent study has shown that year-round spawning activity generates distinct recruitment cohorts that span several weeks to months in the Region. In some instances, peak spawning had little or no alignment with existing seasonal fisheries closures around the new moon.[1357] Given the recent indication of variability and uncertainty in peak spawning times,[1357] the coral trout fishery may further benefit from additional and longer seasonal closures, or alternative fisheries management strategies, to maximise the recruitment contribution from periods of greatest reproductive success.[2088]



1950: Commercial coral trout fishery begins.

1976: MLS introduced at 35 cm for 'coral trout' (nominally *Plectropomus maculatus*).

1988: Commercial logbooks implemented.

1990: Sale of recreational catch prohibited.

1993: MLS increased to 38 cm and recreational bag limit (10 fish) introduced for coral trout (all *Plectropomus* species).

1997: Investment warning is issued.

2003: Recreational bag limit reduced to 7 coral trout (all *Plectropomus* species) and 20 reef fish.

2004: Spatial fishing closures introduced through the *Great Barrier Reef Marine Park Zoning Plan 2003* (Cth).

ITQs and a TACC of 1350 tonnes introduced.

Spawning closures for coral trout introduced — 9 days around each new moon in October, November and December each year.

2005: TACC reduced to 1288 tonnes.

2009: Coral trout spawning closures reduced to 5 days in October and November each year.

2021: Changes to logbook reporting (specific coral trout recorded). Quota changed regularly between 2005 and 2021.

Figure 8.6 **Australian east coast stock assessment biomass estimate, 1953 to 2022**

The chart presents the biomass ratio of common coral trout and key management actions from 1953 to 2022. The ratio is relative to a value of 1 in 1953. Data used in the stock assessment include 53 years of commercial catch data, 37,061 fish aged, 41,472 commercially caught fish measured, 6778 recreational catches measured, 8242 fish measured in underwater visual surveys and 26,883 fish observed in underwater visual surveys. MLS: minimum legal size. ITQs: individual transferable quotas. TACC: total allowable commercial catch. Source: Modified from Queensland Department of Fisheries (2022), original plot generated 08 March 2022.[2104]

Evidence for recovery or decline

The latest stock assessment modelling for coral trout indicated that between 1953 and 2011 biomass declined to 46 per cent relative to unfished spawning stock biomass. Spawning stock biomass has been steadily increasing since 2012. In 2022, the stock level was estimated to be at 60 per cent unfished biomass.[1270] Coral trout stock assessment modelling draws upon Reef fishery catch and effort data and fishery-independent underwater visual census data. The use of fishery-independent data is fundamental to accounting for differences in coral trout abundance and size between reefs that are open and closed to fishing within the Marine Park.[1270]

Fisheries controls and the zoning plan have helped coral trout populations

It is important to note that these modelling results do not take into consideration environmental factors known to affect stock levels, and they incorporate limited information on recreational catches. Nevertheless, the stock assessment provides the best evidence that fishery controls on catch and effort, combined with Marine Park zoning and compliance, have led to an increase in coral trout population size and enhanced the sustainability of reef line fishery catches. There is growing concern about the impacts of climate change on coral trout populations.[1270] While coral cover in the Region has recovered recently to record highs in some reefs,[161] continuing increases in cumulative disturbances, such as cyclones and increased sea temperatures, can result in significant coral loss. Habitat degradation may increase the vulnerability of common coral trout to exploitation and undermine fisheries sustainability.[58,1646,2105]

8.3.5 Loggerhead turtles

The south-west Pacific population of loggerhead turtles nest on the Region's mainland and island beaches. The primary nesting sites for this stock are from Mon Repos near Bundaberg (outside and just south of the Region) to Wreck Rock (inside the Region). Key nesting sites within the Region include Wreck, Erskine and Tryon islands and the southern Reef. Post-hatchling loggerhead turtles disperse to oceanic pelagic foraging areas off Chile, Peru and Ecuador via the East Australian Current and the South Pacific Gyre.[2106, 2107] They remain in oceanic waters for approximately 16 years, returning to recruit to benthic foraging areas in continental shelf waters in the south-west Pacific as juveniles.[2108]



Loggerhead turtle at Lady Elliott Island. © Chris Jones 2020

The population has been affected by several historical, ongoing and recently emerging pressures. From the 1970s to the year 2001, bycatch mortality in the Northern Prawn Fishery, Torres Strait Prawn Fishery and Queensland East Coast Otter Trawl Fishery contributed to the population's severe decline of 86 per cent during that period in northern

and eastern Australia.[2109,2110] The use of turtle excluder devices was made mandatory in the otter trawl fisheries of northern Australia in the early 2000s. This reduced the incidental capture and mortality of subadult and adult loggerhead turtles. A recent study reported that most loggerhead turtles returning to Wreck Rock beaches in the 2022–23 breeding season had breeding histories spanning less than 20 years.[471] This indicates they commenced their breeding life following the mandating of turtle excluder device use.

Predation of loggerhead nests by foxes, dogs and goannas on the mainland has led to significant loss of clutches since the 1970s. Predation by goannas and foxes is still recorded at Wreck Rock.[471] The draining of the swamp behind Mon Repos beach in the 1960s and 1970s lowered the water table, contributing to low hatching success in hot and dry conditions. Hatching success is poor at mainland nesting beaches due to natural erosion, storm erosion and flooding.[471,2111] Erosion is increasingly evident as extreme weather events become more frequent. Entanglement in fishing gear and recreational boat-strike are identified as high-risk threats for loggerhead turtles.[444] Ingestion of marine debris, particularly ingestion of plastic by small post-hatchlings who feed at the surface, is increasingly reported.[2112]

Climate change is also affecting loggerhead turtles in the Region. Much like other marine turtle species in the Region, hatchling sex ratios for loggerhead hatchlings are changing due to increased sand temperatures affecting their temperature-dependent sex determination.[443] Extreme weather events are expected to increasingly cause erosion and loss of nesting sites.[2113] Furthermore, altered sand budgets, rising sea levels, changes in forage communities, ocean acidification and shifts in prevailing ocean currents are emerging threats that are poorly understood and are likely to be beyond the influence of local management efforts.[443]

As sea temperatures continue to affect sex ratios of turtles, male sea turtles may become increasingly rare due more females being produced at warmer temperatures.[443,2114] However, there is strong evidence that males generally breed more frequently than females, and that individual breeding males actively search for females and may mate with multiple females from different nesting sites.[2114] These characteristics can help mitigate female-biased hatchling sex ratios, conferring a degree of resilience against warming in the short term.

Management

Loggerhead turtles are listed as endangered in Australia under both Commonwealth (EPBC Act) and Queensland (*Nature Conservation Act 1992*) legislation. Loggerhead turtles are protected under the CITES convention as they are listed in Appendix 1, species threatened with extinction. A single species action plan [2115] has been prepared to guide regional management of the South Pacific Ocean stock of loggerhead turtles under the Convention on Migratory Species (Bonn Convention), to which Australia is a signatory. Additionally, 80 per cent of loggerhead turtle nesting occurs adjacent to the Great Barrier Reef Marine Park within the Queensland National Park estate, which is managed by the Queensland Parks and Wildlife Service under the *Nature Conservation Act 1992*. Management of loggerhead turtles and their habitat within these areas is conducted by Queensland Parks and Wildlife Service, the Reef Authority, local government councils, the Indigenous Land and Sea Ranger Program and community volunteers.

The Queensland Turtle Conservation Project is one of the world's longest running research and monitoring programs, having collected loggerhead turtle nesting data since 1968. The *Queensland Marine Turtle Conservation Strategy 2021–2031*,[443] and the *Recovery Plan for Marine Turtles in Australia 2017–2027* [1351] outline key threats to marine turtles in the Region and management objectives to support recovery of their populations.

Understanding and responding to impacts on marine turtles are also goals of the Reef 2050 Plan.[2116] Recent targeted initiatives to support loggerhead turtles include plans to re-establish the swamp behind Mon Repos to improve water flow to the nesting beach, led by Queensland Parks and Wildlife Service. The Department of Climate Change, Energy, the Environment and Water's *National Light Pollution Guidelines for Wildlife* [2117] outlines recommendations to address potential adverse effects of artificial light on marine turtles. Public awareness campaigns along the Woongarra coast promote reducing artificial light during the nesting season to help mitigate disorientation in female turtles and hatchlings and increase recruitment success.[2118]

Beach cooling trials along the Woongarra coast nesting beaches commenced in the 2021–22 nesting season. The success of interventions, placing nests in shaded incubation cages and hatcheries or applying artificial rain to *in situ* nests, is yet to be evaluated.[470]

Funding has also been provided through the Nest to Ocean Turtle Protection Program as projects funded aim to reduce the threat of predation on marine turtle nests and hatchling (including loggerhead turtles).[2119]

Evidence for recovery or decline

Populations of nesting females are declining on both the mainland and islands. Along the Woongarra coast, numbers of nesting female loggerheads decreased from 497 in 1977–78 to 207 in 2001–02 (Figure 8.7). From 2001, mainland nesters began showing initial recovery in numbers [471,2120] following the introduction of mandatory turtle excluder devices in the Northern Prawn Fishery, the Torres Strait Prawn Fishery and the East Coast Otter Trawl Fishery.

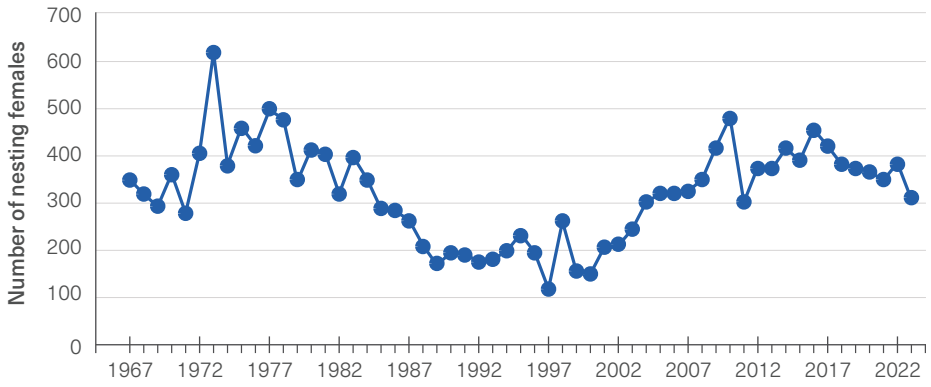


Figure 8.7 **Number of tagged loggerhead turtles nesting, Woongarra coast, 1967 to 2023**
Data for the 1967 and 1968 nesting seasons are population estimates. Data for nesting seasons from 1969 to 2023 are derived from population censuses. Nesting seasons occur over summer and are referred to by the year in which they start. Source: Queensland Department of Environment and Science (2023) [438] and Limpus (2008).[2108]

The number of females nesting on the Woongarra coast had increased to 385 in 2022–23, but the 2023–24 the figure is lower (Figure 8.7).[438] Further north along the mainland coast, numbers at Wreck Rock beaches also recovered somewhat after 2001, but they are showing signs of decline over the 6 years leading up to 2023–24.[471] The recent downturn in the size of the annual nesting population of loggerhead turtles is of concern.

In the 1970s, island beaches hosted most loggerhead nesting in the Region, but more recent numbers nesting on island beaches are very low. Negligible recovery has been observed at the island rookeries in the Region, 58 females were recorded nesting at Wreck Island in 2022 compared to 57 in 2001. These numbers are significantly lower than the

589 recorded in 1977.[438] The difference in recovery between island and mainland nesters is attributed to their different foraging distributions.[467] Island nesters typically migrate further, and northward, to their foraging grounds. This movement means they are more likely to traverse unprotected habitats in international waters, where they are susceptible to harm during migration and foraging.[467]

Recruitment of young turtles has declined by half over the last 20 years

Recruitment of young turtles to Australian foraging grounds has declined by 50 per cent over the last 20 years, approximately.[470,2121] The proportion of first-time breeding female loggerheads within the annual nesting population on the Woongarra coast has declined from 41.5 per cent in 2001 to 20.9 per cent in 2021.[438] The loggerhead population foraging in eastern Australian is already excessively biased to males in all age classes, and most juveniles successfully recruiting to foraging grounds are males. The island beaches produce relatively high proportions of male hatchlings, suggesting that the recruiting cohort predominantly originate from the islands and mainland hatchlings may be experiencing barriers to successful recruitment. Post-hatchling turtles from the mainland may be affected by changes to winds that could reduce their ability to move away from the nesting area and enter the East Australian Current to begin dispersal. However, research is required to confirm this. Similarly, ambient night-time light can disorient emerging hatchlings, causing them to go the wrong way or congregate around artificial structures where they are vulnerable to higher levels of predation.[2122] The impact of artificial light on the Woongarra coast has been highlighted in recent years as coastal urban expansion continues near major mainland nesting sites. Low recruitment is expected to result in a decline in nesting once the current juvenile cohorts grow and reach maturity.

Despite the Region's loggerhead population showing initial recovery in response to the local management actions, the population is facing a suite of continuing and increasing threats, many of which are unquantified. Existing management efforts, such as mandatory use of turtle excluder devices, predator control programs and beach cooling projects, including re-establishing the swamp behind Mon Repos beach, are considered essential to the long-term recovery and resilience of the stock.

8.3.6 Urban coast dugongs

Urban coast dugongs are those found along the coast of Queensland, between Cooktown and the southern Region. Dugongs are seagrass community specialists and are generally sighted in the vicinity of seagrass meadows.[2123] Urban dugong populations belong to two distinct breeding units, separated by a genetic break in the Whitsunday Islands region. It is not known if individuals of these populations cross between these two genetic units [518] but movement has been inferred from aerial surveys.[519]

Direct human impacts that kill adult animals are dugongs' greatest threat. [141,1904] These include incidental entanglement in fishing gear, vessel strike and illegal and legal harvest. The impact of legal harvest and illegal poaching on dugong populations remains a knowledge gap. Extreme weather events, such as prolonged or heavy rain, floods, marine heat waves, algal blooms and cyclones can indirectly affect dugong populations by reducing food availability, which in turn can increase adult mortality, reduce fecundity, delay breeding and lead to changes in dugong movement habits.[2124]

Dugongs feed mainly on seagrasses,[2123] making them susceptible to indirect impacts that affect the extent and community composition of their seagrass habitat. The frequency of extreme weather events is increasing over time due to climate change. Loss of seagrass can exacerbate the anthropogenic pressures directly affecting dugongs.[2125]

Management

Dugongs are listed as Vulnerable in the IUCN Red List.[1354] They are recognised in the Statement of Outstanding Universal Value for the Great Barrier Reef World Heritage Area, as are seagrass meadows, which are primary feeding grounds for dugongs. Dugongs are designated a matter of national environmental significance as a migratory and a protected marine species under the EPBC Act.

The *Action Plan for Australian Mammals 2012* has a list of information needs for dugongs.[2126] Local-scale information is collected by Indigenous rangers and the Queensland Parks and Wildlife Service in the marine wildlife strandings database, StrandNet, which records numbers of stranded and injured animals through time. The Queensland Department of Agriculture and Fisheries collects data on interactions between dugongs and fishing equipment via inspection of commercial logbooks and data on incidental interactions with the Queensland Shark Control Program (Section 5.4.3). Information on bycatch, hunting and poaching is still lacking.

Further initiatives to reduce direct threats to dugongs include fishery-wide cameras being installed on boats for validation of data and scrutiny of current practices. Additionally, new and continuing agreements with Traditional Owners support sustainable traditional use, research and monitoring of the Region's dugong populations.[2127]

Despite the collective effort to monitor dugong populations in the Region, there is considerable uncertainty in spatial estimates of populations,[520] primarily due to poor detectability by aerial surveys of dugongs in deep water and under different environmental conditions. Dugong abundance estimates in Australia were recalculated in 2019 using improved methods.[2128 2129,2130] Using drones provides the potential to conduct repeated surveys and collect long-term information at local scales.[1904,2131] There may be increasing opportunities for involvement of First Nations rangers on vessel-based surveys. Monitoring changes in the density of dugong feeding trails can also inform population trend estimates.[2128]



Dugongs seen during aerial surveys. © Christophe Cleguer 2023

Evidence for recovery or decline

Declines of dugong populations along the urban coast of Queensland have been estimated based on changes in the catch per unit effort of dugong bycatch in a government shark control program since the 1960s.[2132] Dugongs have been monitored along the coast of Queensland using standardised aerial surveys for estimating long-term distribution and abundance since the 1980s. Monitoring is also a requirement under the objectives of the Reef 2050 Plan. It is estimated that the current size of the urban coast dugong population is small compared to pre-European numbers and may never recover.[2128]

Between 2005 and 2022, the lowest density of urban coast dugongs was recorded in 2011, following floods and cyclones in the 2010–11 summer.[522] Record numbers of dugong strandings occurred during that period. Numbers recovered by 2016, and fewer strandings have been reported since 2011, likely due to the recovery of the seagrass food resource. Another post-flood decline in seagrass occurred in the intertidal areas of south-east Queensland in the 2021–22 monitoring year.[145] The life history traits of dugongs, such as long lifespan and late maturity, contribute to their slow recovery rate even under good conditions.

The most recent aerial surveys, conducted in November and December 2022 from Mission Beach to the Queensland–New South Wales border, estimated an overall long-term decline in Great Barrier Reef urban coast dugongs of 2.3 per cent per year since 2005.[522] Previously, it was estimated as declining at a rate of 4 per cent per year from 2005 to 2016. The current dugong population in the urban coast of the Region is estimated to be around 2124 individuals, based on the Mission Beach to Bundaberg surveys. This is the lowest population estimate across all surveyed regions.[522]

There are spatial differences in reported population trends. Hervey Bay had an estimated decline of 5.7 per cent per year.[522] Decline is occurring throughout the southern section of the Region, corresponding to seagrass areas that were lost in the 2022 floods in the Burnett Mary region.[149] However, the number of dugongs in Bowling Green Bay increased, and north of Hinchinbrook near Cardwell recorded its highest numbers since 2005.[522] The proportion of new calves in the population is a measure of population health and resilience, and in 2022 this measure was lower for the urban coast than in previous years. Despite Australia having the largest dugong population in the world, the outlook for the southern Region is poor.[2128]

Trend estimates can be confounded by temporary emigration between sites. Large-scale movements of dugongs are stochastic. Many individuals are relatively sedentary, while others may travel hundreds of kilometres. Large-scale movements may be driven by limiting foraging resources, fluctuations in water temperature or exploratory behaviour. Group movements are known to occur in response to regional loss of food.[2124] The diversity in movement patterns dugongs exhibit may be indicative of their adaptability to short-term changes, such as loss of seagrass meadows,[2124] and they highlight the importance of population connectivity. Resilience of populations following habitat loss relies on dugongs having alternative areas to forage.[2133]



Recovery of urban coast dugong populations hinges on reducing threats

Dugong populations depend on seagrass meadows, and their recovery hinges upon reducing direct and indirect threats. Resilience continues to be influenced by interactions between anthropogenic impacts and climate change. The potential impacts of future coastal development, increases in fishing and recreational use of the Marine Park can further affect the already threatened coastal dugong populations.

8.3.7 Humpback whales

Individuals in the eastern Australian subpopulation of humpback whales typically migrate from feeding areas in the Southern Ocean along the east coast of Australia to breed in the Region. Prior to exploitation, the eastern subpopulation comprised an estimated 26,000 whales[2134] but whaling had reduced the subpopulation to 200 to 500 whales in 1962.[2135] The population was estimated to consist of more than 24,000 whales in 2015, comparable to estimates of the pre-whaling population, and it continues to grow at a rapid rate.[504] The recovery of humpback whales has been assisted by having little competition for food with other whale species whose populations were also historically depleted.

Humpback whales have recovered to pre-whaling levels



Humpback whale taking a breath off the coast of Lucinda. © Connie Rowe 2023

The influence of climate variability on humpbacks in the Southern Hemisphere is under-studied.[501] However, some breeding habitats are predicted to become unsuitably warm by the end of this century.[2136] Climate-related changes to prey supply may also result in calving occurring further south.[2137] Generally, baleen whale populations are predicted to decline by the year 2100 because of increasing inter-specific competition [2138] and because ocean acidification, warming and sea ice dynamics are reducing habitat for krill development.[2139]

Declines in reproductive success have been associated with environmental conditions generating insufficient prey to support the energy demands for pregnancy and lactation in some Northern Hemisphere humpback whale populations.[2140] Timing of migrations has also shifted in response to earlier ice break and increases in sea surface temperature.[2141] The resilience of humpback whales to ongoing climate change depends on behavioural adaptability in terms of diet and movements.

Local-scale threats to humpback whales include the risk of vessel strike, which is increasing as more vessels and whales share the water of the Marine Park.[506] Humpback whales' abundance in coastal waters makes them prone to injury or mortality from entanglement in fishing equipment, shark nets and marine debris. Underwater vessel

noise can cause behavioural disturbance in humpback whales: simulated loud boat noise has been shown to increase swim speeds and respiration rates in individual animals.[2142] Habitat degradation, including from coastal development, may become a greater issue as humpback whale and human populations grow.

Management

Since whaling was banned, other management initiatives have included establishing best-practice guidelines for whale watching, researching gear modification, spatial closures and using whale alarms to reduce entanglement.[2138] As the population increases and climate changes, ongoing monitoring will be required to assess the future risk to humpback whales from marine activities, coastal development and changes to prey communities.

Humpback whales are a matter of national environmental significance under the EPBC Act because they are protected as Cetaceans and are a listed migratory species under the Bonn Convention. In 2021, the humpback whale was removed from the vulnerable list under the *Nature Conservation (Animals) Regulation 2020* (Qld) and is now considered least concern. The Operational Policy on Whale and Dolphin Conservation in the Great Barrier Reef Marine Park complements measures outlined in Queensland's Nature Conservation (Whale and Dolphin) Conservation Plan 1997 to further address the risks to whales.

Evidence for recovery or decline

After decades of whaling reduced the population to possibly as few as 200 individuals by the early 1960s, the eastern Australia humpback whale population has since recovered to its pre-whaling levels. The population size was estimated to be approximately 24,000 whales in 2015,[504] and the growth rate was estimated growth rate to be 10 to 11 per cent per year (close to the maximum plausible rate of increase of 11.8 per cent).[2143] The population may have increased to a projected 40,000 animals and is predicted to reach carrying capacity by 2026.[504] Humpback whales exhibit the strongest recovery of all whale species and, as a result, were removed from Australia's threatened species list in 2022.[505]

8.4 Heritage resilience

Heritage resilience is the ability of a heritage place, structure or value to experience impacts or disturbance while retaining the inherent heritage value for which it has been recognised. Poor community awareness and a lack of appreciation of heritage values are recognised as key threats to the Region's heritage values and their resilience.[5] Communication and interpretation of heritage values are important drivers of resilience: they make heritage accessible to the community and engender community support and heritage protection.

Since 2019, the improved focus on social and economic elements of heritage resilience has continued at both a national and state level. These elements include the importance of collaboration and partnerships, sustainable tourism and adaptive re-use, and engaged and appreciative communities. Management of heritage values is hindered by a lack of publicly available data on threats and impacts to heritage, which would provide an early warning and allow more effective management. The current level of resourcing for heritage protection across Australia, and in Queensland, is also limiting the ability of any level of government to effectively meet standard heritage protection requirements.[1964]



Loss of knowledge and tradition impairs the resilience of intangible cultural knowledge

More broadly, loss of knowledge and tradition and incremental damage continue to impair the resilience of intangible cultural knowledge across many of the world's indigenous cultures, including in the Region (Section 4.3). However, on a Region-wide scale, Indigenous heritage values continue to experience heightened awareness and reconnection. Since 2019, the Reef's Traditional Owners have continued to access Sea Country and strengthen their capacity for natural and cultural resource management (Sections 4.3 and 5.9.1). A new strategy to guide management, adopted since 2019, is the *Reef 2050 Traditional Owner Implementation Plan*.[1120] The plan details actions to achieve Traditional Owners' aspirations for the Reef as part of the Reef 2050 Plan. It includes specific objectives and actions across six work areas: climate change, land-based activities, water-based activities, partnerships and capacity, knowledge systems and investment.

8.5 Case studies of heritage resilience

The two case studies below illustrate the likely resilience of the social and Indigenous heritage values in the Region and whether they have recovered or declined following disturbances. The case studies presented are:

- social heritage — resilience of the Reef's tourism industry following back-to-back mass bleaching events and the COVID-19 pandemic
- Indigenous heritage — sacred sites, sites of particular significance, and places important for cultural tradition

8.5.1 Social heritage

Commercial marine tourism is the largest Reef-dependent industry in the Region (Figure 8.1: the system's identity). It supports the resilience of social heritage values through providing access to the Reef, livelihoods for community, connection to nature, and opportunities for stewardship and education (Figure 8.1: system's functions and processes, and values). In the 2015–16 financial year, before the COVID-19 pandemic, commercial marine tourism contributed an estimated $5.7 billion to the Australian economy and provided 38,000 full-time equivalent Reef-dependent jobs [1324] (Figure 8.1: system's structure and value).

The closure of the Australian and Queensland borders during the COVID-19 pandemic was devastating to the Reef tourism industry, particularly in 2020 and 2021 (Figure 8.1: disturbance [to the system]). Tourism numbers began to recover after travel restrictions were eased in February 2022, but they are yet to return to pre-pandemic levels. Tourism operators are still suffering from loss of customers and income (Figure 8.1: system's structure). However, impacts varied depending on the type of business and location. The pandemic and the post-pandemic geopolitical situation have resulted in flow-on negative effects for Reef tourism operators, including staff shortages, regional housing shortages, loss of supply chain services and general stress and mental health issues [2144] (Figure 8.1: disturbances, feedback processes and system's values).

Management

The Australian and Queensland governments responded swiftly to ease the financial crisis in the Reef tourism industry at the onset of the COVID-19 pandemic. In addition to the national JobKeeper Payment scheme to support staff retention and livelihoods, specific Reef initiatives included a waiver of the environmental management charge for Reef tourists and marina fees for tourism operator vessels until 30 June 2023 (Figure 8.1: absorbing and/or adapting the system's structure and functions).

In February 2021, the Reef Authority launched the Tourism Industry Activation and Reef Protection Initiative to support ongoing tourism operations when revenue was severely reduced due to COVID-19 restrictions (Figure 8.1: absorbing and/or adapting the system's structure and functions). The Australian Government invested $3.2 million in engaging 17 tourism operators to undertake site stewardship activities at their usual tourist destinations over the course of 6 months. The program has since expanded, and it received significant additional investment in late 2022. It is now called the Tourism Reef Protection Initiative. The Reef Authority also increased its support and training for its Master Reef Guides and Eye on the Reef programs. These initiatives provide training to tourism operators to become expert Reef guides and to collect ecological data about their regular operating sites. In June 2021, the Queensland Government initiated the Great Barrier Reef Education Experience Program to subsidise school student excursions to the Reef, bringing further income to Reef tourism and providing thousands of Australian school children with a unique experience.

While nearly all tourism operators had to cut costs, many also adapted by reconfiguring their operations for the domestic market, undertaking different activities and consolidating their service offerings (Figure 8.1: absorbing and/or adapting the system's structure and functions). As with other processes during the COVID-19 pandemic, many tourism operators became more highly digitised by managing their own bookings and cancellations through a single online source.[2144] A culture of cooperation rather than competition emerged in some areas among tourism operators. For example, one tourism operator reported:

"For those that are still owner-operators, I know them quite well, and so what we did at the beginning of COVID, and we still do it today, is that we share the load. Rather than poach each other's business … we try to run the week so that we're not overlapping each other all the time, we try to spread it out a little bit, and we've been doing that now since the beginning of COVID." [2144]

Peak tourism industry bodies also adapted by fostering a collaborative culture (Figure 8.1: absorbing and/or adapting the system's structure and functions). Many waived membership fees and provided increased support and advocacy for their members. These cooperative and collaborative measures, as processes, are positive for human wellbeing in creating connection and support in difficult times.

Evidence for recovery or decline

The amplified role of tourism operators as Reef stewards enhances the social heritage values of the Reef and contributes to the social resilience of the Reef.[2145]



Master Reef Guide surveying a reef. © Commonwealth of Australia (Reef Authority) 2023

Since the mass coral bleaching events of 2016 and 2017, Reef tourism operators have increasingly participated in citizen science and Reef interventions. The COVID-19 pandemic catalysed new initiatives and partnerships between Reef managers and tourism operators. These partnerships brought into focus the relationship between the Reef, stewardship and human wellbeing, demonstrating both how resilient the tourism industry can be and how human adaptations can enhance social health. The introduction of the *Tourism Management Action Strategy* by the Reef Authority in 2021 further highlights the importance of these relationships and simplifies tourism management processes.



Social heritage resilience depends on the strength of human relationships with the Reef

The resilience of social heritage values depends on the strength of human relationships with the Reef. Successful stewardship is a great example of this healthy relationship. When the right conditions for stewardship are met, the conditions exist in a virtuous cycle, building resilience and wellbeing of both people and the social values of the Reef. The collaborations within and between the tourism industry and Reef management that led to these stewardship-focused adaptations bode well for human-Reef relationships as society and the ecosystem face the challenges of climate change.

8.5.2 Indigenous heritage

"Our connections as Mandubarra Traditional Owners extend from jabun (the coast) out across wajali (the sea).

Our ancestral links to country extend to our relationships to garri (the sun), gagalum (the moon), girnyja (the stars), girribirr (wind), gambal (rain) and yugan (the sky).

In the name of our Old People, we are custodians of Mandubarra Sea Country and hold obligations for the ongoing care of the places, animals, birds and plants of our Sea Country."



Source: Mandubarra Sea Country Cultural Values: 2019–2020 mapping project, 2020 [76]

"Our vision is to provide sustainable outcomes for our members and community with cultural awareness and education. Mandubarra people are committed to caring for our Country. To pass on knowledge and Culture. To protect our cultural sacred sites, with GBRMPA [Great Barrier Reef Marine Park Authority] and QPWS [Queensland Parks and Wildlife Service], as these are the responsibilities to our ancestors, children and our culture."

Source: Mandubarra Traditional Use of Marine Resources Agreements Aspirational Statement, 2018 [2146]

The Reef's Traditional Owners are the custodians of Indigenous heritage values (Section 4.3), and resilience of these values depends on the Traditional Owners' continuing connection to Culture and Sea Country. The protection of culturally important sites is built on strong traditions of intergenerational knowledge sharing within and between communities, according to traditional lore, customs, and cultural authority governance systems. Across the Region, sacred sites, sites of particular significance, and places

important for cultural tradition (Section 4.3.2) are not widely known outside the Traditional Owner groups responsible for their custodianship. Retaining confidential knowledge within communities is vitally important for safeguarding cultural integrity.

Resilience of Indigenous heritage values depends on connection to Sea Country

Management partners, such as the Reef Authority share in the responsibility of caring for and protecting Sea Country. Partnerships with Traditional Owners through Sea Country cultural values mapping projects and Traditional Use of Marine Resources Agreements provide a Traditional Owner–led approach to identify, prioritise and protect cultural heritage values.

As a case study, the Reef Authority has been working closely with the Mandubarra Traditional Use of Marine Resources Agreement steering committee who are representatives of each family group of the Mandubarra people from the Cassowary Coast area to document culturally significant areas in a plan that will be used to inform future management of their Sea Country. Mandubarra Sea Country covers an offshore area of more than 1500 square kilometres. It includes the coastal land and waters from immediately to the south of the Mourilyan Harbour to Maria Creek at the southern end of Kurrimine Beach. It incorporates Cowley Beach, Kurrimine Beach and surrounding Islands. The *Mandubarra Sea Country Cultural Values: 2019–2020 mapping project* (Sea Country Cultural Values plan)[76] documents important aspects of the area's cultural history and will be a valuable source of information for Traditional Owners and managers in guiding management of the area.



Participants at the Mandubarra Cultural Values Launch. © Commonwealth of Australia (Reef Authority) 2021

Management

The Mandubarra people are engaged in formal management arrangements under Australian and Queensland government statutes for their Land and Sea Country. Mandubarra Sea Country is managed under the *Mandubarra Traditional Use of Marine Resources Agreement*. The marine resource agreement, which began in 2018 for a period of 10 years, is an accredited statutory agreement developed by the Mandubarra people in partnership with the Reef Authority. It recognises traditional lore, customs, cultural authority and boundaries over Sea Country estate, and it allows for collaborative partnerships and co-management of this area.

The Sea Country Cultural Values plan supports the marine resources agreement through the provision of shareable cultural knowledge and the aspirations of Mandubarra people for managing Country and Sea Country with partners. This plan was delivered as part of the implementation of the *Aboriginal and Torres Strait Islander Heritage Strategy for the Great Barrier Reef Marine Park*, released by the Reef Authority in 2019. It was developed in a way that protects sensitive cultural knowledge while enabling the Reef Authority to better support and partner the Mandubarra people in fulfilling their custodial obligations and responsibilities for protecting their Sea Country.

The Mandubarra Land and Sea Rangers program,[2147] was established in 2022 to look after Mandubarra Sea Country, including monitoring, compliance and threatened species management on sea country within Mandubarra Land and Sea Country. The rangers support the marine resource agreement with knowledge sharing through junior rangers, on-country activities and experiences and community days. An important aspect of their role is protecting, restoring and maintaining cultural sites (middens, fish traps, occupation sites and burial sites), and maintaining the cultural heritage database and records under the cultural values plan.

Evidence for recovery or decline

Mandubarra Traditional Owners have ongoing custodial responsibilities for, and customary obligations towards, Mandubarra Sea Country and for the culturally significant and other native species which inhabit Sea Country. Successful mapping of shareable cultural values for the Sea Country Cultural Values plan occurred in 2020.

Mandubarra Traditional Owners have compiled their own internal, restricted-access cultural heritage database to record site-specific traditional knowledge, imagery, condition reports and monitoring data. This database is directly managed by Mandubarra Aboriginal Land and Sea Inc.

"This resource has created an educational awareness tool to promote the significance and the importance of protecting our cultural values on our Sea Country. Through education and community awareness programs, community is supporting and engaging in our activities and aspirations. We feel we are moving forward together" (Mandubarra Traditional Owners).[2148]

Knowledge shared with management partners has broadened the capacity for protecting important sites, many of which are listed Mandubarra cultural heritage sites under the *Aboriginal Cultural Heritage Act 2003* (Qld) and included on the *Aboriginal Cultural Heritage Database and Register* maintained by the Queensland Government.

"The documentation and sharing of cultural information has been a success. However, there needs to be more authority for sole decision-making on our Country. The Mandubarra people's aspirations is to manage our reefs including the authority to make decisions to look after our Country through closures, rezoning and other management tools, such as Native Title over our Sea Country." (Mandubarra Traditional Owners).[2148]

8.5.3 Historic heritage

Not assessed in this edition of the Outlook Report.

8.6 Assessment summary — Resilience

Paragraph 54(3)(e) of the *Great Barrier Reef Marine Park Act 1975* (Cth) requires *'an assessment of the current resilience of the ecosystem ...'* within the Great Barrier Reef Region.

Section 176(3)(e) of the *Great Barrier Reef Marine Park Regulations 2019* (Cth) requires *'an assessment of the current resilience of the heritage values ...'* of the Great Barrier Region.

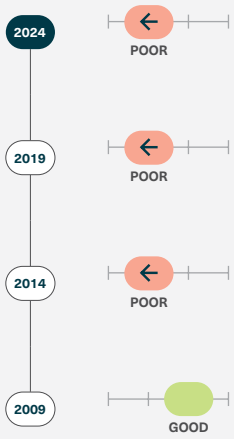
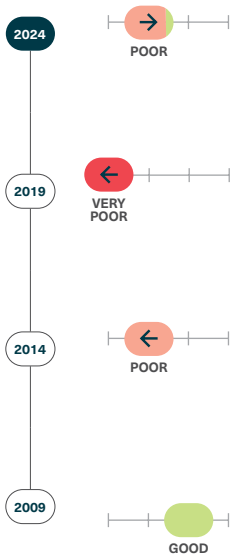
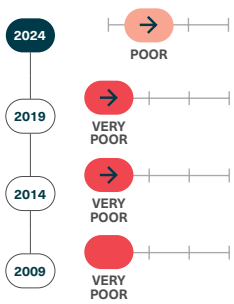
These assessments of ecosystem and heritage resilience are based on the information provided in earlier chapters, namely, the current state and trends of the Reef's natural heritage values (biodiversity and ecosystem health) and heritage values (Indigenous and social). They are also based on trends in direct use, the factors influencing values now and into the future, and the effectiveness of protection and management arrangements. A series of case studies provide more information on the two areas of assessment:

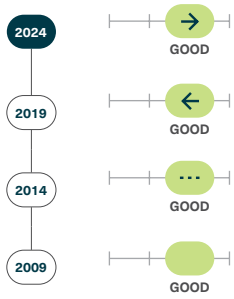
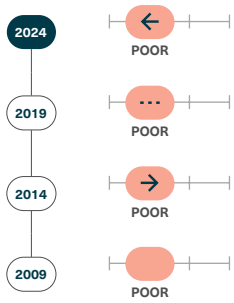
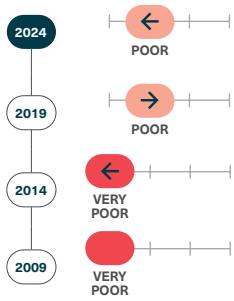
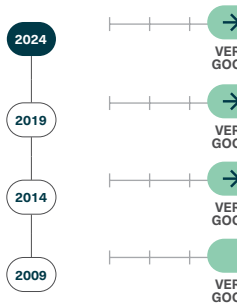
- ecosystem resilience (natural heritage values)
- heritage resilience (Indigenous and social heritage values).

Over time, the case studies may be expanded or more case studies developed.

8.6.1 Ecosystem resilience

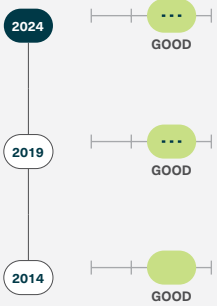
Grading statements — Ecosystem resilience		Trend since previous report	Confidence
	**Very Good:** Under current management, throughout the ecosystem, populations of affected species are recovering well, at rates close to their maximum reproductive capacity. Affected habitats are recovering within expected natural timeframes, following natural cycles of regeneration.	Improved Stable Deteriorated No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
	**Good:** Populations of affected species are recovering at rates below their maximum reproductive capacity. Recovery of affected habitats is slower than naturally expected but structure and function are ultimately restored within a reasonable timeframe.		
	**Poor:** Populations of affected species are recovering poorly, at rates well below their maximum reproductive capacity. Recovery of affected habitats is much slower than expected natural timeframes and the resultant habitat is substantially different.		
	**Very Poor:** Affected species are failing to recover and affected habitats are failing to recover to their natural structure and function.		
	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

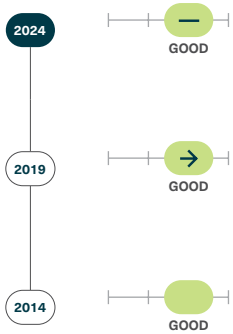
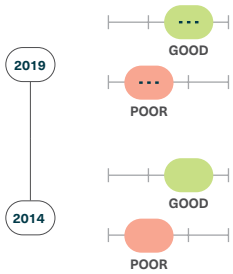
Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Ecosystem resilience: Elements of the natural ecosystem have been severely affected by repeated mass bleaching events, heavy floods and marine pollution. These elements include coral reef habitats, dugong populations, and loggerhead turtles. The resilience of these species and communities is likely to be compromised. Recovery has been observed in seagrass meadows in the northern Region although the southern meadows are likely to be less resilient to future disturbances. Coral trout and black teatfish populations have also shown signs of recovery. It is projected that humpback whales will reach carrying capacity before 2026, showing how management actions can support recovery of natural populations.			
Coral reef habitats: The 2019 assessment found the resilience of the Region's coral reef habitats had been substantially reduced by various disturbances. Since then, signs of resilience have emerged, despite mass coral bleaching events in 2020 and 2022. These include the recovery of coral cover at many shallow offshore reefs, driven primarily by fast-growing *Acropora*. However, inshore reefs in some areas have not shown similar levels of recovery. Loss of local species diversity has been reported over time in the wake of multiple disturbance events at reefs around Lizard Island, and may also have occurred more widely. While the resilience is considered to have improved since 2019, shortening recovery windows are expected to have implications for the ongoing resilience of coral reef habitats and the ability of the reefs to maintain their structure and function. The magnitude of changes in coral cover in the last decade may point to increasing instability in coral cover succession dynamics. (The impact of the 2023-24 summer cyclones and mass bleaching event is not known at time of writing and is not considered in this assessment).			
Seagrass meadow habitats: Resilience in seagrass meadows is affected by environmental features, such as good water quality and stable climate, ecological processes, grazing pressures and intrinsic characteristics of the meadows. Seagrass meadows in the northern Region have shown resilience since 2019 despite being affected by heatwaves in 2020 and 2022. However, meadows in the southern region of Fitzroy and Burnett Mary regions remain in poor state and are likely to be less resilient to future disturbances.			
Black teatfish: Sea cucumbers are sedentary and in high market demand. Their population recovery can be slow, so they can be easily overfished. The most recent stock assessment indicates the biomass of black teatfish has shown some recovery since the fishery was closed in 2001, but it has been slower than expected. Confidence in stock assessments is hampered by uncertainty regarding some biological parameters.			

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Coral trout: Spawning stock of coral trout has steadily increased since 2012. The latest stock assessment indicates biomass is currently at 60 per cent of unfished biomass, an increase from 2011. Coral trout populations have benefited from local management actions as well as increases in coral cover in some locations. However, resilience of this species is at risk due to ongoing cumulative disturbances that cause coral loss and habitat degradation.		LIMITED	LIMITED
Loggerhead turtles: Despite the Region's loggerhead turtle population showing initial recovery in response to the local management actions, the population is facing a suite of continuing and increasing threats. Climate change impacts and interactions with marine debris are concerning. Recruitment of young turtles to foraging grounds has declined by half over recent decades. This will have negative consequences for the population's resilience into the future.		ADEQUATE	ADEQUATE
Urban coast dugongs: Dugong populations continue to show an overall long-term decline. More significant declines have been detected in the southern Region. The 2022 floods in the Burnett Mary region resulted in significant seagrass losses likely to directly affect dugong populations. Resilience of dugongs continues to be influenced by interactions between local impacts and climate change, primarily those that affect seagrass meadows.		ADEQUATE	LIMITED
Humpback whales: Humpback whales have demonstrated resilience to past overharvesting, fully recovering to their pre-whaling population size. Currently, the estimated rapid recovery rate suggests humpback whales will likely reach carrying capacity in the Region before 2026. Resilience of this species will now depend on ongoing impacts of climate change, particularly on their food source outside the Region.		ADEQUATE	ADEQUATE

8.6.2 Heritage resilience

Grading statements — Heritage resilience		Trend since previous report	Confidence
	**Very Good:** Under current management, heritage values are understood, well recorded and well protected. Actions are being taken to address major threats and restore values. Cultural connections and community awareness are strong.	→ Improved — Stable ← Deteriorated ··· No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
	**Good:** Heritage values are described and recorded for many components. Many of the values are protected under current management arrangements. Some actions are being taken to address major threats and there is restoration work in some areas. Cultural connections are generally strong and there is some community awareness of values.		
	**Poor:** Some of the values are described and recorded, but most remain unrecorded and poorly understood. Some are protected under current management arrangements. The number of values where actions are being taken to address major threats and restore values is relatively small. Cultural connections have deteriorated. There is limited community awareness of values.		
	**Very Poor:** Heritage values are not well understood, recorded or protected. Few, if any, actions are being taken to address major threats and restore values. Cultural connections have deteriorated significantly and there is little community awareness.		
	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Heritage resilience: The resilience of Indigenous heritage values continues to depend on the active involvement of First Nations peoples in management and their connection and access to Land and Sea Country. The resilience of social heritage values similarly depends on the strength of human relationships combined with the health of the Reef. Resilience of historic heritage values has not been widely analysed by managers. Based on available evidence, the resilience of the Region's heritage values is assessed as good.			

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Social heritage: The resilience of social heritage values depends on the strength of human relationships combined with the health of the Reef. The tourism industry has shown great resilience in the face of the COVID-19 pandemic and has created new partnerships that enhanced stewardship of the Reef. Stewardship actions can increase the resilience of social heritage values and contribute to the wellbeing of people, especially when supported by managing agency actions. A strengthened relationship with the Reef and stewardship actions can, in turn, contribute to resilience of the Reef. The resilience of social heritage values is in good condition.			
Indigenous heritage: The resilience of this component relies on Traditional Owners maintaining connection with their Land and Sea Country. Mapping of Sea Country values, such as sacred sites, sites of particular significance, and places important for cultural tradition, can inform management and improve protection of Indigenous heritage values. Strong governance and co-management principles that connect Traditional Owners and Custodians to their Country and retaining confidential knowledge within communities are vitally important for safeguarding cultural integrity.			
Historic heritage: Not assessed in this edition of the Outlook Report. *In 2019, lightstations were assessed as in good condition (same grade as 2014, no consistent trend) and historic shipwrecks were assessed as poor (same grade as 2014, no consistent trend).*			

8.7 Overall summary of resilience

The Region is home to the world's largest coral reef ecosystem and has enduring natural, social and heritage values. Widespread disturbances, such as repeated mass bleaching events, cyclones, reduced water quality and outbreaks of crown-of-thorn starfish can have negative impacts on the overall resilience of the Reef. Yet, impacts have been highly variable, and some ecosystems have demonstrated capacity to recover. The natural resilience of the Region's values is being undermined by increases in the severity and frequency of disturbances.[5]

The Reef's natural resilience is being undermined by increasing disturbances

Resilience-based management should be underpinned by an understanding of the Reef's natural process of vulnerability and recovery potential, which are key elements in identifying how management interventions can be targeted to protect and support resilience. There is also a recognised lag between implementing actions to improve resilience and observable ecosystem improvements.[5] Outcomes of conventional management approaches indicate the Reef's systems are able to recover naturally when stressors are removed. For example, controlling crown-of-thorns starfish can suppress coral loss, and compliance with fishing regulations has had a demonstrated positive impact on fisheries across the Region. As the effects of climate change exacerbate pressures and reduce recovery windows, this capacity to recover is increasingly challenged. Maintaining the systemic resilience of the Reef will continue to depend on reducing or removing pressures. Although there is high uncertainty about the risks posed by ongoing climate change, there is also an opportunity to enhance the processes that drive recovery.

Resilience-based management should support natural recovery

The Region's resilience is assessed through nine case studies: seven ecosystem studies and two heritage studies. Among the ecosystem case studies, humpback whales stand out as having made a strong recovery and this recovery is due to an international agreement put in place several decades ago to protect them against hunting in the Southern Ocean. Seagrass meadows in the northern Region have been recovering from recent cumulative disturbances, while the southern meadows remain vulnerable especially after the 2020 floods in Burnett Mary catchments. Black teatfish populations have recovered from their lowest point in the 1920s and the fishery re-opened in 2019, but the degree of improvement over the past 2 decades is less clear. The latest coral trout assessment indicates that stocks are recovering, but they remain sensitive to coral habitat loss and the risk of overfishing. In contrast, urban coast dugongs and loggerhead turtles have shown declines in population and recruitment and continue to be affected by global and local disturbances. Loss of seagrass habitat remains one of the main causes of dugong mortality, particularly in the southern Region. While loggerhead turtle populations showed recovery over past decades due to local interventions, numbers of nesting females have been declining more recently. Impacts, such as fishing bycatch, marine debris, and temperature increase continue to threaten the resilience of turtle populations.

Coral reef habitats, seagrass meadows and coral trout show signs of resilience

Responses of coral reef habitats to global and local stressors have been highly variable. Offshore reefs have shown signs of recovery of coral reef condition following repeated mass bleaching events, but this has been primarily associated with increases in cover of fast-growing *Acropora* corals, which are also extremely sensitive to future acute disturbances. The magnitude of changes in coral cover across the last decade, compared to the previous decade, may indicate that the coral reefs may be moving into an era of increasing instability in coral cover succession. Coral cover does not reveal information such as diversity, community composition, or demography and recruitment of key reef species. These elements are vital for ecosystem resilience. Therefore, coral reef habitats remain vulnerable to further disturbances as changes to *Acropora*-dominated communities can result in the erosion of resilience. Additionally, as recovery windows diminish so does the capacity to bounce back from disturbances each time.



Resilience of social and Indigenous heritage values is underpinned by a healthy ecosystem and the connections people have with each other and the Reef

Social heritage values are being maintained, and are demonstrated by strong evidence from the Reef's tourism industry. The tourism industry was significantly affected by repeated mass coral bleaching events and more recently by the COVID-19 pandemic. This industry has shown great resilience to adapt to changes and has created new partnerships that enhanced stewardship of the Reef. However, the resilience of social values is only as strong as the resilience of the ecosystems that underpin it. Therefore, in this complex social–ecological Reef system, a resilience-based management approach will continue to be vital for maintaining the outstanding universal value of the Region.

The Reef's Traditional Owners are the Custodians of Indigenous heritage values, and resilience of these values depends on their continuing connection to Culture and Sea Country. The protection of culturally important sites is built on strong traditions of intergenerational knowledge sharing within and between communities, according to traditional lore, customs, and cultural authority governance systems. Indigenous knowledge of Country and management practices provide a valuable approach for caring for the environment for all Australians. Strong governance and co-management principles that connect Traditional Owners and Custodians to their Country and support the agency of First Nations peoples in land and sea country management will benefit the resilience of ecosystem and heritage values of the Reef.



Vessel wreckage washed up on shore after ex-cyclone Jasper. © Commonwealth of Australia (Reef Authority) 2023



Chapter 9

Risks to the Region's values

Risks to the Region's values

'an assessment of the risks to the ecosystem...' within the Great Barrier Reef Region, s 54(3)(d) of the *Great Barrier Reef Marine Park Act 1975* (Cth)

'an assessment of the risks to the heritage values...' of the Great Barrier Reef Region, s 176(3)(b) of the Great Barrier Reef Marine Park Regulations 2019 (Cth)



Damselfish swimming over a bleached reef. © Johnny Gaskell 2020

"As Traditional Owners we have been on Country and Sea Country for a very long time. Through our ancestors, we are the first traditional Custodians, it's where we learnt biodiversity. We were the land managers for millennia. We've got the knowledge on how to read country, manage country and we want to work together and come up with a plan to comanage country."

— Brendan Fletcher, Traditional Owner, Gurang People

When *Shen Neng 1* ran aground in April 2010, it caused extensive damage to Douglas Shoal (Box 5.5). This grounding occurred on the Sea Country of the Gooreng Gooreng, Gurang, Byellee and Tarebilang Bunda people. For traditional Custodians it was important to be at the centre of the clean-up effort. Sea rangers from Gidarjil Development Corporation became important partners in a longstanding recovery project aimed at improving management of risks and remediation of their Sea Country.

In 2023, following extensive remediation to the site, and with long-term involvement from Gidarjil Development Corporation, Sea Country is being restored. The role of the local traditional Custodians has been vital to the transfer of knowledge.

"Mob's role has been key. Young Indigenous rangers and Elders have all been involved with the remedial project. We initially sent out three rangers and went out and did surveys and that was using scuba divers to survey the damage done. All the rangers are Traditional Owners, and it was a large achievement for them to be involved in such a large project."

"Through these partnerships with the Reef Authority and Boskalis and our ability to use technology, it's become a great tool for us to teach young Indigenous people the technology — aero drones and underwater drones. And it's a good educational tool for our young ones to be more hands on, and by working in partnership they have grown their knowledge and understanding of technology and the use of data."

The project is also providing an opportunity for Elders to share their cultural knowledge and to be at the centre of caring for Sea and Land Country.

"We know that our traditional knowledge and languages need to be sustained, and my goal is that when an Aunty or Elder passes on knowledge, we fly a drone over an area and find a cultural site we never knew existed. Together we can come up with a collective idea on how to manage country.

Healthy country and healthy people — we will continue to look after Land and Sea Country to sustain it for generations to come. These projects are about looking after nature and responding to community needs who live and exist on the Reef."

Source: Caring for Sea Country — Traditional Owner Stories from the Great Barrier Reef [1]

9.1 Background

Management and leaders of the Region must consider the full range of threats to the Region's ecosystem and heritage values (natural, Indigenous, historic and other heritage values). Action should be focused on addressing threats that pose the greatest risk while recognising the cumulative contribution of those threats and their interactions.[11,1982,2149,2150]

The comprehensive risk assessments contained in the Outlook Reports for 2009, 2014 and 2019 [3,4,5] identified climate change, land-based runoff, coastal development, outbreaks of crown-of-thorns starfish and some fishing-related threats as the greatest risks. The assessments have guided subsequent decision-making and updates to management priorities.[2,5]

The risk assessment described in this chapter is based on the information presented in preceding chapters of this report. The assessment systematically reviews the current and future risks presented by known threats and summarises the residual risk to the Reef after consideration of existing protection and management measures. The risk assessment considered input from Reef scientists, managers, Traditional Owners and heritage experts, who provided advice for the list of threats in Appendix 6 in a series of elicitation workshops.[12]

The assessment is based on overall risk to the ecosystem (natural heritage values) and to the heritage values (Indigenous, historic and other heritage values).

9.2 Identifying and assessing the threats

9.2.1 Identifying the threats

The current and potential threats to the Region's ecosystem and heritage values considered in this risk assessment are informed by the evidence presented in Chapters 2 to 8. The 45 threats considered in this risk assessment are listed in Appendix 6, including a comparison with those assessed in the Outlook Report 2019.

The list includes direct and indirect threats and some that are consequential, that is, they arise due to other threats. For example, environmental pressures, such as sea-temperature increase and nutrient runoff, may lead to an increased chance of coral disease.

This assessment considers only threats that are known and identified. Any currently unknown or unexpected threats that are identified in future will be assessed in future reports.



Ships at anchor in the Region. © Matt Curnock 2022

9.2.2 Assessing threats

Separate risk assessments are presented for the Region's ecosystem (natural heritage value) and heritage (Indigenous, historic and other) values. The Australian Standard was followed for risk management (AS ISO 31000)[2151]. The likelihood and consequence of each threat is ranked on the five-point scale set out in Appendix 7. The criteria for selecting a consequence level differs between ecosystem and heritage values. An overall risk level for each threat is determined by applying a risk matrix that combines its likelihood and consequence.

The risk assessment for each threat is based on effectiveness of existing management measures so the overall risk rating is considered the residual risk. For example, the risk levels for climate change related threats are based on the current policy environment and commitments to emissions reduction. The assessment is based on information in Chapters 2 to 8 of this report, including the current state and resilience of the Region's ecosystem and heritage values, major factors influencing the Region's values (including human use) and effectiveness of management. Further input on risk levels was sought from experts both external [12] and internal to the Reef Authority.

Due to the size and complexity of the Region, this assessment is high level because many threats, which interact in different ways, affect its values over varying time and spatial scales, at different intensities. The assessment is based on the following considerations:

- Each threat was initially assessed in isolation from others; cumulative impacts are discussed separately (Section 9.3.7)
- Each threat was assumed to be possible at any geographic location within or, where relevant, adjacent to the Region
- Threats were assessed as they were at the end of 2023 (for example, current fishing techniques and catch amounts) or on the basis of documented trends (for example, trends in sea temperature and ocean acidification)
- Threats were assessed in consideration of existing management measures only. The mitigating effect of any future management measures were not considered
- Threats were assessed in consideration of the effectiveness of existing management measures (Chapter 7).

In understanding the consequence of a threat to the ecosystem (natural heritage value), variations in the extent of the threat's likely effect were taken into account through different criteria for broadscale and local-scale effects (Appendix 7). In order to understand the true level of risk for each threat, the higher consequence grade is adopted in determining the overall risk. For heritage values (Indigenous, historic and other), consequence level is considered using a single criterion that encapsulates both the geographic scale of effects and the range of heritage values affected (Appendix 7).



A lemon damselfish sheltering in bleached coral. © Johnny Gaskell 2020

9.2.3 Information on community views

The risk assessment considered a variety of sources of information on community perceptions on the threats to the Great Barrier Reef and to the Catchment waterways (Table 9.1). These sources generally provided information at different scales and from different parts of the Australian community. The method of eliciting a ranking of threats differs across sources and within them.



Community views helped inform the risk assessment

Table 9.1 **Characteristics of the sources used to inform Section 9.3.1**

For some sources, a list of potential threats was presented, and respondents used either a 5- or 7-point scale to indicate how serious they think the threat is (for example, on a spectrum from 1 of 'not a threat at all' to either 5 or 7 'an extremely serious threat'). One source used this method and then asked the same respondents to list, in free text mode, what they thought were the top three threats to the Reef. This method returned different results from the same group of respondents than when presented with a list of identified threats. Therefore, while some generalisations can be made from these sources, the methodology affects the results.

Source name	Method	Number of responses	Respondent information	Question asked	Reference
Reef Restoration and Adaptation Program: Stakeholder, Traditional Owner and Community Engagement Assessment	Survey — 2018	2743	National representative sample of Australian residents	List of threats and risks — 7-point agreement scale	2152
Reef Restoration and Adaptation Program: Stakeholder, Traditional Owner and Community Engagement Assessment	Survey — 2018	1293	Reef sample — residents within 50 km of the Great Barrier Reef	List of threats and risks — 7-point agreement scale	2152
Design and implementation of social surveys for Regional Report Cards in the Great Barrier Reef Catchment	Survey — 2021	1877	Catchment residents in 4 regions: Wet Tropics, Townsville, Mackay Whitsunday Isaac, Fitzroy	List of threats — 5-point agreement scale	1159
Social and Economic Long-Term Monitoring Program	Survey — 2021	2488	Catchment residents	Open-ended question "What do you think are the 3 most serious threats to the Great Barrier Reef?"	1075
Social and Economic Long-Term Monitoring Program	Survey — 2021	2488	Catchment residents	List of threats — 5-point scale	1075
Traditional Owner Implementation Plan	Report — 2022	Steering group	Steering group	Report statements	1120

9.3 Outcomes of risk assessment

9.3.1 Community views

Climate change is perceived by many in the community as the greatest threat to the Great Barrier Reef. This perception aligns with expert consensus that climate change is the most significant threat to the Reef. Catchment residents consistently perceive climate change, illegal fishing and land-based runoff as among the greatest threats to the Reef and Catchment waterways, although the results differ slightly between different catchments (Table 9.2).

The community views climate change as a serious threat to the Reef

Reef resident respondents recognised the seriousness of these threats to the Reef. Between 80 and 90 per cent of these respondents rated loss of coral cover, seagrass and mangroves, low abundance of fish, and poor coastal water quality as 'moderate to big problems'.[1075] Reef residents' perceptions of threats to the Great Barrier Reef have changed through time (Figure 9.1). Threats perceived as the most serious by different stakeholder groups, such as commercial fishers, tourism operators and coastal residents, converged after the 2016 and 2017 mass bleaching events. Climate change became the most frequently reported threat by all stakeholder groups following the events, and perceptions of fishing and poor water quality as threats also ranked high.[1074]

The effects of climate change on the Great Barrier Reef have influenced Australians to view climate change more seriously.[1532] However, in one national survey, Australian residents perceived environmental pests, such as crown-of-thorns-starfish, as a greater threat to the Reef than climate change.[2153] This result possibly reflects an understanding of crown-of-thorns starfish as a direct and specific threat to the Reef and climate change as a more universal threat across multiple ecosystems.



Pelicans at the Cairns Esplanade. © Dieter Tracey 2021

Table 9.2 **Community views on threats facing the Great Barrier Reef and catchment waterways**

Views were canvassed using a variety of methods over different time periods and are not directly comparable (Table 9.1). To rank the seriousness of threats, some sources used a mean score derived from the Likert scale while others used only the highest-scored, most-serious threats. The top five threats in this table are a subset of all threats listed in the different methods and reflect the ranking method used in each different survey. These results from the various surveys represent the views of respondents from different postcodes and not necessarily specific community sectors.

Survey Group		Ranking of perceived threats				
		First	Second	Third	Fourth	Fifth
National survey[2152]	Threats to the Great Barrier Reef	Environmental pests e.g. crown-of-thorns starfish	Climate change	Mining	Shipping	Agriculture
Catchment residents — open questions[1075]		Climate change	Pollution	Fishing	Humans	Water quality
Catchment residents — listed threats[1075]		Climate change	Illegal fishing and land-based runoff (equal second)	Coastal development	Mining	Crown-of-thorns starfish
Traditional Owners[1120] *Note: no ranked threats listed*		Climate change			Water quality	
Catchment residents (4 regions listed below) [1159]	Threats to Catchment waterways	Climate change	Mining	Land clearing	Land-based runoff	Illegal fishing practices
Wet Tropics catchment residents [1159]		Climate change	Mining	Land clearing	Land-based runoff	Illegal fishing practices
Townsville Reef catchment residents [1159]		Climate change	Illegal fishing practices	Land clearing	Land-based runoff	Mining
Mackay Whitsundays Reef catchment residents [1159]		Climate change	Illegal fishing practices	Land-based runoff	Mining	Overfishing
Fitzroy Reef catchment residents [1159]		Mining	Climate change	Land-based runoff	Land clearing	Overfishing

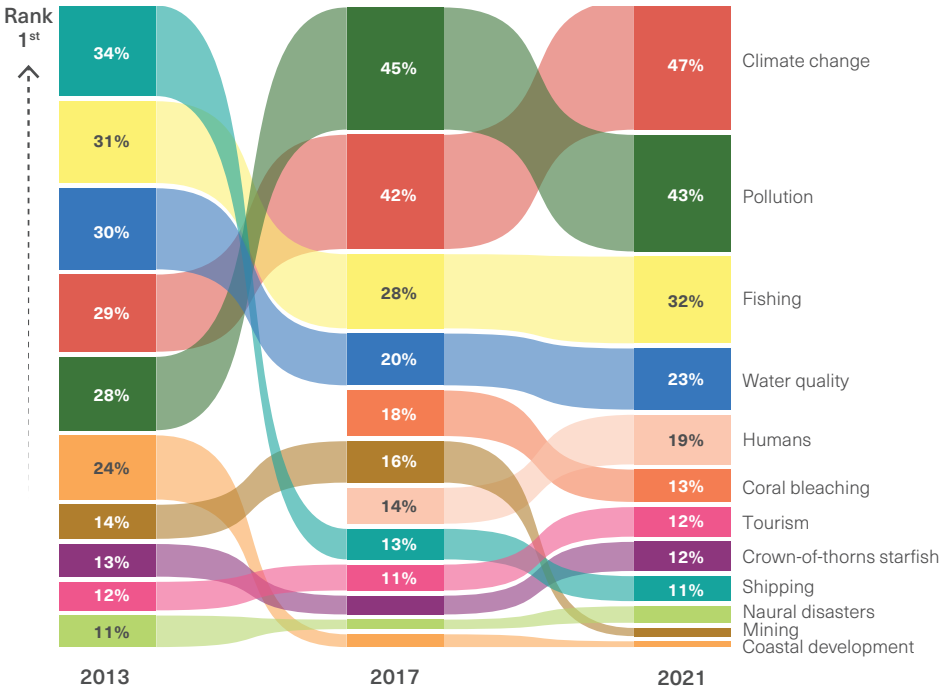


Figure 9.1 **Reef residents' perception of threats to the Great Barrier Reef**
These results, from the Social and Economic Long-Term Monitoring Program survey 2021, are in response to the open-ended question: 'What do you think are the three most serious threats to the Great Barrier Reef?' Source: Hobman *et al.* 2022 [1075]

9.3.2 Level of likely risk

The outcomes of the risk assessments for the 45 threats to the Region's ecosystem (natural heritage value) and heritage values (Indigenous, historic and other) are presented in Appendix 8 and summarised in Figure 9.2.

As the Region's ecosystem and heritage values are closely connected, the projected risk of many threats is the same in both assessments — although for some threats the likelihood and consequence may differ between ecosystem and heritage values.

Risk is often similar across ecosystem and heritage values

Threats from illegal activities (other than fishing and extraction) and extraction of herbivores present different levels of risk between the Region's ecosystem and heritage values. As in 2019, the risk posed by such illegal activities is higher for heritage values when compared to ecosystem values. Reasons for this include the potential for Indigenous and historic sites to be damaged. The extraction of herbivores, however, poses a lower risk to heritage values than to ecosystem values. This is because it is unlikely to affect historic heritage values and is important to Indigenous cultural practices. Note illegal fishing and extraction, and interactions with species of conservation concern, are considered separately.

9.3.3 Sources, scale and timing

The identified threats to the Region's ecosystem and heritage values arise from a number of sources and are highly variable in scale and timeframe. Figure 9.3 links individual threats to their probable causes (that is, the factors identified in Chapter 6 as key influences on the condition of the Region's values) and indicates the spatial scale and likely timing of each threat's effect.

The threats identified as highest risk are currently affecting the ecosystem and heritage values at a broad, often Region-wide scale. Similar to 2019, most of the very high risk threats are associated with climate change and land-based runoff, with the remaining very high risks associated with coastal development and direct use of the Region (illegal fishing and extraction). The threats rated as high risk mostly relate to direct use, at both Region-wide and local or regional scales (such as damage to reef structure, discarded catch, extraction from spawning aggregations, extraction of particle feeders, marine debris). Overall, threats which have localised effects (such as dredging and noise pollution) are generally associated with direct use and are rated as having a lower risk.

9.3.4 Highest risk threats

Based on the assessments of the 45 identified threats (Figure 9.2 and Figure 9.3), 8 out of the 10 threats identified in 2019 as presenting a very high risk to the Region's ecosystem and heritage values are again rated as very high risk. Another 13 and 18 threats are rated as high risk to the Region's ecosystem and heritage values, respectively. Very high is the highest level of risk in the assessment matrix (Appendix 7); no further increase in risk level occurs despite any additional increases in a threat's likelihood or worsening of its consequences (Appendix 7).

Climate change remains the greatest risk to the ecosystem and heritage values of the Region, on a Region-wide scale, with four climate change related threats posing a very high risk, and one posing a high risk (Figure 9.2 and Figure 9.3). The risk of climate change is predicted to continue increasing (Section 6.3).[608,1539]



Climate change threats pose the highest risk to the Region's ecosystem and heritage values

Climate change associated threats impact the natural resilience of the Region's key habitats and underlying ecological processes through exacerbating both acute and chronic disturbances and shrinking recovery windows.[541,644,1604] For instance, deoxygenation is associated with the warming of the surface ocean (sea-temperature rise)[657] (Box 6.2). While impacts of deoxygenation on tropical ecosystems are demonstrated, the degree to which deoxygenation is currently affecting the Region remains a knowledge gap. It is anticipated that impacts on species and habitats will be observed within the Region in the future if, as predicted, global and coastal deoxygenation of oceans continues alongside other climate related impacts. Climate change can also exacerbate the impact of other threats. For example, the health of inshore coral reefs is influenced by land-based runoff and coastal development. The effects of climate change, such as sea-temperature rise,[1615] ocean acidification[1665] and altered weather patterns,[554] may cause additional stress for these reefs and further increase their susceptibility to disease.

Risks to Indigenous, historic and other heritage values from activities that physically disturb or place material on the seafloor are likely to remain underestimated due to limited systematic identification and understanding of the extent and location of many heritage values, such as burial sites, wrecks and archaeological sites. The potential for significant or permanent damage to sites of cultural or historical importance is a concern.

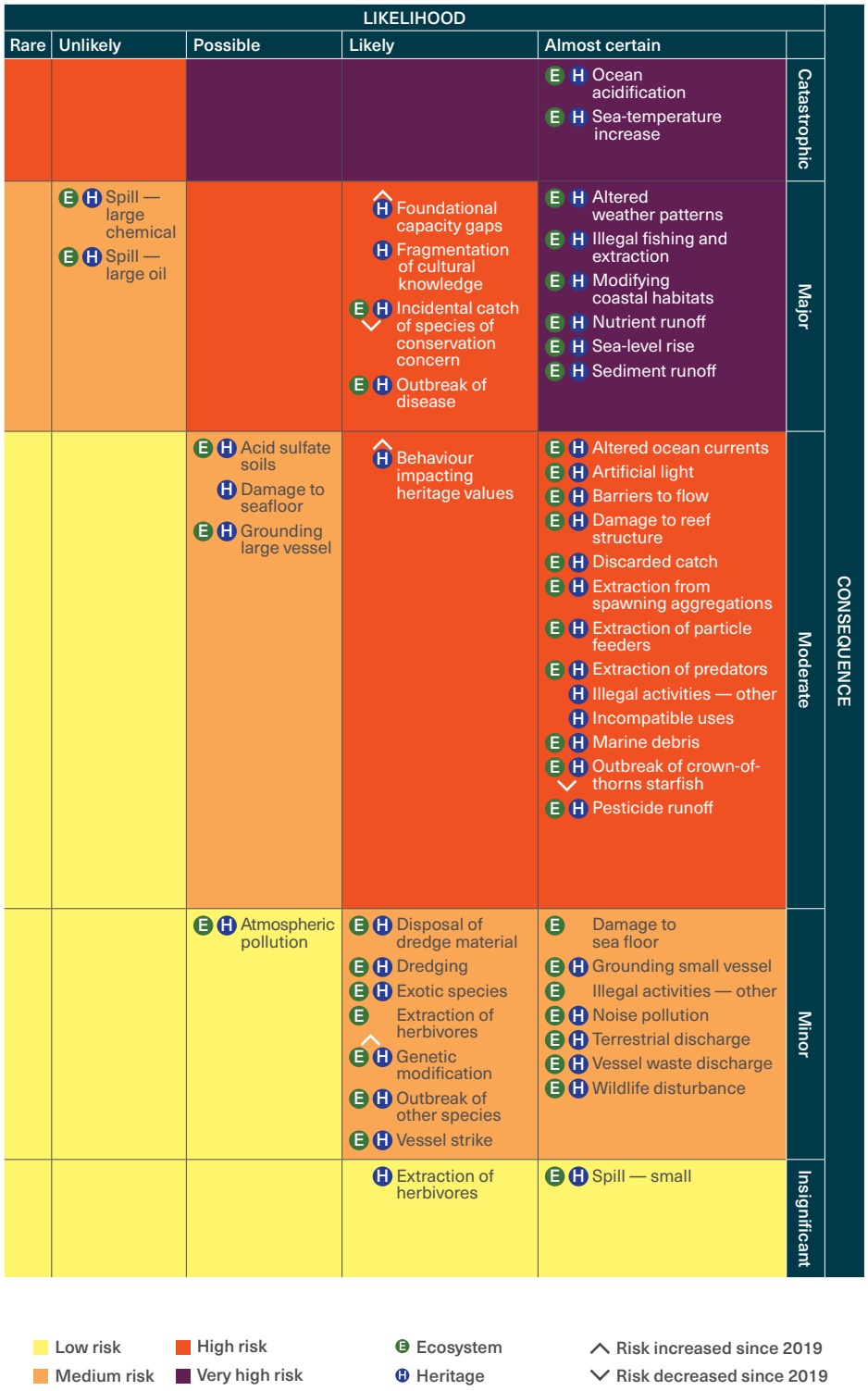


Figure 9.2 **Risks to the Region's ecosystem and heritage values from identified threats**

This risk matrix is consistent with the principles, framework and processes outlined in the Australian Standard (AS ISO 3100) using terms and definitions detailed in Appendix 7. The assessment is based on current and documented future trends in the identified threats and existing management measures. The compounding effects of threats are not considered. The full description of each of the identified threats is provided in Appendix 6 and the risk assessment for each threat is summarised in Appendix 8. Symbols indicate where a threat has been assessed as having the same combination of likelihood and consequence ratings for both ecosystem and heritage values (that is, its natural, Indigenous, historic and other heritage values). If a threat has different ratings for ecosystem and heritage, it is presented twice and each entry is shown with a single symbol. Some threats are only relevant to heritage values and only appear once. If the assessed risk has increased or decreased since 2019, this is indicated.

Threats	Risk		Timing	Influencing factor			
	Ecosystem	Heritage values		Climate change	Coastal development	Land-based runoff	Direct use
Altered weather patterns	■	■	▲	●			
Ocean acidification	■	■	▲	●			
Sea-temperature increase	■	■	▲	●			
Sea-level rise	■	■	10+	●			
Modifying coastal habitats	■	■	▲		●		
Nutrient runoff	■	■	▲		●	●	
Sediment runoff	■	■	▲		●	●	
Illegal fishing and extraction	■	■	▲				●
Altered ocean currents	■	■	▲	●			
Barriers to flow	■	■	▲		●		
Discarded catch	■	■	▲				●
Extraction of particle feeders	■	■	▲				●
Extraction of predators	■	■	▲				●
Foundational capacity gaps		■	▲				●
Fragmentation of cultural knowledge		■	▲				●
Incidental catch of species of conservation concern	■	■	▲				●
Incompatible uses		■	▲				●
Marine debris	■	■	▲		●	●	●
Outbreak of crown-of-thorns starfish	■	■	▲			●	●
Artificial light	■	■	▲		●		●
Behaviour impacting heritage values		■	▲				●
Damage to reef structure	■	■	▲				●
Extraction from spawning aggregations	■	■	▲				●
Outbreaks of disease	■	■	▲	Cumulative effect of many factors			
Pesticide runoff	■	■	▲			●	
Illegal activities — other	■	■	▲				●
Acid sulfate soils	■	■	▲		●	●	
Damage to seafloor	■	■	▲				●
Disposal of dredge material	■	■	▲		●		●
Dredging	■	■	▲		●		●
Exotic species	■	■	▲		●	●	●
Genetic modification	■	■	▲				●
Grounding — large vessel	■	■	▲				●
Grounding — small vessel	■	■	▲				●
Noise pollution	■	■	▲		●		●
Outbreak of other species	■	■	▲	Cumulative effect of many factors			
Spill — large chemical	■	■	▲		●		●
Spill — large oil	■	■	▲		●		●
Terrestrial discharge	■	■	▲			●	
Vessel strike	■	■	▲				●
Vessel waste discharge	■	■	▲				●
Wildlife disturbance	■	■	▲				●
Extraction of herbivores	■	■	▲				●
Atmospheric pollution	■	■	▲		●		●
Spill — small	■	■	▲				●

Threat	Risk		Timing
■ Region-wide	■ Low risk	■ High risk	▲ Now
□ Local or regional	■ Medium risk	■ Very high risk	10+ More than 10 years

Figure 9.3 **Summary of threats arising from factors influencing the Region's values, and associated scale, timing and risk level**

This figure links identified threats with the key factors (Chapter 6) that have the most influence on them (indicated by the black dots), either directly or indirectly. Instances where a factor is likely to only have an insignificant influence on a threat are not displayed (no dot shown). The risk level for each threat is shown, along with the scale of the risk and expected timing of the effects of the threat.

9.3.5 Trends in risks to the Region's values

The risk level for some threats to the Region's ecosystems have changed since the assessment presented in the Outlook Report 2019 (Figure 9.4).

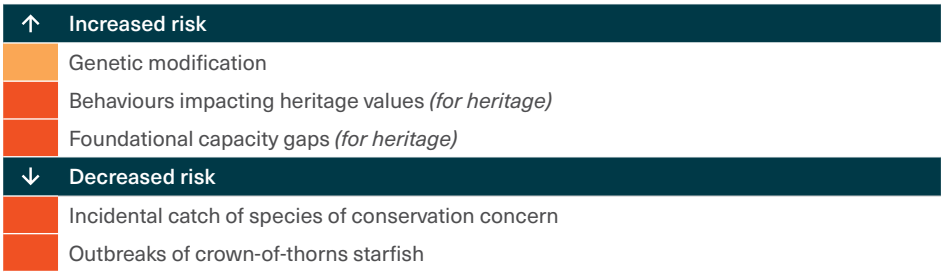


Figure 9.4 **Threats with changed risk levels since 2019**
Threats that have a different risk level in 2024 compared to 2019 are shown. Where the change is only related to either the ecosystem or heritage values, this is indicated.

Increases in risk: Risk level has increased for three threats: genetic modification, behaviour impacting heritage values, and foundational capacity gaps. Definitions of these threats are available in Appendix 6.

The new medium risk level for genetic modification considers the manipulation and modification of coral and symbiont genetics and is based on the acceleration of intervention research programs. These research programs are designed to have a positive impact by identifying methods to increase the resilience of coral reefs to stressors such as higher sea temperatures and lower ocean pH. Since 2019, small-scale *in situ* trials have explored the survival of corals and symbionts that have been subject to selective breeding. There are plans to scale up these trials on the Reef (Box 5.4) so that they will occur more than once in a year.

The trials have a degree of risk associated with potential negative impacts that are generally not well understood. Major impacts could occur when modified organisms are released into the wild or when attempts to influence genotype frequencies are implemented. However, a negative impact at this scale remains unlikely under the current program plans and existing management measures. As scientific knowledge and modification techniques advance, and as the results from trial interventions become available, information on the likelihood, and consequential positive and negative impacts, is expected to grow rapidly over the next decade. In 2024, there are no current or planned interventions involving products of synthetic biology entering the Region.

Since 2019, the knowledge of heritage values has increased, and it is now understood that the occurrence of behaviours affecting heritage values is higher than previously thought. The actual occurrence is also likely to have increased due to population growth and increasing recreational activities (Section 5.5.1). Despite improvements in the integration of Indigenous and historic heritage values into decision-making since 2019 (Chapter 7), undesirable behaviours that affect intangible and tangible Indigenous and historic heritage are likely to occur each year. The likelihood of impact from this threat is higher at sites where visitors are unaware of the local Indigenous cultural significance or desired behavioural guidelines from Traditional Owners.

The scale and longevity of these impacts will vary depending on the nature, frequency and intensity of the undesirable presence or behaviour. Increasing the awareness and incorporation of Indigenous heritage information in decision-making (for example, through co-management principles) may help reduce this likelihood.

Improved understanding of the impacts from foundational capacity gaps elevated the consequence of this threat to major in 2024. Indigenous heritage values are compromised due to the lack of agency and access by First Nations people to manage their Country. This is especially apparent where differences in power dynamics, inequalities and inequities exist within Reef management and society more broadly.[1958] Further restraints, such as remoteness of Country, skill gaps, equipment and safe transport contribute to capacity gaps. Self-agency is essential to avoid and mitigate the risk of fragmentation of cultural knowledge. Through co-management principles, managing agencies can continue to build an enabling environment and increase opportunities for Traditional Owners to protect Land and Sea Country with benefits for ecosystem and heritage values.[77,1962]

Gaps in enabling environments for Land and Sea Country management increase risk

An improved understanding around the nature, intensity, distribution and impact of the three threats with increased risk levels — genetic modification, behaviour impacting heritage values and foundational capacity gaps — would better inform management decisions.

Reductions in assessed risk: The likelihood of incidental catch of species of conservation concern in fishing activities has decreased due to the planned phase-out of gillnets in the Reef by 2027, which was enacted by the Fisheries and Other Legislation (Structural Reform) Amendment Regulation 2023. Efforts to implement independent data validation in commercial fisheries will improve understanding of the occurrence of this threat. It is likely that this risk level will continue to reduce across the next 3 years as the phased plan is implemented.



Crown-of-thorns starfish feeding on coral. © Johnny Gaskell 2021

The risk level associated with crown-of-thorns starfish outbreaks has reduced since 2019 from very high to high. This reduction is driven by management actions including proactive surveillance and targeted culling by the Crown-of-thorns Starfish Control Program, coupled with improved understanding of the program's effectiveness.[187] Benefits have also accrued from past establishment of no-take zones, which protect starfish predators[828,1012] and enhance recovery from outbreaks, [1974] and from additional protection measures for predators implemented through fisheries reforms.[828,1251]

Coral protection through crown-of-thorns starfish control can enhance ecosystem resilience

While it is almost certain that localised crown-of-thorns starfish outbreaks will continue to occur, evidence suggests that targeted, sustained, sufficient and early intervention may suppress region-wide outbreaks.[187] Since 2019, increased capacity and improvements to the tools that support decision-making and prioritisation have supported an enhanced control program. Effective coral protection through crown-of-thorns starfish control is an established management tool to enhance ecosystem resilience under a changing climate.

Unchanged risk levels: Ongoing and evolving management of direct use activities has, in general, resulted in stable risk levels for many associated threats (Figure 9.2). The effectiveness of this management limits the risk of impacts on the Region's values from spills, exotic species, groundings and other threats. Nevertheless, further efforts to reduce the very high and high risk threats from direct use are still needed.

Some fishing-related threats have remained very high or high risk since 2019. Ongoing implementation of the reforms under the *Queensland Sustainable Fisheries Strategy 2017–2027*, including planned improvements in data collection and validation, remains a high priority and may reduce risk associated with these threats in future. The 2020 stock status assessments highlight that five stocks are depleted. Knowledge gaps remain around the likelihood and consequence of some fishing-related threats.

Climate change continues to be an extremely significant influence on the Region, as reflected in the continued assessment of very high risk levels for the related threats, including sea-temperature increase, altered weather patterns and ocean acidification. Similarly, risk levels for key coastal development-related and land-based runoff-related threats have not changed since 2019. Barriers to flow and modification of coastal habitats continue to be of concern given the implications for functional connectivity among terrestrial, freshwater and marine ecosystems and the delivery of ecological services to the Region. Sediment, nutrient and pesticide runoff remain very high and high risk threats, underscoring the relevance of ongoing efforts to manage these issues.

9.3.6 Effectiveness of threat management

Many of the threats with the highest risk levels originate outside the Region, such as those related to climate change, coastal development and land-based runoff. The overall risk associated with climate change (very high) coastal development (high) and land-based runoff (high) have remained the same as in the Outlook Reports for 2009, 2014 and 2019. Management of climate change and coastal development is considered weaker than that for land-based runoff (Chapter 7).



Information sign detailing rehabilitation of the Gulngay wetlands in the Tully River catchment.
© Tony Weber 2022

Management of climate change, however, has seen some improvements since 2019 (Section 7.3.9). Specifically, planning and outputs in the management cycle have improved through enhancements to the management of climate change risks, and advances in climate change policy at national, state and local levels. However, outcomes for climate change remain ineffective (Table 7.4).

Many of the threats with the highest risk levels originate outside the Region

In contrast, the management effectiveness of coastal development and land-based runoff have weakened since 2019 with declines seen in most elements of the management cycle (Sections 7.3.10 and 7.3.11). However, ongoing and effective implementation of the Reef Protection Regulations, gully remediation, streambank and site erosion activities, and a net increase in private protected areas may have a positive influence in future on coastal development and land-based runoff (Section 6.4.2).

The overall risk to the Region from direct use remains medium (Figure 9.5). Port expansion activities in Cairns, Townsville and Gladstone consist of capital dredging activities that have indirect environmental impacts, such as damage to the seafloor (Sections 5.7.1 and 5.7.3). Sustained population growth and economic development will continue to increase the demand for recreational activities within the Region, which potentially increases the risk associated with marine incidents (Section 5.5.3). Fishing and ports remain as uses with high impact (Figure 9.5).

Direct uses within the Region are generally well managed; however, the outcomes for managing fishing are considered only partially effective (Table 7.4). Although there have been relatively few improvements in management effectiveness grades for direct use since 2019 (Table 7.4), advances through the Reef 2050 Plan and ongoing fishing reforms may see benefit in the future.

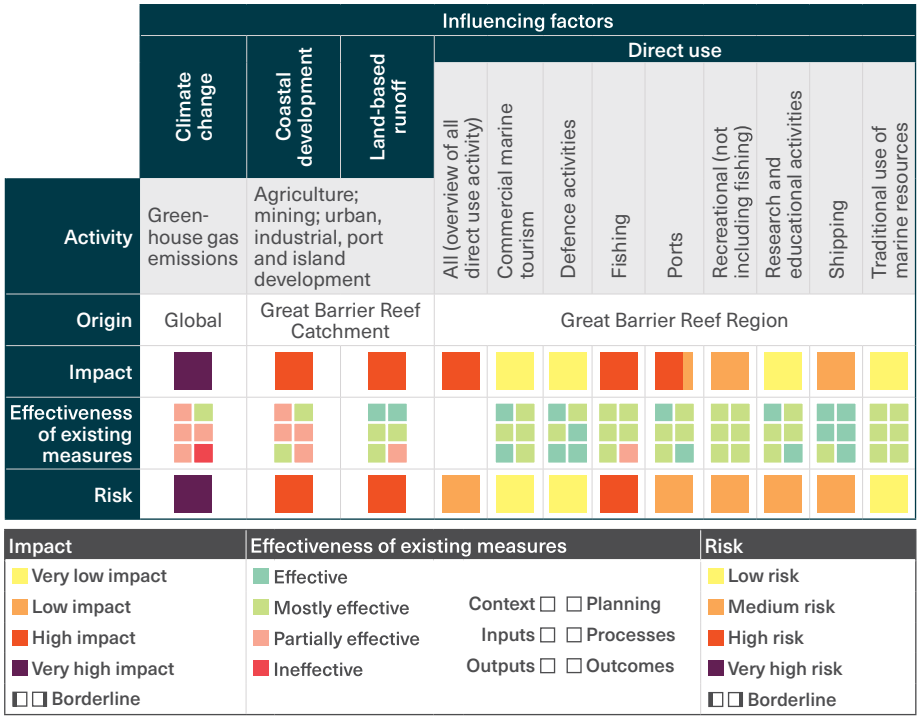


Figure 9.5 **Management effectiveness, impacts and risk associated with factors influencing the Region's values**

Grades for the impact of factors influencing the Region's values (Chapters 5 and 6), the independent assessment of the effectiveness of current protection and management (Chapter 7), and overarching risk levels (Figure 9.2) are shown, including for component activities of direct use. The effectiveness grades are for the six elements of the management framework (Chapter 7). The assessment for climate change is only in relation to management measures undertaken specifically to protect and manage the Reef. The influencing factors that present the highest overall risk to the Region's values have their origins outside the Region. Higher risk also corresponds with uses and influencing factors that have both higher impact on values and weaker management effectiveness.

9.3.7 Cumulative impacts

The threats assessed individually in Figure 9.1 do not affect the Reef in isolation. Cumulative impacts result from the interaction of effects from one or more threats, as well as from past, present and reasonably foreseeable future influences.[2149] Responses to a single threat can be complex, such as indirect or not linear, variable in space and time, and compounded by other stressors or ecological processes.[2154] In isolation, a single threat can affect specific life stages or ecological processes that may also interact with other environmental factors, which are often difficult to detect. Some threats build up slowly over decades and have a chronic effect in the ecosystem, while exposure to others can occur as acute events over short periods of time.[1404]

The Reef and its Catchment are exposed, directly or indirectly, to diverse and extensive human activities, including ports, shipping, fishing, tourism, land-based runoff and coastal development. The impacts of these activities do not occur in isolation, and often interact with threats, such as ongoing sea-temperature increase, altered weather patterns, and outbreaks of coral predators and diseases.[2155] These cumulative impacts can interact with each other in different ways. For example, they can be additive (the combined effect is the sum of each independently), synergistic (the combined effect is greater than the sum of each independently) or antagonistic (the combined effect is less than the sum of each independently).[1572] These multiple impacts can also occur at the same time or can arise if the pressures occur at different times when they occur in the same space (due to the long-term effects of past pressures).



Multiple stressors favour algae in competition with coral. © Johnny Gaskell 2020

A wide variety of threats, either in isolation or in conjunction with others, are affecting the Region's natural, Indigenous, social, historic, and other heritage values (Chapters 2, 3, 4, 5 and 6). For example, chronic impacts from land-based runoff are often associated with declining trends in reef-building coral cover, but cyclones and thermal stress have also emerged as a major driver of changes in inshore coral reef ecosystems dynamics.[190] Similarly, impacts from heavy rainfall and floods have resulted in the decline of seagrass abundance. The extent of decline in some inshore regions and the recent impact of marine heatwaves are likely impairing recovery, even when meadows exhibit a substantial level of resilient traits.[145]

The complexity and uncertainty created by multiple threats can hinder the capacity of managers to identify and address the stressors that are contributing to changes in the Region's values and affecting the Reef's resilience. These stressors are particularly difficult to identify in habitats such as coral reefs and seagrass meadows, where acute and chronic pressures simultaneously affect the reproduction, growth and mortality of habitat-forming species.[2154,2156] Given the spatial scale and environmental diversity of the Reef, the resilience of communities at any point in space or time will almost certainly vary based on their exposure to pressures, the sensitivity of species to those pressures and the scale of disturbance that may affect population-level feedback processes.[1404] Sophisticated modelling approaches, calibrated and validated with empirical data, are required to capture the ecosystem-level effects of multiple stressors and to provide enhanced guidance for the strategic planning and spatial prioritisation of management actions and interventions.[2154]



Vessel grounding scar on a reef. © Johnny Gaskell 2023

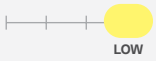
9.4 Assessment summary — Risks to the Region's values

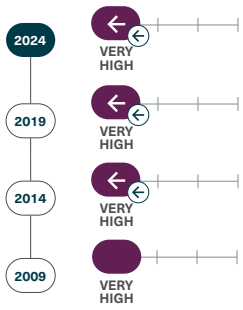
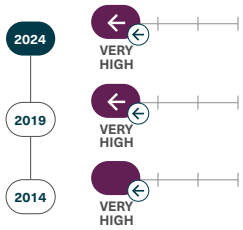
Paragraph 54(3)(d) of the *Great Barrier Reef Marine Park Act 1975* (Cth) requires '... an assessment of the risks to the ecosystem...' within the Great Barrier Reef Region.

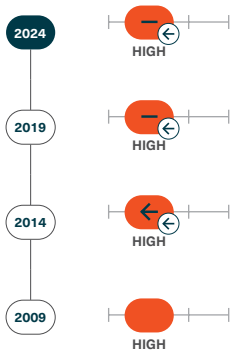
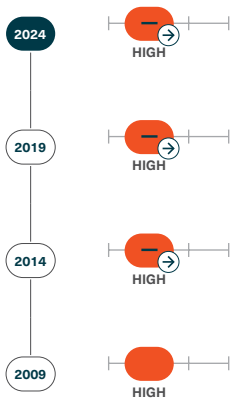
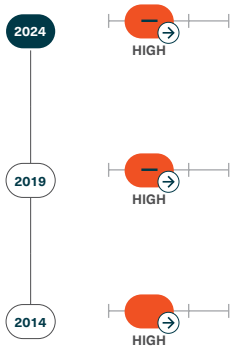
Paragraph 176(3)(b)(2)(b) of the *Great Barrier Reef Marine Park Regulations 2019* (Cth) requires '... an assessment of the risks to the heritage values ...' of the Great Barrier Reef Region.

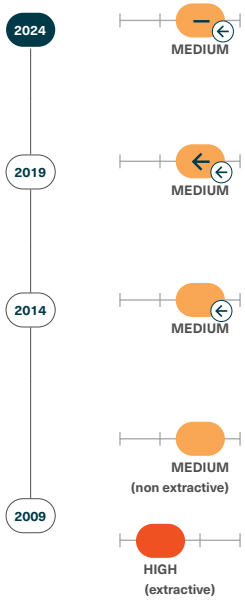
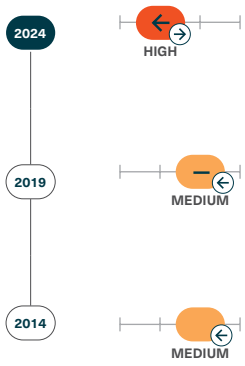
Separate risk assessments are provided for the Region's ecosystem (natural heritage value) and its heritage values (Indigenous, historic and other values) based on their current condition (and trends in condition), factors influencing them, the effectiveness of protection and management measures, and an understanding of the overall resilience.

9.4.1 Risks to the Region's ecosystem and heritage values

Grading statements — Risks		Trend since previous report	Confidence
	**Low risk:** Given current management arrangements, any threats considered likely or certain to occur are predicted to have no more than insignificant consequences for the Region's ecosystem or heritage values. There may be minor or moderate consequences for the Region's ecosystem or heritage values for other less likely threats.	Increased Stable Decreased No consistent trend	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence
	**Medium risk:** Given current management arrangements, few of the threats considered likely or certain to occur are predicted to have moderate consequences for the Region's ecosystem or heritage values and none will have catastrophic consequences. Some unlikely threats may have major consequences for the Region's ecosystem or heritage values.		
	**High risk:** Given current management arrangements, many of the likely or almost certain threats are predicted to have moderate or major consequences for the Region's ecosystem or heritage values.		**Future trend**
	**Very high risk:** Given current management arrangements, there are likely or almost certain threats that are predicted to have catastrophic consequences for the Region's ecosystem or heritage values.		Increasing Stable Decreasing No consistent trend
	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

Criterion and component summaries		Grade and trend	Confidence	
			GRADE	TREND
Overall risk to the ecosystem	**Natural heritage values:** Threats to the Region's ecosystem are multiple, compounded and expected to pose increasing risk, putting the ecosystem at very high risk. The most serious risks are from threats associated with climate change, coastal development, land-based runoff and some aspects of direct use (such as illegal fishing and extraction).			
Overall risk to heritage values	**Indigenous, historic and other heritage values:** Heritage values are at very high and increasing risk. The close connection between many heritage and ecosystem values means the risk from most threats is the same for heritage values as for the ecosystem. Additional high risk threats, particularly for Indigenous values, are fragmentation of cultural knowledge, foundational capacity gaps and behaviours affecting heritage values.			
Climate change	**Ecosystem:** Climate change related threats continue to pose significant risks to the Region. Impacts are increasingly challenging the resilience of key species and habitats.			
	Heritage: Climate change poses a serious risk to both tangible and intangible Indigenous heritage, the Great Barrier Reef World Heritage Area's outstanding universal value, as well as historic heritage sites.			

Criterion and component summaries		Grade and trend	Confidence	
			GRADE	TREND
Coastal development	**Ecosystem:** Coastal development remains a serious risk to the Region. Legacy impacts, such as barriers to flow, and modification of coastal habitats continue to affect connectivity and species requiring specific habitats within the Region. Impacts from artificial light continue from urban and industrial areas, and population growth may lead to further coastal development.		ADEQUATE	ADEQUATE
	Heritage: Changes to the ecosystem of the Region and Catchment could interrupt the flow of storylines across the landscape. The connectivity for some totemic species may also be affected. Many Indigenous and historic heritage values are irreplaceable and may be lost where additional modification of coastal habitats occurs in the future. Changes to the coastal environment affect the aesthetic attributes contributing to the Reef's outstanding universal value.		LIMITED	LIMITED
Land-based runoff	**Ecosystem:** Key threats associated with land-based runoff continue to pose a serious risk to the ecosystem via ongoing input of pollutants, such as sediments, nutrients, pesticides and marine debris. Risk levels for some threats may decrease when implemented Catchment management practices and programs are adequately resourced and outcomes become apparent after inherent time lags.		ADEQUATE	ADEQUATE
	Heritage: Marine debris that washes up in culturally important areas and sacred sites can injure or kill marine animals and birds of Indigenous cultural significance through entanglement or ingestion. Pesticide runoff may have adverse effects on some culturally important species. Changes to the environment will affect the aesthetic attributes contributing to the Reef's outstanding universal value.		LIMITED	LIMITED

Criterion and component summaries		Grade and trend	Confidence	
			GRADE	TREND
Direct use	**Ecosystem:** Threats to the Region's ecosystem values from direct use range from low to very high risk. If developed successfully, intervention techniques, using genetic modification, could increase the resilience of reefs to multiple stressors. Potential for negative consequences of these techniques exists, but the consequences are considered to be minor under the constraints of the current research program and management arrangements. A decrease in the risk of incidental catch of species of conservation concern is likely to continue from the planned phase-out of gillnet fishing and the implementation of independent data validation in commercial fisheries.		ADEQUATE	ADEQUATE
	Heritage: Since 2019, the level of risk relating to behaviour affecting heritage values and foundational capacity gaps has increased. Behaviour affecting heritage values may cause serious and permanent damage to Indigenous and historic heritage sites. Increasing co-management and participation of First Nations peoples in decision-making is expected to help reduce risk to heritage values into the future.		LIMITED	LIMITED

9.5 Overall summary of risks to the Region's values

The overall risks to the Region's ecosystem and heritage values (natural, Indigenous, historic and other) values remain very high and likely to increase in the future, based on current management. The identified threats to the Region's values are highly variable in space and time and arise from a range of sources. As ecosystem components and heritage values are closely connected, the projected risk for many threats is similar for both values.

The most serious threats to ecosystem and heritage values are associated with climate change, coastal development, land-based runoff and some aspects of direct use, for example illegal fishing and extraction. Threats associated with climate change, such as sea temperature, ocean acidification, altered weather patterns and rising sea level, have the highest negative impacts and risk levels are also expected to continue increasing into the future. Since 2019, there have been discernible changes in sea temperature, ocean chemistry and specific weather phenomena and these are expected to continue.



Climate change threats have the highest risk levels and are expected to continue increasing

Land-based runoff overall presents a high risk, though implementation of programs and practices to reduce its impacts should see these risks decrease in the future, albeit with a lag time on realisation of the outcomes from work already completed or to come. Threats associated with coastal development remain a high risk to both ecosystem and heritage values under current management, which is generally considered partially effective.

Management plans, policies and activities are keeping many risk levels stable. For example, strong management of commercial marine tourism and defence activities contribute to an overall assessment of low risk for these direct uses. However, some threats associated with direct use activities pose a serious risk to the Region's values. For example, illegal fishing and extraction is considered a very high risk to both ecosystem and heritage values, and discarded catch, incidental catch of species of conservation concern and some extractive fishing activities are considered high risk. Overall, direct use of the Region is assessed as a medium risk the values of the Region.

Across the assessment, risk posed by two threats has decreased since 2019. Outbreaks of crown-of-thorns starfish dropped from very high to high risk, as did incidental catch of species of conservation concern. These reductions are a direct reflection of management actions. For example, outbreaks of crown-of-thorns starfish remain a serious threat to coral reef habitats, but effective coral protection through targeted, sustained and sufficient crown-of-thorns starfish control can contribute to the resilience of this habitat.



Two risks have decreased as a direct result of management actions

Three risks have increased since 2019 — genetic modification from low to medium, and behaviour affecting heritage values and foundational capacity gaps, both from medium to high. For genetic modification the increase is based on an acceleration of interventions research, as trials occur more often. While it is currently unknown whether this could have potentially negative impacts on wild populations, consequences are considered minor at the moment considering the current research program and existing management

controls. It is important that new interventions are underpinned by sound science, calibrated against a range of risk factors (including inaction), consider ethics and the social and cultural acceptability, and are cost effective.

A deeper understanding of the impacts of a lack of agency of First Nations peoples in management of, and differences in access to, Sea Country underpins the increased risk of foundational capacity gaps since 2019. Increasing the agency and capacity of First Nations peoples will be critical to protecting Indigenous and natural heritage values of the Region. Behaviour that impacts heritage values is also understood to occur more frequently than was previously thought and may increase with population growth and use of the Reef. This impact is likely to be highest where users are unaware of the local cultural significance or desired behavioural guidelines from First Nations Traditional Owners. Co-management principles and integration of traditional knowledge into decision-making will be key to reducing risk levels.

Community views on the major threats to the Region's ecosystem and heritage values are generally aligned with those identified through the risk assessments in this chapter. While climate change is perceived as the greatest threat to the Reef, Catchment residents viewed illegal fishing and land-based runoff as among other serious threats to the Reef and Catchment waterways.



Understanding and responding to cumulative impacts is crucial

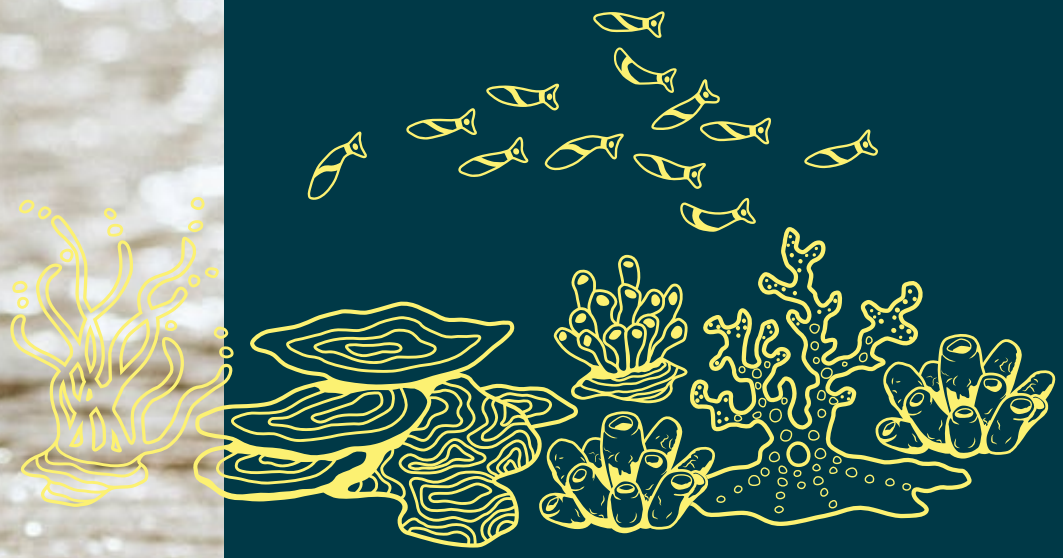
Climate change challenges the natural resilience of the Region's key habitats through exacerbating both acute and chronic disturbances, shrinking recovery windows and affecting ecological processes that underpin ecosystem resilience. The need to continue to understand and respond to cumulative impacts is crucial. In this way, new tools and approaches can be sought for implementation at Reef-wide, regional and local scales to help look after the Reef in the future.



Master Reef Guide connecting with the ocean. © Commonwealth of Australia (Reef Authority) 2024

Chapter 10

Long-term outlook



Long-term outlook

'an assessment of the long-term outlook for the ecosystem...' within the Great Barrier Reef Region, s 54(3)(h) of the *Great Barrier Reef Marine Park Act 1975* (Cth)

'an assessment of the long-term outlook for the heritage values...' of the Great Barrier Reef Region, section 176(3)(f) of the *Great Barrier Reef Marine Park Regulations 2019* (Cth)



Beach on Konomie (formerly known as North Keppel Island). © Reef Authority. Photographer Ryan Ramasamy 2023

"Our outlook has always been one of nurture — our health, our story and our spirit are tied to the spirit and health of Country — when she is well, we are well."

Aboriginal and Torres Strait Islander peoples are the Traditional Owners, Custodians and stewards of the Reef and its catchments. Some 70 Traditional Owner groups, whose traditional Country extends along the Reef's coastline and many more whose customary lands form part of the Reef's catchments, work to care for Sea Country.

This connection extends deep into the past, with the lives of Sea Country people at one with the life of the Reef. It is also a connection that stretches into the future.

"We can tell how much that has shifted and changed. People in the community know who we are and what we do, and we have children who are starting to stand up in front of their classrooms and saying they are junior rangers. That's a positive impact compared to when we were young. You can see the benefit on how they feel about their Indigenous heritage.

I feel like us being able to work on Country, to be based on Country, a ranger base is not only for our junior rangers, but for all of us, our community, for tourism. Mandubarra regards sharing what we do with community highly. The more everyone knows, the more respect happens on Country, the Country becomes healthier, and the people become healthier and that is a big aspiration for us."

— Mel Ball, Mandubarra Traditional Owner and business manager

Mel's journey is intergenerational. She works on Country with her mother and daughter. Together they are reinvigorating the journeys of First Nation Sea Women leading the care of their Sea Country. Collectively, they are aspirational and future-focused, while maintaining strong connections to their ancestors, cultural heritage, and traditional customs and knowledge.

"One of my main purposes is working on Country and I feel proud. Hopefully the bloodline can keep working on Country."

— Frederick Lefoe, Gunggandji-Mandingalbay Yidinji Traditional Owner and former Indigenous Ranger

Building the next generation of Sea Country custodians is underway along the Region's coastline, which is hemmed by waterways, rainforest and mountains. It is a World Heritage Area and Sea Country as diverse as its traditional custodians, who have inhabited their Country for more than 65,000 years. The commonality is the deep commitment to custodianship, love and respect for Sea Country, and an abiding ambition to share Culture with the younger generation, the broader community and the world.

Resilient Country and resilient people across all Sea Countries spanning the Great Barrier Reef is the future.

Source: Caring for Sea Country — Traditional Owner Stories from the Great Barrier Reef [1]

10.1 Background

Chapters 2 to 9 of this Outlook Report provide the evidence to inform an assessment of the long-term outlook for the Region's ecosystem and heritage values. Specifically, the long-term outlook discussed below is built from an understanding of the:

- current condition (and trend in condition) of the ecological (natural heritage value), economic, social and heritage (Indigenous, world and historic) values of the Region (Chapters 2, 3, 4 and 5)
- factors influencing those values (Chapter 6)
- effectiveness of protection and management measures (Chapter 7)
- resilience of the Region's ecosystem and its heritage values (Chapter 8)
- threats to the ecosystem and heritage values (Chapter 9).



Chapters 2 to 9 inform the assessment of the Region's long-term outlook

Figure 10.1 summarises key findings from these chapters. The main influences on the long-term outlook for the Region include human-induced climate change, population growth, land-based runoff and direct use of the Region (Chapters 5 and 6). These drivers and pressures interact, resulting in cumulative effects on the condition (and trend in condition) of values.

10.2 Likely future trends

The window of opportunity to secure a positive future for the Reef is closing rapidly. Multiple habitats, species, and ecosystem processes remain healthy or capable of recovery in the absence of acute disturbances, and the Reef retains its outstanding universal value as a World Heritage Area. Nevertheless, ongoing trends point to further deterioration of the Region's values if the highest risk threats are not effectively mitigated.



The window of opportunity to secure a positive future for the Reef is closing rapidly

The prognosis for an increasing disturbance regime linked to global climate change underscores the critical need for deep, rapid and sustained reduction in global greenhouse gas emissions to limit temperatures to 1.5 degrees Celsius of warming, or as close as possible.[1100] Limiting warming to 1.5 degrees Celsius (with no or limited overshoot) requires achieving global net-zero carbon dioxide emissions in the early 2050s, followed by net-negative carbon dioxide emissions.[2157] Local actions to reduce cumulative pressures on the Reef, maintain ecosystem condition, and facilitate recovery, remain imperative to a positive long-term outlook for the Region.

10.2.1 Possible long-term futures for the Region

The Region's ecosystems can still recover from disturbances given sufficient opportunity. However, cumulative pressures associated with human-caused climate change and other escalating drivers (such as population growth and catchment development) are narrowing recovery windows. Warming has already brought significant impacts, and repeated widespread coral bleaching events highlight the vulnerability of Reef ecosystems. An

increase in global average temperatures to 1.5 degrees Celsius above pre-industrial levels is expected in the near-term irrespective of cuts to greenhouse gas emissions.[1157] Such a scenario would see substantial changes occurring to the Region's ecosystems and associated community benefits, and every increment of additional warming would increase the projected severity of impacts.[159,1157] Without strong global action to curb greenhouse gas emissions, coral reefs are likely to become extremely diminished within the next 20 to 30 years.[165,2017] People and Reef-dependent industries need to prepare for this change.

Figure 10.2 shows two possible futures for the Region, in the medium term (2030 to 2050) and long term (beyond 2050). These possible long-term outlooks are indicative and based on information presented in previous chapters of this report.

Whether the Region's condition continues to deteriorate depends primarily on immediate national and global action on climate change, combined with effective management of remaining risks that originate within the Region and its Catchment, and the Region's resilience. Resilience-based management (Figure 10.3) that reduces threats and identifies and prioritises management actions that protect and build the Reef's capacity to withstand and recover from disturbances will become critical.[1984] Actions that protect foundational species, such as controlling coral predators, are important in the face of increasing and compounding threats.[187] Likewise, the rate and scale at which water quality can be improved is a critical factor for nearshore habitats at a regional level. A steadily increasing Catchment population means use of the Reef will grow in hotspots across the Region. Effective responses will require agility in Marine Park management and compliance and continued improvement in the management of activities in the Catchment that influence the Region.

Effective responses involve emissions reductions and local actions in the Region and its Catchment



Snorkeller taking photos of a reef © Johnny Gaskell 2021

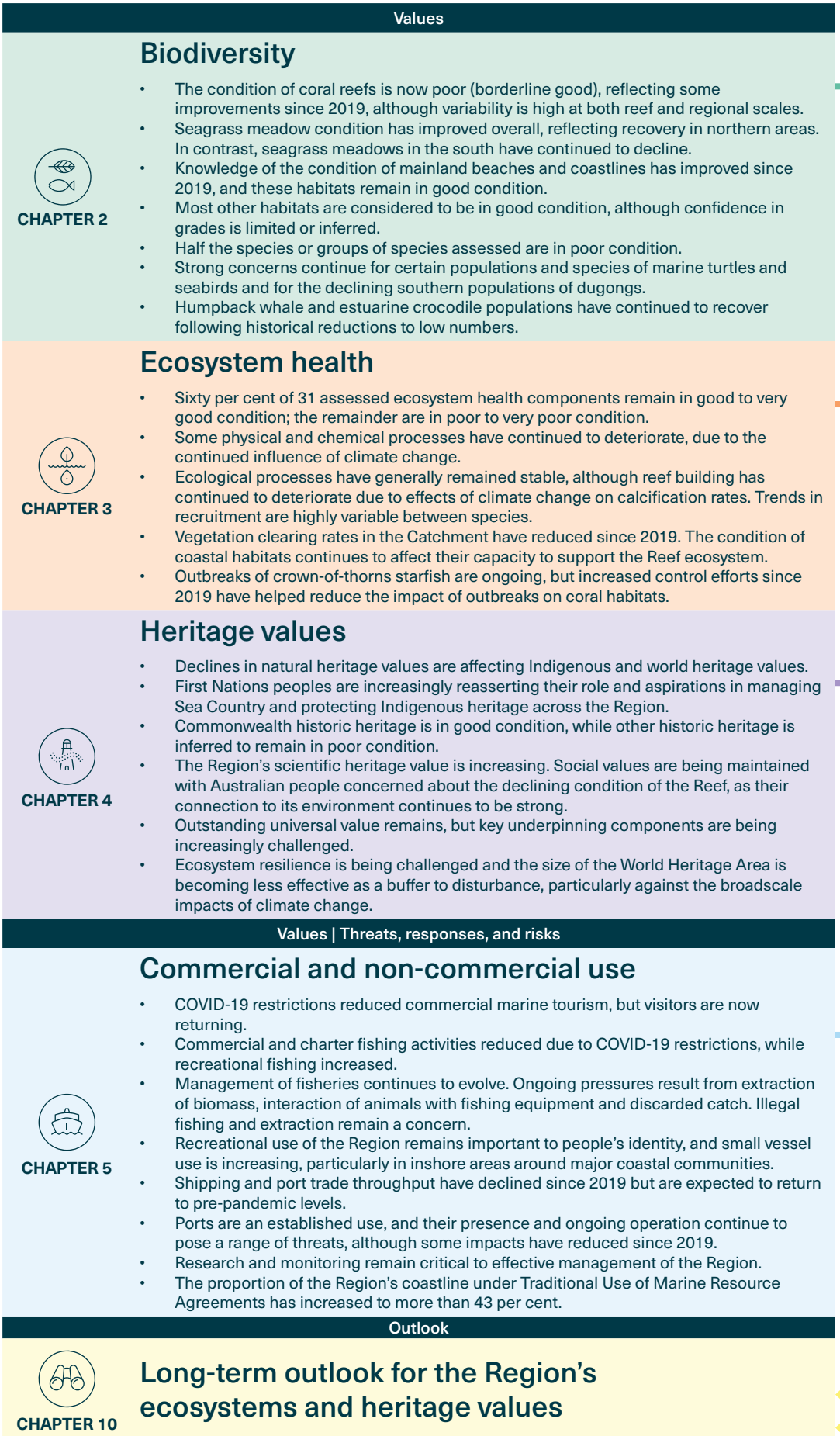


Figure 10.1 Summary of the findings underpinning the long-term outlook for the Region's ecosystem and heritage values

Factors influencing the Region's values

- Climate change poses the greatest risk to the Region's values, and its effects are projected to become more frequent, severe and widespread.
- Sea temperatures have continued to increase in line with climate change trajectories and mass bleaching events in 2020 and 2022 affected the Reef's ecosystems.
- Coastal development has been relatively minor since 2019, partly due to COVID-19, but projected population growth is likely to increase pressures in coming decades.
- Recent improvements in water quality are reported across inshore areas of the Reef, despite slow progress towards reducing pollutant loads in adjacent catchments. Recovery of some inshore ecosystems, such as seagrass meadows, is linked to improved water quality.
- Changes have occurred in all direct uses (including tourism, recreation and fishing) since 2019 driven by increasing population, the COVID-19 pandemic, market activity and fisheries reforms. Reductions in direct use observed during the pandemic have generally reversed.
- The cumulative effects of climate change and other pressures are increasing the impact on the Region's ecological, heritage, economic and social values.



CHAPTER 6

Existing protection and management

- Management to protect the Region is mostly effective across all six elements of the management cycle when considering the 14 management topics as a group.
- Funding and planning initiatives have been enhanced through the Reef 2050 Plan and the *Queensland Sustainable Fisheries Strategy 2017–2027*.
- Management of threats from climate change remains a challenge despite advances in policy at national, state and local levels.
- Declines in effectiveness of managing research activities, traditional use of marine resources, coastal development and land-based runoff occurred for various reasons, such as recognition of knowledge gaps, lack of integration of Indigenous knowledge, and lag times in achieving outcomes.
- Challenges involved in managing a large and diverse system are significant, and many threats to the Reef are being addressed in meaningful and positive ways.



CHAPTER 7

Resilience

- Some species show continuing recovery from past impacts, but concerns remain for other ecosystem components that have been severely affected by repeated mass bleaching events, heavy floods, crown-of-thorns starfish and marine pollution.
- Recovery of coral cover has been observed in many locations, especially on mid- and outer-shelf reefs. However, recovery of some corals and other reef species has likely been slower, which has implications for resilience.
- Humpback whales have recovered, but their future resilience may depend on impacts from climate change, particularly on food sources outside the Region.
- Coral trout biomass has steadily increased since 2012; however, their resilience is at risk from ongoing cumulative disturbances to coral reef habitat.
- Urban coast dugong populations show an overall long-term decline, with more significant declines detected in southern areas. Their resilience is influenced by climate change and local impacts, particularly to seagrass meadows.
- Loggerhead turtle resilience has been weakened by low levels of juvenile recruitment to foraging grounds, which has declined by half in recent decades.
- The reef tourism industry has shown strong resilience in the face of repeated mass coral bleaching events and the recent COVID-19 pandemic.
- Strong governance and co-management principles that connect First Nations peoples to, and support their agency in, Land and Sea Country management will benefit the resilience of ecosystem and heritage values of the Reef.
- A resilience-based management approach continues to be vital for maintaining the outstanding universal value of the Region.



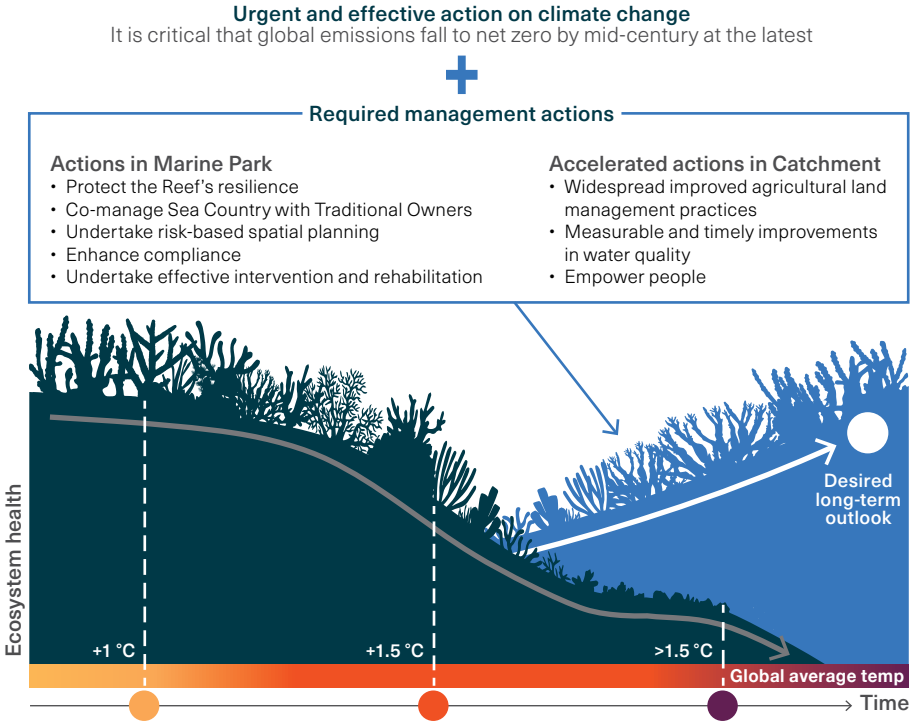
CHAPTER 8

Risks

- The Region's ecosystem and heritage values remain at very high risk and are projected to face increasing risks in future.
- Overwhelmingly, the threats with the highest risks to the Region are from climate change and its effects.
- Coastal development, land-based runoff and some aspects of direct use (such as illegal fishing and extraction) also present a high risk, although current management measures may decrease risk for certain threats in future.
- Outbreaks of crown-of-thorns starfish remain a serious threat and risk can be reduced through direct interventions.
- Ecosystem and heritage values are closely linked, so in many cases the same threats apply to both sets of values.
- Foundational capacity gaps, fragmentation of cultural knowledge, incompatible uses, illegal activities and other behaviours affect and pose high risks to Indigenous heritage values.
- Community views on risks to the Region's ecosystems and heritage values align with those identified in this assessment.



CHAPTER 9



2024 – Current Reef condition	2030 to 2050 – Possible Reef	2050 onwards – Possible Reef
+1 °C above pre-industrial	+1.5 °C above pre-industrial	>1.5 °C above pre-industrial
• World heritage values deteriorated • Indigenous heritage and community wellbeing impacts detectable • Less diverse coral reefs and some reef fish declining • Coral bleaching events and other impacts accumulating, and recovery time increasing • Intensifying pressures are slowing seagrass meadow recovery • Warmer temperatures cause more female and fewer male marine turtles • Stable nature-based tourism industry, but in restricted locations as areas recover post-disturbance • Viable fishing industries, but lower catches post-disturbance	• World heritage values significantly deteriorated • Indigenous heritage and community wellbeing impacts significant • Increasing boom and bust of branching and plate corals, loss of large slow-growing corals, increasing rubble • Fewer colourful reef fish • Loss and degradation of some seagrass meadows • Impacts to coastal habitats and coastlines from sea level rise, particularly in estuaries and on low-gradient shores • Marine turtle, seabird, and dugong populations in continued decline • Marine heatwaves increase in frequency, duration, spatial extent and intensity • Unreliable and increasingly extreme weather affects reef use • Fisheries may target different species • Higher disease prevalence across multiple species	• World heritage values not intact • Indigenous heritage and community wellbeing impacts irreversible • Coral reefs replaced with flatter rubble and algal-dominated systems • Significant impacts for reef associated species, including reef fish • Major reductions in seagrass abundance, more frequent and extensive loss events • Mangroves and saltmarsh shift shoreward as sea levels rise; losses due to coastal squeeze • Coastal protection reduced and coast less habitable; more beach erosion • Marine turtles, seabirds, and dugongs in rapid decline • Marine heatwaves 4 to 8 times more likely by the end of the century • Extreme weather events increasingly frequent or intense; impacts on reef use and the Reef • Fisheries may transition to new products and markets (e.g., algae and herbivorous fish) • Increasing incidence of disease

Figure 10.2 **Future pathways for the Great Barrier Reef Region**

The two outlook pathways shown provide examples of what the future might look like depending on whether key risks are adequately mitigated within required timeframes. The pathways are indicative and based on a large body of evidence from the previous chapters. Mitigating risks requires action on climate change and management actions in the Great Barrier Reef Marine Park and the Catchment. Reef condition and social values have already changed and will continue to change. Some change to the Reef is inevitable, but a more positive outlook pathway is still possible if global, regional and local mitigation and management actions are accelerated and implemented in time.

Given the scale of the challenges, it is critical that management actions are prioritised to optimise resource allocation, maximise impact and manage risk in alignment with long-term goals. In particular, the immediacy of the threat of rising ocean temperatures to coral reefs requires managers to consider a range of novel active and targeted interventions to support reef resilience, limit declines and promote recovery processes (Boxes 5.4 and 8.1). Implementation of effective interventions at scale may slow the rate of deterioration and allow time for development of further interventions, natural adaptation and further global action on climate change.[2158] Effective and timely mitigation of compounding risks will require adaptive management approaches and cutting-edge decision-support systems (Figure 10.3 and Box 10.1).

The long-term outlook for the Reef hinges on immediate global action on climate change and the effectiveness of management in the crucial decades ahead, during which warming already locked into the global climate system will have profound effects on the Region's ecosystems. By protecting the natural and heritage values of the Region, the lifestyles and livelihoods of the communities who live on its coastline and the intrinsic value to the global community will also be maintained. Prioritising actions that promote Reef recovery processes and limit further decline will improve the Region's long-term outlook.

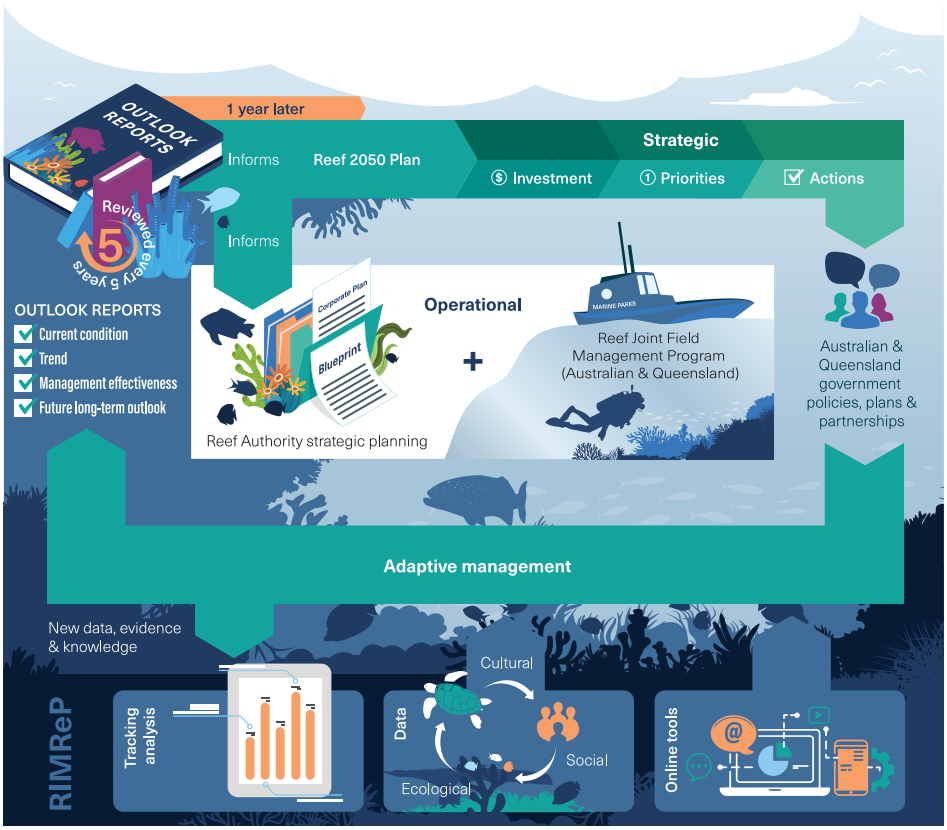


Figure 10.3 **Adaptive management cycle for the Great Barrier Reef**
Adaptive management is an important part of enabling resilience-based management. It entails the continuous collection and use of information to iteratively update management strategies, both immediate and longer-term. RIMReP = Reef 2050 Integrated Monitoring and Reporting Program. Source: modified from a diagram produced for the Reef Authority by Dr Sue Pillans.

10.2.2 Prospects for the outstanding universal value of the Great Barrier Reef World Heritage Area

The spatial extent of the World Heritage Area has not changed. However, the Reef is being increasingly exposed to broadscale impacts that are affecting it at a regional level. Human-induced climate change continues to challenge the integrity of the World Heritage Area and its size is becoming a less effective buffer against global impacts. Without additional national and global action on the greatest threats to the Reef through this critical decade and beyond,[182,1100] the protective capacity of size as a buffer will continue to be eroded by persistent and broadscale impacts on the Region and adjacent areas. The effectiveness of local and regional scale management actions is ultimately determined by the success of actions to address external influencing factors (for example, climate change).



The size of the World Heritage Area is becoming a less effective buffer against global impacts

Safeguarding mechanisms for the World Heritage Area are generally good, despite some decline since 2019 in how effectively external factors influencing the Region are managed. World heritage attributes in good condition at a Region-wide scale include the geographical scale and extent of the property, more than half the ecosystem processes, most habitats (noting large knowledge gaps exist for many habitats) and a range of species components.

The property's outstanding universal value remains whole and intact, but the condition of many elements that make up the four natural world heritage criteria continues to be a concern:

- The beauty of underwater seascapes (criterion vii) endures, as evidenced by a very high proportion of survey respondents rating the aesthetic beauty of the Reef as outstanding (Section 4.5.2). However, the longer-term trajectory is one of decline, as key habitats and species, such as reef-building corals, are increasingly exposed to cumulative impacts.
- Structures of biological origin important to major stages of the Earth's evolutionary history (criterion viii) (Section 4.2.3), including the structural components of coral reefs and *Halimeda* bioherms, are generally more resilient than the living ecosystems they support. Nevertheless, incremental declines in reef-building processes, along with an increasing disturbance regime, will increase pressure on the geomorphological integrity of these structures.
- More than one-third of the ecosystem processes assessed (criterion ix) are in poor to very poor condition (Chapter 3), including several critical processes essential for whole-of-system functioning (recruitment, symbiosis and reef building).
- Coral reefs, the most iconic of the Region's habitats, support a high diversity of species, including species of conservation concern (criterion x). They are in poor (borderline good) condition overall (Chapter 2) and are at immediate threat from climate change (Section 6.3.2). Marine turtles are in poor condition overall, and many populations show declining trends.

Historically, protection and management of the Reef was generally considered to be effective in protecting the World Heritage Area.[2159] However, the Great Barrier Reef World Heritage Area, like other world heritage properties globally, is increasingly affected by anthropogenic climate change. Australia and many other countries will find it increasingly challenging to deliver effective protection and management for their world heritage-listed properties.



The Region is managed through a joint partnership between Commonwealth and State agencies.
© Queensland Government 2023

To combat the deterioration of the Reef's outstanding universal value, its managers, Traditional Owners and stakeholders are increasingly intervening where the condition of critical habitats or species can be improved (Chapter 8). The most significant interventions have been the successful culling of crown-of-thorns starfish and interventions on islands, where active conservation actions have protected critical nesting habitats for vulnerable species and restored ecosystems. Novel interventions to support resilience continue to be explored.

While understanding of the Region's heritage values (natural, Indigenous and historic heritage values) remains far from comprehensive, filling key gaps remains a priority under the *Reef 2050 Long-Term Sustainability Plan* (Reef 2050 Plan).[1414] Building on previous efforts, heritage values continue to be better defined, including social, aesthetic, geomorphological attributes and Indigenous heritage values (Chapter 4). A deep understanding of the resilience and adaptation of ecosystem and heritage values in the face of climate change and cumulative pressures should remain a key focus to inform adaptive management.

10.3 Current and future initiatives to improve the long-term outlook

The long-term outlook for the Reef will depend on decisions and actions taken at a global level to address climate change, and on effective management of threats to the Region's values. The threats are multiple, cumulative, and intensifying, so management approaches must be constantly evolving and agile (Box 10.1). The urgency of responding to threats currently facing the Reef, combined with the limited time and resources available, compels management to identify, prioritise and safeguard key species, habitats or processes that will enhance the resilience of the Reef ecosystem, including potential climate refugia.[2160] Finding more effective ways to plan for, and respond to, changing environmental and social conditions is essential.

This assessment of the long-term outlook for the Region's ecosystem and its heritage value includes consideration of current management arrangements and relevant management initiatives identified but not yet fully implemented (Figure 10.4). The future initiatives under the Reef 2050 Plan, the *Great Barrier Reef Blueprint for Climate Resilience and Adaptation*[1984] (Blueprint 2030), and the *Reef 2050 Water Quality Improvement Plan*[1883] and *Reef 2050 Traditional Owner Implementation Plan*[1120] set the framework for improving resilience-based management and protection of values. Also considered are the future commitments of the Australian and Queensland governments and partners under the Reef 2050 Plan.

Significant management initiatives continue to protect values and support resilience of the Region. Despite this, and the documented recovery of some key habitats and species (Chapter 8), overall resilience is being challenged. The scientific evidence is clear: the most urgent initiatives are those that will halt and reverse climate change and those that will effectively improve water quality at the regional scale. International forums, national and state energy transition agendas, and partnerships at all levels provide opportunity for advocacy and encouragement around transformative actions for emissions reduction.[1984] Further improvements in water quality, protecting and restoring supporting coastal habitats, and reducing fishing pressure on certain fish stocks will support the resilience of the Reef ecosystem in the face of climate change threats. In addition, recent evidence confirms that controlling crown-of-thorns starfish populations represents an essential management tool for enhancing Reef resilience.

Overarching

- Great Barrier Reef Intergovernmental Agreement
- *Reef 2050 Long-Term Sustainability Plan* (2021), Reef Trust and Queensland Reef Water Quality Program investment
- *Reef 2050 Traditional Owner Implementation Plan*
- *Great Barrier Reef Blueprint for Climate Resilience and Adaptation* (2024) — Reef Authority
- Reef 2050 Integrated Monitoring and Reporting Program
- Reef Authority Policy and *Planning Strategic Roadmap*
- Scientifically valid, ongoing monitoring involving the community



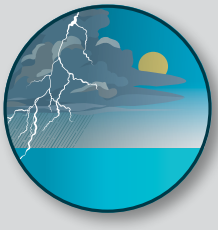
Natural heritage values (biodiversity and ecosystem health)

- Reef Joint Field Management Program — expanded biodiversity protection and enhanced compliance activities
- *Queensland Sustainable Fisheries Strategy 2017–2027* — ongoing implementation and expanded reforms
- *Nature Positive Plan: Better for the Environment, Better for Business* (2022) — Australian Government
- Crown-of-thorns starfish control — expanded efforts to protect coral cover
- Islands and fringing reefs — Queensland Government values-based framework for Queensland islands
- Reef Restoration and Adaptation Program



Heritage values (Indigenous and historic)

- *Aboriginal and Torres Strait Islander Heritage Strategy for the Great Barrier Reef Marine Park* (2019) (Cth) — increasing understanding and protection of Indigenous heritage — Reef Authority
- Queensland Government *Gurra Gurra Framework 2020–2026* (Qld)
- Great Barrier Reef Marine Park Commonwealth Heritage Listed Places and Properties Heritage Strategy 2022–25
- *Underwater Cultural Heritage Act 2018* (Cth)



Climate change

- *Climate Change Act 2022* (Cth)
- Queensland *Climate Action Plan and Queensland Climate Adaptation Strategy (2017–2030)*
- *Position Statement: Climate Change* (2024) — Reef Authority
- International Partnership for Blue Carbon
- National Environmental Science Program — long-term commitment to environment and climate research



Coastal development and land-based runoff

- *Environmental Protection Regulation 2019* (Qld)
- *Reef 2050 Water Quality Improvement Plan 2017–2022 — Australian and Queensland governments*
- Queensland vegetation management laws and State Planning Policy
- *Sustainable Ports Development Act 2015* (Qld) — management of port related development
- *Reef 2050 Wetlands Strategy: A Strategy to manage wetlands in the Great Barrier Reef and its catchments — Australian and Queensland governments*



Direct use

- *Tourism Management Action Strategy — Australian and Queensland Government*
- Public moorings and reef protection markers — expanded network
- *North-East Shipping Management Plan* — Australian Government
- Queensland priority port master plans and overlays, and *Maintenance Dredging Strategy for Great Barrier Reef World Heritage Area Ports*
- Sea dumping legislation
- Vessel monitoring — for commercial fishing vessels and shipping
- Traditional Use of Marine Resources Agreements — expanded coverage
- Marine debris-reduction initiatives — national threat abatement plan and funded citizen science programs

Improved resilience of the Great Barrier Reef Region

Figure 10.4 Current and future initiatives to improve the Region's values and support resilience

BOX 10.1 Decision-support tools for adaptive management

Faced with an increasing disturbance regime, Reef managers increasingly require effective decision support systems that integrate modelling and monitoring data from across the Region to recommend optimal times and locations for management interventions.

In the Catchment, scenario modelling validated against observational data is used in setting water quality targets and evaluating the impacts of on-ground management to address land-based runoff. On the Reef, decision-support systems aggregate and integrate: (i) high-quality observational data collected by Marine Park staff, research partners, and Reef users; (ii) data from remote sensing platforms and in-water sensors; and (iii) model predictions for factors such as wave and wind conditions, thermal stress,[2161] and connectivity. Spatial analysis is then used to synthesise this information to develop flexible and targeted management actions. This process is part of an adaptive management approach that allows for continuous monitoring and adjustment of management strategies based on near real-time data and feedback, so that management strategies can be updated as new information becomes available.

For example, the Crown-of-thorns Starfish Control Program has the capacity sufficient to manually cull starfish outbreaks on approximately 200 reefs per year. Surveillance and culling effort must be deployed to the right reefs at the right times to achieve optimal outbreak suppression and coral protection. The Reef Authority works with research partners and program contractors to prioritise reefs for crown-of-thorns starfish control on an annual basis. The annual reef prioritisation and work planning process is led by the Reef Authority in collaboration with government, research and industry partners. It draws on the latest field and model data to rank reefs according to a range of ecological and economic variables, including crown-of-thorns starfish risk, coral status, capacity to produce and spread starfish and coral larvae, and tourism value. The highest-ranking 200 to 250 reefs are selected as target reefs and then systematically actioned by teams of professional divers in accordance with the *Integrated Pest Management framework* developed for the control program.[1024]

New research demonstrates the effectiveness of this approach.[187] Connectivity modelling and other tools developed for this program[2162] have potential wider applicability and could be used in combination with aerial and in-water survey data to better understand, predict and facilitate reef recovery following disturbances, such as cyclones and marine heatwaves.

Engagement: Continued productive working relationships between management partners (Traditional Owners and government agencies) and a diverse range of Reef stakeholders provide a collective understanding of the conditions (and trends in condition) of key values across the Region, the pressures affecting the Reef and shifting societal attitudes.

Australian and Queensland government agencies, Traditional Owners, Reef industries and many other partners continue to make significant contributions to protecting and managing the Region. Agreements such as the Great Barrier Reef Intergovernmental Agreement[1300] form the basis of effective partnerships and collaboration between the Australian and Queensland Governments and associated agencies. Traditional Owner engagement has increased through the expanded Traditional Use of Marine Resources

Agreements program, policy commitments to co-management, and strengthened communication between managers and Traditional Owners (Box 10.2). There are also continued, strong and growing connections between research and decision-making bodies.



Surveying the Freshwater Bay midden at Jiigurru (Lizard Island). © Sean Ulm 2022

Stakeholders and community members are involved at multiple levels. Advisory bodies, such as the Reef Authority's Local Marine Advisory Committees, Indigenous Reef Advisory Committee, and Tourism Reef Advisory Committee provide advice to management about local and Reef-wide management. The Australian and Queensland governments also receive advice regarding the Reef 2050 Plan and related issues from a Reef 2050 Advisory Committee and an Independent Expert Panel.

Stewardship programs, such as the Reef Guardians program, empower schools and local government councils within the Region to build their capacity to protect the Reef. Citizen science programs such as Eye on the Reef assist management and science through the provision, by tourism operators and others, of information on species of conservation concern or major events (such as coral bleaching). Monitoring information from these groups feeds into decision-support systems that guide management decisions to benefit the Region (Box 10.1). Community groups are also active in delivering local management actions, such as removing marine debris and responding to marine animal strandings.

Stewardship within the Region and continued on-ground initiatives to reduce risks and improve Reef and Catchment health are important and are making a collective difference. This continued approach will provide a strong foundation for maintaining a balance between protecting the Region's values and supporting sustainable use.

BOX 10.2

The Reef 2050 Traditional Owner Implementation Plan

Traditional Owners play a crucial role in caring for the Reef and have a deep understanding of its ecosystems. The 'Heart of the Reef — A Call for Healing' statement outlines the deep-rooted connections Traditional Owners have with the Reef and showcases both their concerns for and understanding of Reef ecosystems.[2163]

The *Reef 2050 Traditional Owner Implementation Plan* [1120] (Implementation Plan) forms part of the overarching Reef 2050 Plan and details Traditional Owner's aspirations for the Reef. The Implementation Plan has been designed and led by Traditional Owners and has a key focus on the vision and outcome of 'Healthy Reef, Healthy People'. The strategic framework underscores the importance of Indigenous perspectives, wisdom, and cultural connections to the Reef and of integrating traditional knowledge, and management practices into the overall strategy for the Reef's conservation.

Actions are set out across six key work areas: climate change, land and coast, Sea Country, partnerships and capacity, knowledge systems and investment. These work areas are designed to nurture meaningful Traditional Owner inclusion, vision, and co-management and they focus on pathways to realising Traditional Owners' aspirations. A key priority is to progress options around the establishment of a Reef-wide Sea Country Alliance to provide Traditional Owners a strong and representative voice for achieving their long-term aspirations for the Reef.

In November 2023, a principles-based 'Agreement to Partner' was signed by the Reef 2050 Traditional Owner Steering Group, the Commonwealth Minister for the Environment and Water, and the Queensland Minister for the Environment and the Great Barrier Reef.[2164] This is designed to give effect to the rights, interests, and aspirations of Traditional Owners for the Reef in delivering the Reef 2050 Traditional Owner Implementation Plan.

Environmental regulation: Effective education and enforcement of current management tools, such as Acts, regulations, zoning plans, plans of management and permits, continue to be critical in reducing direct risks to the Region and supporting resilience of the Reef. The Reef Authority's *Policy and Planning Strategic Roadmap* (2019) [1188] has been developed to ensure policies and plans are pro-active, contemporary and risk-based, which will help managers ensure people continue to use and access the Reef in a sustainable manner. The Australian Government's *Nature Positive Plan: Better for the Environment, Better for Business*[2011] aims to strengthen and streamline the national environmental laws in response to an independent review of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act). Australia's commitment to emissions reductions is now legislated under the *Climate Change Act 2022* (Cth). The Queensland Government has continued their significant fisheries reform process, including legislative changes to prohibit the take of hammerhead sharks and phase-out gillnet fishing in the Region by 2027, as well as implementing harvest strategies and improving data collection and independent data validation.

Significant investment in the Reef Joint Field Management Program has increased the capability of marine and island national park management and enabled delivery of field activities identified in the Reef 2050 Plan and Blueprint 2030. The program's on-water capacity has been drastically increased, growing from an annual base funding commitment of $17 million in 2017–18 to more than $38 million in 2020–21.[72] This funding will see more than a 60 per cent increase in staffing and an enhanced vessel fleet of more than 21 vessels. These resources will enable an increased focus on compliance, island and reef rehabilitation activities, incident response, collaboration with Traditional Owners to deliver field activities, and engagement with Reef and island users.

There has also been significant investment through the Queensland Reef Water Quality Program to support ongoing implementation of the Reef protection regulations and the Reef 2050 Water Quality Implementation Program.



Compliance staff in the field. © Commonwealth of Australia (Reef Authority) 2024

Knowledge, integration and innovation: The independent review on the existing protection and management of the Region (Chapter 7) again rated managers' understanding of the Region as the strongest element of the management cycle. This reflects a strong understanding of Reef values, national and international influences, and relevant government and non-government actors. Nevertheless, known and emerging gaps in knowledge (including around threats, their effects and suitable management approaches) present an ongoing challenge.

Following the Outlook Report 2019, key gaps in scientific and other knowledge of the Region were identified. The high-priority gaps needed to inform evidence-based decision-making and help improve management and protection strategies over the long-term were summarised into a report, *Science and Knowledge Needs for Management.*[1386] This report sets out the Reef Authority's priority information needs and is supported by an interactive tool on the online Reef Knowledge System (Box 10.3). The National Environmental Science Program continues to contribute to filling priority knowledge gaps. A recent project explored evaluation of recreational fishing behaviour, use, values and motivations that relate to compliance.

First Nations people have cared for Land and Sea Country for many generations. Integrating traditional knowledge and cultural science into decision-making will be important to inform future adaptive management of the Reef and Catchment. Critical to achieving this will be fostering greater participation of Traditional Owners in decision-making, increasing their access to the Reef, and enhancing their on-ground capacity and opportunities.

Integrating traditional knowledge and cultural science into decision-making is important



Ngaro Traditional Owner preparing for a smoking ceremony. © Commonwealth of Australia (Reef Authority) 2024

Agile approaches are needed to protect key values and prevent human use patterns becoming unsustainable and hard to manage. Access to relevant information on biological and human dimensions will be key to supporting evolving policies and spatial planning. To do this, managers require up-to-date spatial and temporal information on how people use and value the Region, and the condition of associated local environmental, Indigenous, historic and social heritage values. Effective collaboration and partnerships with a network of providers will ensure best-available science continues to underpin management and allow evaluation of the effectiveness of actions.

Developing ways to understand and respond to the effects of cumulative impacts remains paramount. While implementation of the Reef-wide *Cumulative Impact Management Policy* (released in 2018) [2149] is underway, cumulative impact management of multiple uses in and adjacent to the Region remains a challenge.[11,1982] Escalating climate change pressures have heightened the importance of implementing this policy and progressing contemporary spatial planning in the Region and Catchment.

BOX 10.3

Bringing knowledge together for Reef management

A key part of the *Reef 2050 Integrated Monitoring and Reporting Program* (RIMReP) is the Reef Knowledge System website, which seeks to provide a knowledge system for resilience-based management of the Reef and its Catchment.

A prototype of the Reef Knowledge System was published in 2020 and the first edition of the website was released in 2022. The content strategy for the system is to curate RIMReP data and information into a streamlined digital space that helps Reef managers navigate to the information they need to make evidence-based decisions. The program achieves this by working with multiple levels of government, research institutions, and Traditional Owners. The system provides a window into the Great Barrier Reef's complex social and natural ecosystem, through a public-facing website and additional access for managers.

Program development focuses on three knowledge system components:

- Collecting and integrating data: For the first time, a centralised location will provide access to information from monitoring and modelling of the Reef's biophysical, social, economic, Indigenous and heritage values, as well as the drivers and pressures on those values.
- Improving data access: Enabling access to data through the knowledge system requires meeting sufficient standards for data management, collection and sharing.
- Visualising data: The knowledge system will allow users to access consolidated and integrated information, becoming a 'first stop shop' for Reef managers.

RIMReP and its Reef Knowledge System aim to connect information from across domains (such as the Reef Restoration and Adaptation Program and Crown-of-thorns Starfish Control Innovation Program [2169]), enabling more-informed strategic and operational decision making. The Reef Knowledge System also links users to partner systems and other useful Reef information (for example, eReefs and Paddock to Reef). The Reef Knowledge System will continue to evolve in response to user needs and the increasing availability of data and new science and technologies. It will further integrate a wide variety of data, information, and knowledge to help inform and guide management decisions in a rapidly changing environment.

Implementing a Reef-wide integrated monitoring and reporting program directly linked to an outcomes-based management framework will underpin adaptive management. The Reef 2050 Integrated Monitoring and Reporting Program (RIMReP) aims to address integrated information needs for future management of the Reef (Box 10.3).

Approaches must be agile and constantly evolving as threats are multiple, cumulative and intensifying

Given the increasing frequency of acute and chronic stressors, timely information on the health of key indicators (species, processes, and human dimension values) and their trajectories over time and space is critical. Indicators for ecosystem health and community

wellbeing are being developed through RIMReP to measure condition (and trend in condition) of values. Good alignment between what is measured, how it relates to relevant thresholds, and how it meets the desired outcomes for the Region's values provides the most powerful insight. For example, a holistic metric of seagrass resilience has been developed based on measurable biological characteristics that exemplify seagrass resistance to pressures and essential mechanisms for recovery (Section 8.3.2).[2063] A similar metric for coral that expands on conventional measures, such as coral cover, is under development.[2055,2056]

It is still essential to investigate intervention strategies and technologies that are scalable and effective at improving the resilience of Reef habitats. For example, the Reef Restoration and Adaptation Program is investigating and developing coral reef intervention techniques that can be feasibly applied at sufficient scale to have a positive effect on Reef condition. This will require a combination of discovery research and applied field testing. Information on how intervention activities can be effective at scale, while minimising harm, is important for researchers, managers, and the community. Given the connection to, and value of, the Region for Traditional Owners and the community, those undertaking intervention activities must understand and consider social attitudes.

Investment in innovative field-based and desktop technologies is needed to support improvements in monitoring and management. Emerging technologies (Section 6.2.3) are increasingly enabling managers to monitor remote and inaccessible parts of the Region. Increasing use of drones, night vision and vessel tracking will increase surveillance and enforcement of Reef rules. Drones continue to provide increased and cheaper monitoring capability and aerial mapping. Environmental DNA is being explored as a means of quantifying species presence and diversity more quickly and affordably than conventional methods. Innovation by individuals and within businesses can broadly support decarbonisation of the Australian economy and can help drive positive actions by setting examples for others. For example, the actions in the Reef Authority's Sustainability Strategy include a detailed roadmap to reducing emissions by the agency to net zero by 2030.[2165,2166] Similarly, the Queensland Department of Environment, Science and Innovation's emissions reduction efforts link to various Queensland strategies and plans.[85,2167,2168]

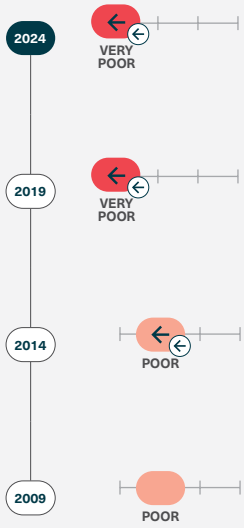
10.4 Assessment summary — Long-term outlook

Paragraph 54(3)(h) of the *Great Barrier Reef Marine Park Act 1975* (Cth) requires '*an assessment of the long-term outlook for the ecosystem* ...' within the Great Barrier Reef Region.

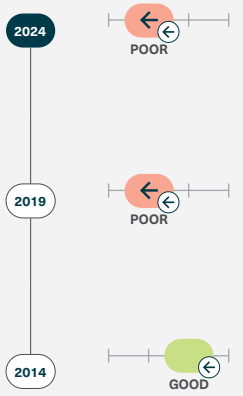
Section 176(3)(f) of the *Great Barrier Reef Marine Park Regulations 2019* (Cth) requires '*an assessment of the long-term outlook for the heritage values* ...' of the Great Barrier Reef Region.

Grading statements — Long-term outlook		Trend since previous report	Future trend
	**Very Good:** The values are likely to remain healthy and resilient for the foreseeable future with strong recovery at damaged locations. Additional management intervention is not required to maintain the values.	→ Improved — Stable ← Deteriorated ··· No consistent trend	→ Improving — Stable ← Deteriorating ··· No consistent trend
	**Good:** With only minor additional management intervention, the values are likely to remain generally healthy and resilient for the foreseeable future, with only some values showing signs of significant deterioration.		
	**Poor:** Without significant additional management intervention, some of the values will deteriorate in the next 25 years, and only a few values are likely to be healthy and resilient in the longer term.	**Confidence**	
	**Very Poor:** Without urgent and effective additional management intervention, the values are likely to deteriorate rapidly with the loss of most values in the longer term.	Adequate high-quality evidence and high level of consensus Limited evidence or limited consensus Inferred, very limited evidence	
	**Borderline:** Indicates where a component or criterion is considered close to satisfying the adjacent grading statement.		

10.4.1 Outlook for the Region's ecosystem

Criterion and component summaries	Grade and trend	Confidence	
		GRADE	TREND
Outlook for the ecosystem: Key habitats, species, and ecosystem processes remain healthy or capable of near-term recovery in the absence of acute disturbances. However, the threats affecting the Region's ecosystem (natural heritage values) are increasing, compounding and expanding in scale. These are driven strongly by climate change and involve steadily increasing chronic threats, such as ocean acidification, as well as a rising probability of acute disturbances, such as marine heatwaves. Multi-jurisdictional solutions and on-ground management involving stakeholders and the community are highly valuable, but outcomes are being undermined by climate change. Current trajectories for global greenhouse gas emissions are not compatible with a healthy and resilient future Reef. The window of opportunity to secure a positive future for the Reef is closing rapidly, and strong, effective actions remain urgent at global to local scales.			

10.4.2 Outlook for the Region's heritage values

Criterion and component summaries	Grade and Trend	Confidence	
		GRADE	TREND
Outlook for heritage values: Many of the Region's heritage values are closely tied to the condition of the ecosystem. The most serious risks to the Region's heritage values are from climate change, land-based runoff, coastal development, and some aspects of direct use. Identification and monitoring of the broad range of Indigenous, historic, and other heritage values is not yet well established but is improving. Indigenous heritage values are compromised due to the lack of agency and access by First Nations people to manage their Country. Adopting and implementing co-management principles and greater sharing of knowledge of heritage values among the Region's managers, Traditional Owners and stakeholders are critical to ensuring recognition and continued protection of those values.			

10.5 Overall summary of long-term outlook

The Great Barrier Reef remains a wonder of the natural world, but it faces an uncertain future. Rising global temperatures are driving unprecedented changes to key habitats, species and ecosystem processes. These will inevitably result in impacts to Reef-dependent human communities. Actions taken now could reduce these effects, if implemented well.



Every effective action taken now contributes to a more positive long-term outlook

The Region's current outlook remains one of continued deterioration. Warming already locked into the global climate system will have profound effects on the Region's ecosystems over the next decade and beyond, and unchecked warming would be devastating for the Reef. The window of opportunity for changing direction is closing rapidly. Only the strongest and fastest possible actions to decrease global greenhouse gas emissions will reduce the risks and limit the impacts of climate change on the Reef. Timely and effective management actions taken now can dramatically alter potential futures.

Although some changes are occurring gradually, most of the outcomes of steadily rising greenhouse gas concentrations are experienced as extreme events. Among the most pressing and inevitable of these are widespread marine heatwaves that can cause mass bleaching and death of corals and affect a range of other species and habitats on a Region-wide scale. Historically such events have been rare, but the chances of them occurring increase with every increment of global warming. Periods with relatively few acute disturbances, such as the past five years, provide vital recovery windows, but these temporary reprieves will become fewer and shorter for as long as greenhouse gas concentrations continue to rise. Efforts to enhance the resilience of Reef ecosystems are vital, as they enable better resistance and recovery from disturbances. The identification and protection of places (including climate refugia), habitats, species and ecosystem processes critical for resilience is also urgent.



Management actions should address compounding threats and create recovery windows for the Reef

The Region was at a crossroads in 2009, with an opportunity for the right decisions to protect the Reef into the future. Since then, the global community has made uneven progress towards the decarbonisation objectives articulated in the Paris Agreement of 2015. The Reef is a global icon at imminent threat if climate objectives are not met, and even if they are, every increment of additional warming will bring additional consequences. Resilience-based management and effective interventions at the right scales may buy time for the Reef while global efforts to decrease greenhouse gas are effectively implemented.



Every increment of additional warming will bring additional consequences

Across the Region and at local scales, it is imperative that management actions continue to address compounding threats and everything possible is done to create recovery windows for the Reef. The Reef 2050 Plan has continued to drive action across the management of land-based runoff, sustainable fisheries management and crown-of-thorns starfish control. Direct management actions can reduce pressures and localised ecosystem recovery has been observed in some areas, but it is slow. Current efforts that are effective in ensuring that use is sustainable and compliant with environmental

protection rules should be continued. Catchment management actions aimed at reducing pollution in land-based runoff have gradually reduced pollutants in some locations, but the accelerated change required is yet to be achieved. Catchment population growth is likely to increase people's use of the Reef. Marine policies and planning that aim to protect representative and potential refuge areas while allowing for multiple uses will need to be agile and responsive to changing use patterns and disturbances.

Many existing arrangements and activities are in place to support the Reef's resilience including zoning plans, regulations and permissions, and the Crown-of-thorns Starfish Control Program. Multi-agency efforts to explore tangible and scalable reef interventions may lead to a suite of innovative and targeted measures that could provide options for management in the future. The success of these interventions will depend on favourable Reef conditions for growth and recovery, which will not occur unless the rate of anthropogenic climate change is halted and reversed.

It is essential that the management of the Region is adaptive as the extent and seriousness of different risks to the Reef change over time. Difficult choices will need to be met head on and more often. Managers may need to change how some things are done, try new approaches, and let go of some longstanding practices. Reef management will increasingly require new and evolving decision support tools.

The social heritage values of the Great Barrier Reef are affected by the condition of the ecosystem, changes to social conditions and human interactions with the Reef. The economic and social benefits the Reef provides to all people who value, enjoy or depend on it will be impacted. Broad, multi-jurisdictional management actions that involve the community and behaviour change will be important in maintaining resilience of social heritage values. People continue to see the Reef as part of their personal and national identity and value its importance. There is an expressed willingness to undertake actions for Reef health, which in turn, supports human wellbeing. Translating this willingness into action requires overcoming acknowledged feelings of uncertainty and a general lack of specific knowledge in how to help address and mitigate these threats on a personal level.



Traditional Owners managing Sea Country will benefit both natural and heritage values of the Reef

The enduring and intrinsic connection Traditional Owners have to Sea Country is being affected by changes in the Reef's condition. Traditional Owners are increasingly reasserting their role in Sea Country management and the protection of Indigenous heritage across the Region. The condition (and trend in condition) of Indigenous heritage values are intrinsically linked to natural heritage values. Knowledge of other components of Indigenous heritage condition remains limited. Adoption and implementation of co-management principles with Traditional Owners will benefit both natural and heritage values of the Reef.



The Reef is already a changed system, communities and industries that depend on it must prepare for change

The Reef is already a changed system, and communities and industries that depend on it must prepare for continued change. As a social–ecological system, the health of the Reef ecosystem will continue to have both impacts on, and benefits for, the community and human wellbeing (socially, culturally, and economically). Society will need to play a pivotal and urgent role in mitigation and adaptation to support the Region's resilience. The future Reef will be vastly altered by climatic changes that already set in motion, but just as every increment of warming will compound impacts, every effective action taken now contributes to a more positive long-term outlook.



Green sea turtle. © Matt Curnock, 2022

Appendices



Appendices

APPENDIX 1: STATUTORY REQUIREMENTS FOR THE OUTLOOK REPORT

Extract from the *Great Barrier Reef Marine Park Act 1975* (Cth)

Section 54 Great Barrier Reef Outlook Report

(1) The Authority must prepare and give to the Minister a report in relation to the Great Barrier Reef Region every 5 years. The first report must be given to the Minister by 30 June 2009.

(2) The report must be prepared in accordance with the regulations (if any).

Content of report

(3) The report must contain the following matters:

- (a) an assessment of the current health of the ecosystem within the Great Barrier Reef Region and of the ecosystem outside that region to the extent it affects that region;
- (b) an assessment of the current biodiversity within that region;
- (c) an assessment of the commercial and non-commercial use of that region;
- (d) an assessment of the risks to the ecosystem within that region;
- (e) an assessment of the current resilience of the ecosystem within that region;
- (f) an assessment of the existing measures to protect and manage the ecosystem within that region;
- (g) an assessment of the factors influencing the current and projected future environmental, economic and social values of that region;
- (h) an assessment of the long-term outlook for the ecosystem within that region;
- (i) any other matter prescribed by the regulations for the purposes of this paragraph.

Peer-review

(4) The Minister must arrange for the content of the report to be peer-reviewed by at least 3 persons who, in the Minister's opinion, possess appropriate qualifications to undertake the peer-review. The peer-review must occur before the report is given to the Minister.

Report to be tabled in Parliament

(5) The Minister must cause a copy of each report to be tabled in each House of the Parliament within 15 sitting days of that House after the day on which the Minister receives the report.

Extract from the *Great Barrier Reef Marine Park Regulations 2019*

Part 8 — Reporting requirements

175 Simplified outline of this Part



This Part is made for the purposes of paragraph 54(3)(i) of the Act.

The Great Barrier Reef Outlook Report is given to the Minister every 5 years under section 54 of the Act. The Report must include an assessment of the relevant heritage values of the Great Barrier Reef Region.

176 Great Barrier Reef Outlook Report

1) An assessment of the relevant heritage values of the Great Barrier Reef Region is prescribed as a matter that must be contained in the Great Barrier Reef Outlook Report.

2) The ***relevant heritage values*** of the Great Barrier Reef Region include the following values to the extent that they relate to the Region:
   (a) the Commonwealth Heritage values;
   (b) the Indigenous heritage values;
   (c) the National Heritage values;
   (d) the world heritage values;
   (e) any other heritage values (within the ordinary meaning of the term) that the Authority considers relevant.

3) An ***assessment of the relevant heritage values*** of the Great Barrier Reef Region, include the following:
   (a) an assessment of the current relevant heritage values of the region;
   (b) an assessment of the risks to the relevant heritage values of the region;
   (c) an assessment of the current resilience of the relevant heritage values of the region;
   (d) an assessment of the existing measures to protect and manage the relevant heritage values of the region;
   (e) an assessment of the factors influencing the current and projected future relevant heritage values of the region;
   (f) an assessment of the long term outlook for the relevant heritage values of the region.

APPENDIX 2: KEY CHANGES SINCE THE OUTLOOK REPORT 2019

Chapter 1 — About this report

- Introduced background section to human dimensions of the Outlook Report. This is to improve understanding of the Reef as a socio-ecological system, and how it is connected with human wellbeing.
- Section 176 of the *Great Barrier Reef Marine Park Regulations 2019* is now implemented for the 2024 Outlook Report.
- First Nations peoples place-based stories were included in the development of the Outlook Report.

Chapter 2 — Biodiversity

- Regional-scale grades are presented for the condition of coral reef habitats.
- Non-reefal shoals are discussed in Sections 2.3.7 (Other banks and shoals) and 2.3.8 (*Halimeda* bioherms and meadows). Many of the submerged banks supporting coral reefs and deeper coral communities are referred to in the Region as shoals, and these were assessed as 'Shoals' in the 2019 Outlook Report.[5] This terminology conflicts with standard international use of this term for 'a shallow elevation composed of unconsolidated material that may constitute a hazard to surface navigation'.[214,218,222]
- *Halimeda* bioherms and meadows component has been renamed from '*Halimeda* banks' because i) the term 'bioherms' more accurately conveys the biogenic origin and unique characteristics of these structures, and ii) the new name reflects the importance of both the geomorphological structures (bioherms) and the living algal meadows as habitats for marine life.

Chapter 4 — Heritage values

- Additional clarity and assessment provided for scope and aspects of social heritage values.

Chapter 6 — Factors influencing the Region's values

- Population figures in Section 6.2.2 have changed since 2019 Outlook Report to include all Local Government Areas that are within and/or cross the Catchment boundary and have a major population centre within the Catchment boundary. This resulted in 30 LGAs being included: Banana, Bundaberg, Burdekin, Cairns, Cassowary Coast, Central Highlands (Qld), Charters Towers, Cherbourg, Cook, Douglas, Fraser Coast, Gladstone, Gympie, Hinchinbrook, Hope Vale, Isaac, Livingstone, Lockhart River, Mackay, Mareeba, North Burnett, Palm Island, Rockhampton, South Burnett, Tablelands, Townsville, Whitsunday, Woorabinda, Wujal Wujal, and Yarrabah. Where appropriate and possible, these same Local Government Areas have been used for other human dimensions information (e.g., vessel registrations in Chapter 5).

Chapter 8 — Resilience

- Seagrass meadows component (case study) added to ecosystem resilience and Lagoon floor (case study) component removed due to minimal new information.
- Heritage resilience components (case studies) changed from *Lightstations, Historic shipwrecks* and *Cultural practices, observances, customs and lore* to *Social heritage, Indigenous heritage* and *Historic heritage*.

Chapter 9 — Risks to the Region's values

- Scope of some threats clarified (Appendix 6).

Appendix 3 — Complementary assessments

- New components added — Chapter 8 case studies

APPENDIX 3: COMPLEMENTARY ASSESSMENTS — LINKING THE OUTLOOK REPORT TO THE GREAT BARRIER REEF'S OUTSTANDING UNIVERSAL VALUE

The Statement of Outstanding Universal Value for the Great Barrier Reef World Heritage Area [1096] is the official statement adopted by the World Heritage Committee outlining how the property meets the criteria for outstanding universal value (OUV). The 2019 Outlook Report mapped the *Statement of Outstanding Universal Value: Great Barrier Reef* [1096] against the approximate 87 components assessed in the Outlook Report. The complementary assessment below includes **minor modifications** from the 2019 version.

This assessment highlights the alignment between:

- the Reef's outstanding universal value;
- the Region's natural, Indigenous and historic heritage value (including where the assessment within the Outlook Report is broader than an assessment of outstanding universal value); and
- the broad analysis of condition and trend in Chapter 2 (biodiversity values) and Chapter 3 (ecosystem health values); and other components of the Region's natural heritage value assessed in chapter 4.

In addition, the integrity of the property and the adequacy of the protection and management to safeguard the outstanding universal value of the property are assessed in the Outlook Report (Chapters 4 and 7, and Appendix 4).

Table A1 **Complementary assessments linking the Outlook Report to the Great Barrier Reef's outstanding universal value**

It includes the current four criteria (grey shaded area; italic text in parentheses) as well as the original criteria (italic text in square brackets) applied at the time of inscription. Attributes considered to contribute to the property's outstanding universal value are listed in the right column. Many Outlook Report components (left column) address several attributes (right column) and may be listed more than once in the left column.

Outlook Report 2024 Components	World Heritage Area Statement of outstanding universal value: 38 attributes	
	Natural beauty and natural phenomena (vii)	
	(vii) contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance	*[iii] unique, rare or superlative natural phenomena, formations or features or areas of exceptional natural beauty, such as superlative examples of the most important ecosystems to man*
2.3.5 Coral reefs 2.4.4 Corals 2.4.7 Bony fishes 4.5.1 Social heritage values 4.5.2 Aesthetic heritage values 8.3.1 Coral reef habitats case study	(1) Superlative natural **beauty** above and below the water	
	(2) Some of the most spectacular **scenery** on Earth	
	(3) One of a few living structures **visible** from space	
	(4) A complex string of reefal structures along Australia's north-east coast	
	(5) Unparalleled aerial panorama of **seascapes** comprising diverse shapes and sizes	
	(10) Beneath the ocean surface, there is an abundance and diversity of shapes, sizes and **colours** … Spectacular coral assemblages of hard and soft corals	
	(11) Thousands of species of reef fish provide a myriad of **brilliant colours**, shapes and sizes	
	(12) The internationally renowned **Cod Hole** is one of many significant **tourist** attractions	
2.3.1 Islands 2.3.2 Mainland beaches & coastlines 2.4.10 Marine turtles 2.4.12 Seabirds 4.2.2 Natural beauty & phenomena 8.3.5 Loggerhead turtles case study	(6) Whitsunday islands provide a magnificent vista of green vegetated **islands** and white sandy beaches spread over azure waters	
	(8) On many of the cays there are spectacular and globally important breeding colonies of **seabirds** and marine **turtles**	
	(9) Raine Island is the world's largest green **turtle** breeding area	
2.3.3 Mangrove forests 2.3.2 Mainland beaches & coastlines 2.4.1 Mangroves 3.5.1 Saltmarshes 3.5.2 Freshwater wetlands 3.5.3 Forested floodplain 3.5.4 Heath & shrublands 3.5.5 Grass & sedgelands 3.5.6 Woodlands & forests 3.5.7 Rainforests	(7) Vast **mangrove** forests in Hinchinbrook Channel, or the rugged vegetated mountains and lush **rainforest** gullies	
2.3.5 Coral reefs 2.4.3 Corals 2.4.10 Marine turtles 2.4.14 Whales 8.3.1 Coral reef habitats case study 8.3.5 Loggerhead turtles case study 8.3.7 Humpback whales case study	(13) Superlative natural phenomena include the annual **coral** spawning, migrating **whales**, nesting **turtles**, and significant **spawning aggregations** of many fish species	

Outlook Report 2024 Components	World Heritage Area Statement of outstanding universal value: 38 attributes	
	Major stages of the Earth's evolutionary history (viii)	
	(viii) be outstanding examples representing major stages of Earth's history, including the record of life, significant ongoing geological processes in the development of landforms, or significant geomorphic or physiographic features	*[i] outstanding examples representing the major stages of the Earth's evolutionary history*
3.4.8 Reef building 4.2.3 Major stages of the Earth's evolutionary history	(14) Globally outstanding example of an ecosystem that has evolved over millennia	
	(15) Area has been exposed and flooded by at least four glacial and interglacial cycles, and over the past 18,000 years reefs have grown on the continental shelf	
	(16) Today, the Great Barrier Reef forms the world's largest coral reef ecosystem … Including examples of all stages of reef development	
	(17) Processes of **geological** and **geomorphological evolution** are well represented, linking continental islands, coral cays and reefs	
3.2.1 Currents 3.2.2 Cyclones & wind 3.2.3 Freshwater inflow 3.2.4 Sediment exposure 3.2.5 Sea level 3.2.6 Sea temperature 3.2.7 Light 3.3.2 Ocean pH (acidity) 3.3.3 Salinity 3.4.8 Reef building	(18) The varied seascapes and landscapes that occur today have been moulded by **changing climates** and **sea levels**, and the erosive power of **wind** and **water**, over long time periods	
2.3.9 Continental slope 2.3.10 Water column	(19) One-third of the Great Barrier Reef lies beyond the seaward edge of the shallower reefs (and) comprises **continental slope** and deep **oceanic waters** and abyssal plains	
	Ecological and biological processes (ix)	
	(ix) be outstanding examples representing significant ongoing ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals	*[ii] outstanding examples representing significant ongoing geological processes, biological evolution and man's interaction with his natural environment*
2.3.1 Islands 2.3.5 Coral reefs 2.3.8 *Halimeda* bioherms & meadows 2.4.4 Corals 3.4.8 Reef building 3.3.2 Ocean pH (acidity) 8.3.1 Coral reef habitats case study	(20) Significant diversity of reef and island **morphologies** reflects ongoing geomorphic, oceanographic and environmental processes	
	(25) Biologically the unique diversity of the Great Barrier Reef reflects the maturity of an ecosystem that has **evolved over millennia**; evidence exists for the evolution of hard corals and other fauna	
3.2.1 Currents 3.2.2 Cyclones & wind 3.4.10 Connectivity	(21) Complex cross-shelf, longshore and vertical **connectivity** is influenced by dynamic **oceanic currents**	
3.3.1 Nutrient cycling 3.4.1 Microbial processes 3.4.2 Particle feeding 3.4.3 Primary production 3.4.5 Predation 3.4.6 Symbiosis 3.4.7 Recruitment	(22) Ongoing ecological processes, such as **upwellings, larval dispersal and migration**	

Outlook Report 2024 Components	World Heritage Area Statement of outstanding universal value: 38 attributes	
2.3.1 Islands 2.3.2 Mainland beaches & coastlines 3.2.2 Cyclones & wind 3.2.4 Sediment exposure 3.4.4 Herbivory 3.4.8 Reef building 3.4.9 Competition	(23) Ongoing **erosion and accretion** of coral reefs, sand banks and coral cays combine with similar processes along the coast and around continental islands	
2.3.8 *Halimeda* bioherms & meadows	(24) Extensive beds of ***Halimeda* algae** represent active calcification and accretion over thousands of years	
2.4.12 Seabirds 2.4.13 Shorebirds 2.3.1 Islands 3.4.7 Recruitment	(26) Vegetation on the cays and continental islands exemplifies the important role of **birds** … in seed dispersal and plant colonisation	
	Habitats for conservation of biodiversity (x)	
	(x) contain the most important and significant natural habitats for in situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation	*[iv] habitats where populations of rare or endangered species of plants and animals still survive*
2 Biodiversity and **3 Ecosystem Health** (e.g. see below and in following rows) 2.3.6 Lagoon floor 2.3.7 Other banks & shoals 2.4.3 Benthic algae 2.4.5 Other invertebrates 2.4.6 Plankton & microbes 2.4.7 Bony fishes 2.4.8 Sharks & rays 2.4.9 Sea snakes 2.4.11 Estuarine crocodiles 2.4.12 Seabirds 2.4.13 Shorebirds 8.3.2 Seagrass meadow habitats case study 8.3.4 Coral trout case study	(28) One of the richest and most complex natural ecosystems on Earth, and one of the most significant for **biodiversity** conservation	
	(29) Tens of thousands of **marine** and **terrestrial species**, many of which are of global conservation significance	
2.3.5 Coral reefs 2.4.3 Corals 8.3.1 Coral reef habitats case study	(30) The world's most complex expanse of **coral reefs** … Contain some 400 species of corals in 60 genera	
2.3.3 Mangrove forests 2.4.1 Mangroves	(31) Large ecologically important inter-reefal areas. The shallower marine areas support half the world's diversity of **mangroves**	
2.3.4 Seagrass meadows 2.4.2 Seagrasses 8.3.2 Seagrass meadow habitats case study	(32) Large ecologically important inter-reefal areas. The shallower marine areas support … many **seagrass** species	
2.4.16 Dugongs 8.3.6 Urban coast dugongs case study	(33) Waters also provide major feeding grounds for one of the world's largest populations of the threatened **dugong**	
2.4.14 Whales 2.4.15 Dolphins 8.3.7 Humpback whales case study	(34) At least 30 species of **whales** and **dolphins** occur here	
	(35) A significant area for humpback **whale** calving	

Outlook Report 2024 Components	World Heritage Area Statement of outstanding universal value: 38 attributes
2.3.1 Islands 2.4.10 Marine turtles 2.4.12 Seabirds 2.4.13 Shorebirds 8.3.5 Loggerhead turtles case study	(36) Six of the world's seven species of marine turtle occur in the Great Barrier Reef. As well as the world's largest green **turtle** breeding site at Raine Island, the Great Barrier Reef also includes many regionally important marine turtle rookeries
	(38) The continental **islands** support thousands of plant species, while the coral cays also have their own distinct flora and fauna
	(37) Some 242 species of **birds** have been recorded in the Great Barrier Reef. Twenty-two seabird species breed on cays and some continental islands, and some of these breeding sites are globally significant
4.3.6 Integrity	Related to assessment of integrity and safeguarding the property's outstanding universal value (OUV)
Appendix 4 Integrity	
7 Existing protection & management	
	Broader than outstanding universal value
4.3 Indigenous heritage values 5.9 Traditional use of marine resources 8.5.2 Indigenous heritage case study	Broader than OUV: (27) Human interaction with the natural environment is illustrated by strong ongoing links between Indigenous people and their sea country, and includes numerous shell deposits (middens) and fish traps, plus the application of story places and marine totems
2.2 Legacies & shifted baselines	
3.6 Outbreaks of disease, introduced species & pest species	
4.4 Historic heritage values	
5 Commercial & non-commercial use	
6 Factors influencing the Region's values	
7 Existing protection & management	
8.5 Heritage resilience	
9 Risks to the Region's values	
10 Long-term outlook	

APPENDIX 4: INTEGRITY TEST — GREAT BARRIER REEF WORLD HERITAGE AREA

Integrity of the Great Barrier Reef is a measure of the wholeness and intactness of the property's natural heritage value. It is one of the five components of the Region's natural heritage value graded in Chapter 4. This test is broad and cuts across all world heritage criteria and natural heritage attributes of the Reef.

The four world heritage natural criteria are about condition and trend of elements or components that make up a criterion (Chapters 2 and 3). The integrity test differs from these four components because it involves the interaction with people, including management for protection and domestic policies. The integrity test criteria are informed by the United Nations Educational, Scientific and Cultural Organization (UNESCO).[1065] An overall integrity grade is included in Section 4.6.1.

Table A2 **Integrity test for the Great Barrier Reef World Heritage Area**



World heritage criteria and integrity test criteria Assessment	Integrity Score
(vii) Natural beauty and natural phenomena The Great Barrier Reef depends on scenic beauty as a value and areas that are integrally linked to the maintenance of the aesthetic qualities of the property	
The Reef continues to provide superlative natural phenomena above and below the water. Values that contribute to the property's beauty can be inferred by the condition of its biodiversity (Chapter 2) and ecosystem health (Chapter 3). Ongoing human use of the property's iconic beautiful places is critically important for the wellbeing and stewardship of adjacent communities, and local and international economies.	2024 GOOD
Taken as a whole, the property's natural beauty and natural phenomena endures. Iconic species, like humpback whales and crocodiles, have shown signs of recovery. But within other charismatic megafauna, like marine turtles, dolphins and dugongs, there has been deterioration. Some land and seascapes have deteriorated since 2019 or remain in poor condition (southern regions of seagrass meadows, potentially coral diversity in some locations), while others have seen some recovery (coral spawning, fast growing coral species). Overall, the condition of this component remains good borderline poor. Much of the evidence is inferred from the assessments in Chapters 2 and 3.	2019 GOOD
(viii) Major stages of the Earth's evolutionary history The Great Barrier Reef contains all or most of the key interrelated and interdependent elements in their natural relationships	
Due to threats to geomorphology, the Reef's resilience is being challenged, and its size is becoming a less effective buffer to support this world heritage criterion. Present-day reef building, sediment accumulation on islands as well as inundation through changes in sea level, all carry on the evolution of the Reef. Yet some processes that impede reef and ecosystem formation have increased since 2019 (ocean acidification, sea temperature and sea-level rise) due to the impacts of climate change. Knowledge about the baseline condition and ecological importance of *Halimeda* habitats has advanced.	2024 GOOD
Further deterioration of this criterion may occur if the physical and chemical processes supporting the geomorphology of the Region continue to be altered.	2019 GOOD
(ix) Ecological and biological processes The Great Barrier Reef is a sufficient size and contains the necessary elements to demonstrate the key aspects of processes that are essential for the long-term conservation of the ecosystems and the biological diversity they contain	
The Region's ecological and biological processes are assessed on the system's ability to maintain its structure and function in the face of external pressures (Chapter 3).	2024 GOOD
In 2019 the Outlook Report found changes in sea surface temperature, symbiosis, and reef building processes had declined to a poor condition. In the 2024 assessment, many processes are stable or show no consistent trend (particle feeding, predation and recruitment). However, further changes to these processes are expected due to the continued influence of climate change and land-based runoff (specifically, nutrient cycling), with broad implications for the Region. Targeted management of the crown-of-thorns starfish since 2019 has seen an improvement in the condition of outbreaks of this pest species from very poor to poor. The size and latitudinal extent of the property has been a protective feature against broadscale declines.	2019 GOOD

World heritage criteria and integrity test criteria Assessment	Integrity Score
(x) Habitats for conservation of biodiversity The Great Barrier Reef is one of the most important properties for the conservation of biological diversity and those that contain habitats for maintaining the most diverse fauna and flora characteristic of the bio-geographic province and ecosystems under consideration	
As a value distributed throughout the whole of the property, habitats to support species have overall remained stable and are assessed as poor overall. However, confidence in some grades is broadly inferred due to limited data. The condition of seagrass meadows and crocodiles have improved. Southern regions of seagrass meadow habitats have deteriorated. Coral reefs and corals have shown signs of recovery. Historically, the Region's size has provided a buffer to periodic and dispersed damage due to its broad latitudinal extent. However, given the global scale of human-induced climate change, the size of the Region is becoming a less effective buffer to some broadscale impacts. Of significance, rising sea temperatures are expected to affect the physiology, behaviour and distribution of marine species, including fish; sessile benthic organisms; sharks; and marine turtles. The flow-on effects from the shortening recovery periods between multiple disturbances, has seen a management paradigm shift towards hands-on intervention and rehabilitation activities. The Crown-of-Thorns Control Program continues to be an early success story, while outcomes from the approximately nineteen in-water coral reef restoration projects (since 2017) are yet to be reported (Chapter 7). The Reef Restoration and Adaptation Program is largely focused on initial trials that are small-scale and have low complexity (Section 7.3.6), but is projected to grow in scale in the next 5 years.	2024 POOR 2019 POOR
Safeguarding (protection and management) **The property and adjacent areas (size and buffer)** — the Great Barrier Reef World Heritage Area has adequately delineated boundaries	
The size of the world heritage property has remained consistent since inscription, at about 348,000 square kilometres. The delineation of the Region's boundaries (that is, its latitudinal extent and size) incorporates all attributes that convey the property's outstanding universal value. The latitudinal extent of the property in combination with legislation, local management actions and Reef stewardship (refer criterion below) is a protective feature against broadscale declines in ecosystem health. The 2019 Outlook Report stated that human-induced climate change is challenging the integrity of the World Heritage Area; its size is becoming a less effective buffer against broadscale impacts. In 2024, the impacts and risks to the Region are mounting (Chapters 2, 3, 4, 6 and 9). Without additional national and global action on the greatest threats to the Reef through this critical decade and beyond the protective capacity of size as a buffer will continue to be eroded by persistent and broadscale impacts on the Region and adjacent areas. The effectiveness of local and regional scale management actions is ultimately impacted by the success of actions to address external influencing factors (for example, climate change). The safeguards of Reef management are assessed below in the management and governance system criterion and Chapter 7. As reported in 2019, the increasing sea surface temperatures and other external factors influencing the Region are affecting the property's intactness. This is also true for adjacent protected marine and terrestrial ecosystems to the property, who are themselves under threat by some of the same persistent and broadscale impacts. For example, the Coral Sea Marine Park sits adjacent to most of the seaward boundary of the property. It is managed under the Commonwealth Coral Sea Marine Park Management Plan 2018 (under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth)). The property is also adjacent to several island national parks managed by the Queensland Government, and to Indigenous Protected Areas and other areas managed under Indigenous Land-use Agreements. Effective and complementary domestic and international management of the land and sea adjacent to the property may contribute to buffering the compounding threats to the property. Although direct human encroachment into the Region via boundary modifications has been negligible since 2019, resource use outside of the boundaries is affecting the integrity of the property. The downgraded assessment of this criterion reflects downward trending elements of effectiveness of management across topics dealing with the major influences on the Reef that straddle the world heritage property boundary (including climate change). The adequacy of the protection and management of the property is outlined below. Overall, human-induced climate change continues to challenge the integrity of the World Heritage Area; its size is becoming a less effective buffer against global impacts.	2024 GOOD 2019 VERY GOOD

World heritage criteria and integrity test criteria Assessment	Integrity Score

Management and governance system — the Great Barrier Reef is adequately protected at the national, regional, municipal, and/or traditional level by legislative, regulatory and contractual measures.

Appropriate management plans are in place, specifying how the outstanding universal value of the property will be preserved

UNESCO states the purpose of a management system is to ensure the effective protection of the nominated property for present and future generations. For the Great Barrier Reef Region, its long-term protection and conservation is underpinned by world-leading legislative, regulatory and management measures. This safeguarding framework has evolved since the Reef's proclamation in 1974 and its inscription in 1981. However, the persistent impacts of climate change are reducing the management effectiveness of the Reef's safeguards.

The adequacy of the safeguards has been independently assessed in Chapter 7. The Region generally continues to be well managed. However, across the management topics, a range of management elements have declined since 2019. Effectiveness of management in achieving positive outcomes for the Reef's values (Chapter 7) remains partially effective for two of the three external influencing factors and ineffective for the third (coastal development and land-based runoff and climate change, respectively). Management of fishing as a direct use remains graded as partially effective for outcomes.

2024
GOOD

Gaps were identified in general governance, the setting of relevant standards and targets for benchmarking, the integration of Indigenous knowledge into decision making and achieving environmental and economic sustainability for the Region. The declines in governance reflect the scale and complexity of matters that need to be addressed as part of Reef management and suggest a need for more substantial institutional redesign or rethinking of principles and values underpinning governance goals (Chapter 7).[2170]

2019
GOOD

The integrity of the property has, and continues to be, safeguarded by national and state environmental legislation and cross-jurisdictional management agreements and plans. These longstanding and complementary management arrangements between the Australian and Queensland governments strengthen the regulatory protection of outstanding universal value. The Reef 2050 Long-Term Sustainability Plan is the Australian and Queensland Government's overarching framework for protecting and managing the Great Barrier Reef to 2050. The Reef 2050 Plan continues to provide a good framework for the delivery of integrated management for the Reef. However, progress had been insufficient in meeting some key targets of the Reef 2050 Plan, in particular those related to water quality, which are critical to the resilience of the property.

APPENDIX 5: INDICATORS USED TO ASSESS MANAGEMENT EFFECTIVENESS

To determine the effectiveness of management for each management topic, 49 indicators were considered across the six management elements.

Understanding of context

- The values of the Great Barrier Reef relevant to managing the topic are understood by managers.
- The current condition and trend of values relevant to managing the topic are known by managers.
- Impacts (direct, indirect and cumulative) associated with managing the topic are understood by managers.
- The broader (national and international) level influences relevant to managing the topic are understood by managers.
- The stakeholders relevant to managing the topic are well known by managers.

Planning

- There is a planning system in place that effectively addresses the topic.
- The planning system for the topic addresses the major factors influencing the Great Barrier Reef Region's values.
- Actions for implementation regarding management of the topic are clearly identified within the plan.
- Clear, measurable and appropriate objectives for management of the topic have been documented.
- There are plans and systems in place to ensure appropriate and adequate monitoring information is gathered in relation to the topic.
- The main stakeholders and/or the local community are effectively engaged in planning to address the topic.
- Sufficient policy currently exists to effectively address the topic.
- There is consistency across jurisdictions when planning for the topic.
- Plans relevant to the topic provide certainty regarding where uses may occur, the type of activities allowed or specifically disallowed, conditions under which activities may proceed and circumstances where impacts are likely to be acceptable.

Financial, staffing and information inputs

- Financial resources are adequate and prioritised to meet management objectives to address the topic.
- Human resources within the managing organisations are adequate to meet specific management objectives to address the topic.
- The right skill sets and expertise are currently available to the managing organisations to address the topic.
- The necessary biophysical information is currently available to address the topic.
- The necessary socio-economic information is currently available to address the topic.
- The necessary Indigenous heritage information is currently available to address the topic.
- The necessary historic heritage information is currently available to address the topic.
- There are additional sources of non-government input (for example volunteers) contributing to address the topic.

Management systems, processes and governance

- The main stakeholders and/or industry(ies) are effectively engaged in the ongoing management of the topic.
- The local community is effectively engaged in the ongoing management of the topic.
- There is a sound governance system in place to address management of the topic.
- There is effective performance monitoring, including. regular assessment of appropriateness and effectiveness of tools, to gauge progress towards the objective(s) for management of the topic.
- Appropriate training is available to the managing agencies to address management of the topic.
- Management of the topic is consistently implemented across the relevant jurisdictions.
- There are effective processes applied to resolve differing views/ conflicts regarding the topic.
- Impacts (direct, indirect and cumulative) of activities associated with the topic are appropriately considered.
- The best available biophysical research and/or monitoring information is applied appropriately to make relevant management decisions regarding the topic.
- The best available socio-economic research and/or monitoring information is applied appropriately to make relevant management decisions regarding the topic.
- The best available Indigenous heritage information is applied appropriately to make relevant management decisions regarding the topic.
- The best available historic heritage information is applied appropriately to make relevant management decisions regarding the topic.
- Relevant standards are identified and being met regarding management of the topic.
- Targets have been established to benchmark management performance for the topic.

Delivery of outputs

- To date, the actual management program (or activities) have progressed in accordance with the planned work program for the topic.
- Implementation of management documents and/or programs relevant to the topic have progressed in accordance with timeframes specified.
- The results have achieved their stated management objectives for the topic.
- To date, products or services have been produced in accordance with the stated management objectives for the topic.
- Effective knowledge management systems regarding the topic are in place within agencies.
- Effective systems are in place to share knowledge on the topic with the community.

Achievement of outcomes

- The relevant managing agencies are to date effectively addressing the topic and moving towards the attainment of the desired outcomes.
- The outputs relating to management of the topic are on track to ensure the values of the Great Barrier Reef are protected.
- The outputs for the topic are reducing the major risks and the threats to the Great Barrier Reef.
- Use of the Great Barrier Reef relating to the topic is demonstrably environmentally sustainable.
- Use of the Great Barrier Reef relating to the topic is demonstrably economically sustainable.
- Use of the Great Barrier Reef relating to the topic is demonstrably socially sustainable in terms of understanding and/or enjoyment.
- The relevant managing agencies have developed effective partnerships with local communities and/or stakeholders to address the topic.

APPENDIX 6: THREATS TO THE REGION'S VALUES

The set of current and likely threats to the Region's ecosystem and heritage values (its natural, Indigenous, historic and other heritage values) considered in the risk assessment (Chapter 9) was developed from the evidence presented in the preceding chapters of this report (particularly 5 and 6), taking into account input from Reef scientists and managers and the outcomes of various community surveys. The 45 threats considered are listed in the table below. The table also provides a comparison with those assessed in the 2019 Outlook Report. As far as possible, the threats and their descriptions are consistent with those used in 2019; differences are shown in **bold** in the 2024 column.

Outlook Report 2024 (45 threats)	Outlook Report 2019 (45 threats)
Acid sulfate soils: Exposure of acid sulfate soils	*Acid sulfate soils:* Exposure of acid sulfate soils
Altered ocean currents: Climate change induced altered ocean currents	*Altered ocean currents:* Climate change induced altered ocean currents
Altered weather patterns: Climate change effects on weather patterns (e.g. cyclones, wind, rainfall, air temperature), includes both chronic and acute aspects	*Altered weather patterns:* Climate change effects on weather patterns (e.g. cyclones, wind, rainfall, air temperature), includes both chronic and acute aspects
Artificial light: Artificial lighting, including from resorts, industrial infrastructure, mainland beaches and coastlines, vessels and ships	*Artificial light:* Artificial lighting, including from resorts, industrial infrastructure, mainland beaches and coastlines, vessels and ships
Atmospheric pollution: Pollution of the atmosphere related to domestic, industrial and business activities **and natural phenomena (e.g. bushfires)** in both the Region and adjacent areas. The contribution of gases, such as carbon dioxide to climate change is not included as this is encompassed under threats, such as sea temperature increase and ocean acidification	*Atmospheric pollution:* Pollution of the atmosphere related to domestic, industrial and business activities in both the Region and adjacent areas. The contribution of gases, such as carbon dioxide to climate change is not included as this is encompassed under threats, such as sea temperature increase and ocean acidification
Barriers to flow: Artificial barriers to riverine and estuarine flow (e.g. dams, weirs, breakwalls, gates, roads and linear infrastructure)	*Barriers to flow:* Artificial barriers to riverine and estuarine flow (e.g. dams, weirs, breakwalls, gates, roads and linear infrastructure)
Behaviour impacting heritage values: Disturbance of, or damage to, the values of intangible Indigenous and historic heritage site through inappropriate presence of people. Examples include: visitation to locations considered dangerous or sensitive in Indigenous culture; access by people of culturally inappropriate gender or seniority; overly high visitor traffic levels at Indigenous sites open to visitation (e.g. creating too much noise); and disrespectful behaviour or activities at Indigenous and historic heritage sites (e.g. burial areas)	*Behaviour impacting heritage values:* Disturbance of, or damage to, the values of intangible Indigenous and historic heritage site through inappropriate presence of people. Examples include: visitation to locations considered dangerous or sensitive in Indigenous culture; access by people of culturally inappropriate gender or seniority; overly high visitor traffic levels at Indigenous sites open to visitation (e.g. creating too much noise); and disrespectful behaviour or activities at Indigenous and historic heritage sites (e.g. burial areas)
Damage to reef structure: Physical damage to reef benthos (reef structure) through actions, such as snorkelling, diving, anchoring, fishing, **and reef-walking** but not vessel grounding (assessed separately)	*Damage to reef structure:* Physical damage to reef benthos (reef structure) through actions, such as snorkelling, diving, anchoring and fishing, but not vessel grounding (assessed separately)
Damage to seafloor: Physical damage to non-reef benthos (seafloor) through actions, such as trawling and anchoring	*Damage to seafloor:* Physical damage to non-reef benthos (seafloor) through actions, such as trawling and anchoring
Discarded catch: Immediate or post-release effects (such as death, injury, reduced reproductive success) on discarded species (non-retained catch) as a result of interactions with fishing gear. Does not include species of conservation concern (assessed separately)	*Discarded catch:* Immediate or post-release effects (such as death, injury, reduced reproductive success) on discarded species (non-retained catch) as a result of interactions with fishing gear. Does not include species of conservation concern (assessed separately)
Disposal of dredge material: Disposal and resuspension of dredge material	*Disposal of dredge material:* Disposal and resuspension of dredge material
Dredging: Dredging of the seafloor	*Dredging:* Dredging of the seafloor

Outlook Report 2024 (45 threats)	Outlook Report 2019 (45 threats)
Exotic species: Introduced exotic species from aquaculture operations, hull fouling, ballast release, biocontrol, translocation of other marine species, and release of aquarium specimens to the Region, plus the introduction of weeds, pests and feral animals to islands. Includes both new introductions and outbreaks of previously introduced exotic species. Does not include considerations covered under the 'genetic modification' threat	*Exotic species:* Introduced exotic species from aquaculture operations, hull fouling, ballast release, biocontrol, translocation of other marine species, and release of aquarium specimens to the Region, plus the introduction of weeds, pests and feral animals to islands. Includes both new introductions and outbreaks of previously introduced exotic species. Does not include considerations covered under the 'genetic modification' threat
Extraction from spawning aggregations: Retained take (extraction) of fish from unidentified or unprotected spawning aggregations	*Extraction from spawning aggregations:* Retained take (extraction) of fish from unidentified or unprotected spawning aggregations
Extraction of herbivores: Retained take (extraction) of herbivores (e.g. some fishes, molluscs, dugongs, green turtles) through commercial and non-commercial uses	*Extraction of herbivores:* Retained take (extraction) of herbivores (e.g. some fishes, molluscs, dugongs, green turtles) through commercial and non-commercial uses
Extraction of particle feeders: Retained take (extraction) of particle feeders (filter feeders, detritivores) through commercial and non-commercial uses	*Extraction of particle feeders:* Retained take (extraction) of particle feeders (filter feeders, detritivores) through commercial and non-commercial uses
Extraction of predators: Retained take (extraction) of predators (e.g. sharks, fish) through commercial and non-commercial uses	*Extraction of predators:* Retained take (extraction) of predators (e.g. sharks, fish) through commercial and non-commercial uses
Foundational capacity gaps: **Gaps in the enabling context for** Traditional Owners to exercise their Indigenous heritage (cultural) rights by accessing and managing their land and sea country. Relates to capacity of Traditional Owners and their groups, and is not about loss of knowledge or about access restrictions or conflicting use. Potential impacts include those on the enduring connection Traditional Owners have with their land and sea country and on the maintenance of culture and the transfer of knowledge to younger generations (e.g. reduced opportunities to conduct knowledge transfer)	*Foundational capacity gaps:* Lack of capacity of Traditional Owners to exercise their Indigenous heritage (cultural) rights by accessing and managing their land and sea country. Relates to capacity of Traditional Owners and their groups, and is not about loss of knowledge or about access restrictions or conflicting use. Potential impacts include those on the enduring connection Traditional Owners have with their land and sea country and on the maintenance of culture and the transfer of knowledge to younger generations (e.g. reduced opportunities to conduct knowledge transfer)
Fragmentation of cultural knowledge: Loss and fragmentation of knowledge of tangible and intangible heritage values (e.g. as Indigenous Elders age and young people leave their traditional land and sea country, or availability of specialist skills in historic heritage preservation declines)	*Fragmentation of cultural knowledge:* Loss and fragmentation of knowledge of tangible and intangible heritage values (e.g. as Indigenous Elders age and young people leave their traditional land and sea country, or availability of specialist skills in historic heritage preservation declines)
Genetic modification: Genetic modification of native species, manipulation of natural genotype frequencies (e.g. through translocations or intentional/unintentional releases of specimens), and products of synthetic biology	*Genetic modification:* Genetic modification of native species, manipulation of natural genotype frequencies (e.g. through translocations or intentional/unintentional releases of specimens), and products of synthetic biology
Grounding large vessel: Grounding of large vessels (>50m), including physical damage and the dislodging of antifoulants	*Grounding large vessel:* Grounding of large vessels (>50m), including physical damage and the dislodging of antifoulants
Grounding small vessel: Grounding of small vessels (<50m), including physical damage and the dislodging of antifoulants	*Grounding small vessel:* Grounding of small vessels (<50m), including physical damage and the dislodging of antifoulants
Illegal activities — other: Illegal activities, such as entering a protected or restricted area, illegal release of industrial discharge, shipping outside of designated shipping areas, and removal or damage of artefacts (e.g. ship anchors, stone implements), scar trees, middens, fish traps, burial grounds, stone arrangements, art work	*Illegal activities — other:* Illegal activities, such as entering a protected or restricted area, illegal release of industrial discharge, shipping outside of designated shipping areas, and removal or damage of artefacts (e.g. ship anchors, stone implements), scar trees, middens, fish traps, burial grounds, stone arrangements, art work
*Illegal fishing and **extraction**:* Illegal fishing, collecting and **extraction, including of species of conservation concern. This may be from domestic or foreign vessels or individuals**	*Illegal fishing and poaching:* Illegal fishing, collecting and poaching
Incidental catch of species of conservation concern: Immediate or post-release effects (such as death, injury, reduced reproductive success) of interactions of species of conservation concern with fishing gear	*Incidental catch of species of conservation concern:* Immediate or post-release effects (such as death, injury, reduced reproductive success) of interactions of species of conservation concern with fishing gear

Outlook Report 2024 (45 threats)	Outlook Report 2019 (45 threats)
Incompatible uses: Activities undertaken within the Region that disturb or exclude other users, such as recreational use in areas important for cultural activities	*Incompatible uses:* Activities undertaken within the Region that disturb or exclude other users, such as recreational use in areas important for cultural activities
Marine debris: Manufactured material discarded, disposed of or abandoned in the marine and coastal environment (including discarded fishing gear, plastics, and abandoned or damaged equipment and infrastructure)	*Marine debris:* Manufactured material discarded, disposed of or abandoned in the marine and coastal environment (including discarded fishing gear, plastics, and abandoned or damaged equipment and infrastructure)
Modifying coastal habitats: Clearing or modifying wetlands, mangroves and other coastal ecosystems in the Catchment or inshore areas or on islands	*Modifying coastal habitats:* Clearing or modifying wetlands, mangroves and other coastal ecosystems in the Catchment or inshore areas or on islands
Noise pollution: Noise from human activities, both below and above water	*Noise pollution:* Noise from human activities, both below and above water
Nutrient runoff: Nutrients from diffuse land-based runoff	*Nutrient runoff:* Nutrients from diffuse land-based runoff
Ocean acidification: Decreasing pH of the Region's waters	*Ocean acidification:* Decreasing pH of the Region's waters
Outbreak of crown-of-thorns starfish: Outbreak of crown-of-thorns starfish	*Outbreak of crown-of-thorns starfish:* Outbreak of crown-of-thorns starfish
Outbreak of disease: Outbreak of disease, both naturally occurring and introduced	*Outbreak of disease:* Outbreak of disease, both naturally occurring and introduced
Outbreak of other species: Outbreak or bloom of naturally occurring species other than crown-of-thorns starfish	*Outbreak of other species:* Outbreak or bloom of naturally occurring species other than crown-of-thorns starfish
Pesticide runoff: Pesticides (including herbicides, insecticides, fungicides) from diffuse land-based runoff	*Pesticide runoff:* Pesticides (including herbicides, insecticides, fungicides) from diffuse land-based runoff
Sea-level rise: Rising sea level	*Sea-level rise:* Rising sea level
Sea-temperature increase: Increasing extreme and average sea temperatures	*Sea-temperature increase:* Increasing extreme and average sea temperatures
Sediment runoff: Sediments from diffuse land-based runoff	*Sediment runoff:* Sediments from diffuse land-based runoff
Spill — large chemical: Chemical spill that triggers a national or regional response or is more than 10 tonnes (includes substances, such as sugar)	*Spill — large chemical:* Chemical spill that triggers a national or regional response or is more than 10 tonnes (includes substances, such as sugar)
Spill — large oil: Oil spill that triggers a national or regional response or is more than 10 tonnes (includes all petroleum products)	*Spill — large oil:* Oil spill that triggers a national or regional response or is more than 10 tonnes (includes all petroleum products)
Spill — small: Chemical or oil spill that does not trigger a national or regional response and is less than 10 tonnes. Includes materials (liquids and solids) used in attempts to restore or protect marine habitats — does not include materials considered under 'Marine debris'	*Spill — small:* Chemical or oil spill that does not trigger a national or regional response and is less than 10 tonnes. Includes materials (liquids and solids) used in attempts to restore or protect marine habitats — does not include materials considered under 'Marine debris'
Terrestrial discharge: Terrestrial point-source discharge (including within ports), such as polluted water, sewage, wastewater and stormwater	*Terrestrial discharge:* Terrestrial point-source discharge (including within ports), such as polluted water, sewage, wastewater and stormwater
Vessel strike: Death or injury to wildlife as a result of being struck by a vessel of any type or size	*Vessel strike:* Death or injury to wildlife as a result of being struck by a vessel of any type or size
Vessel waste discharge: Waste discharge from a vessel (including sewage)	*Vessel waste discharge:* Waste discharge from a vessel (including sewage)
Wildlife disturbance: Disturbance to wildlife (including from snorkelling, diving, fish feeding, walking on islands and beaches, and the presence of boats and drones); not including noise pollution	*Wildlife disturbance:* Disturbance to wildlife (including from snorkelling, diving, fish feeding, walking on islands and beaches, and the presence of boats and drones); not including noise pollution

APPENDIX 7: CRITERIA FOR RANKING LIKELIHOOD AND CONSEQUENCE OF THREATS TO THE REGION'S VALUES

Likelihood scale

Likelihood	Expected frequency of a given threat
Almost certain	Expected to occur more or less continuously throughout a year
Likely	Not expected to be continuous but expected to occur one or more times in a year
Possible	Not expected to occur annually but expected to occur within a 10-year period
Unlikely	Not expected to occur in a 10-year period but expected to occur in a 100-year period
Rare	Not expected to occur within the next 100 years

Consequence scale

Based on current management.

Consequence	Ecosystem (natural heritage)		Heritage (Indigenous, historic and other)
	Broad scale	Local scale	
Catastrophic	Impact is clearly affecting, or would clearly affect, the nature of the ecosystem over a wide area. Recovery periods greater than 20 years likely.		Impact is destroying, or has the potential to destroy, a class or collection of heritage places on a large scale; or is clearly affecting, or would clearly affect, a range of heritage values over a wide area.
Major	Impact is, or would be, significant at a wider scale. Recovery periods of 10 to 20 years likely.	Impact is, or would be, extremely serious and possibly irreversible to a sensitive population or community. Condition of an affected part of the ecosystem possibly irretrievably compromised.	Impact is adversely affecting, or would adversely affect, the heritage values of a number of places; destroy individual heritage places of great significance; or significantly affect the heritage values over a wide area.
Moderate	Impact is, or would be, present at a wider scale, affecting some components of the ecosystem. Recovery periods of five to 10 years likely.	Impact is, or would be, serious and possibly irreversible over a small area. Recovery periods of 10 to 20 years likely.	Impact is adversely affecting, or would affect, individual heritage places or values of significance; or affect to some extent the heritage values at a wider scale.
Minor	Impact is, or would be, not discernible at a wider scale. Impact would not impair the overall condition of the ecosystem, or a sensitive population or community, over a wider level.	Impact is, or would be, significant to a sensitive population or community at a local level. Recovery periods of five to 10 years likely.	Impact is adversely affecting, or would affect, heritage places or values of local significance, but not at a wider scale. Impact would not impair the overall condition of the heritage values.
Insignificant	No impact; or if impact is, or would be, present then only to the extent that it has no discernible effect on the overall condition of the ecosystem.	No impact; or if impact is, or would be, present then only to the extent that it has no discernible effect on the overall condition of the ecosystem.	No impact; or if impact is, or would be, present then only to the extent that it has no discernible effect on the heritage values; or positive impact.

Risk matrix legend

Likelihood and consequence is combined to determine risk level, consistent with the principles and guidelines of the Australian Standard for risk management (AS/NZS ISO 31000:2018). Risk level is considered to be residual — the risk that remains once existing management measures have been taken into consideration.

Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	Low	Medium	High	Very high	Very high
Likely	Low	Medium	High	High	Very high
Possible	Low	Low	Medium	High	Very high
Unlikely	Low	Low	Low	Medium	High
Rare	Low	Low	Low	Medium	High

APPENDIX 8: ASSESSMENT OF RISKS TO THE REGION'S VALUES

The assessment of the 45 threats is provided for the Region's is presented as two separate risk assessments for ecosystem (natural heritage values) and additional heritage values (Indigenous, historic, other heritage). The description of each threat is included in Appendix 6.

Risks to the ecosystem

Table A8.1 considers the risk to the Region's ecosystem and processes (Chapters 2 and 3). Therefore, this provides a risk assessment for the Region's natural heritage values, including its world heritage value and outstanding universal value (to the extent to which that value is an ecosystem value).

Table A8.1 **A risk assessment for each potential threat to the Region's ecosystem values (including natural heritage and aspects of world heritage values)**
A full description for each of the identified threats is provided in Appendix 6. An arrow indicates the direction of change since 2019.

Potential threats — Ecosystem	Likelihood	Consequence	Risk
Acid sulfate soils: Future coastal development in the Catchment in certain locations and intertidal areas creates possible risk of exposure to acid sulfate soils. Post-storm removal of vessels marooned in coastal mangroves and dredging can expose these soils. Once disturbed, if not treated, acidic water and heavy metals would continue to be released in rain events over decades, if not longer, causing effects that may be irreversible in a local area.	Possible	Moderate	MEDIUM
Altered ocean currents: Changes to currents are almost certain due to altered weather patterns and other impacts from climate change, but a major change in oceanic currents of the Reef over the next few decades remains unlikely. The East Australian Current is increasing in intensity, with potential impacts on ecosystems due to thermal heat stress. Altered ocean currents may not have uniformly negatively impacts on the values of the Region.	Almost certain	Moderate	HIGH
Altered weather patterns: A number of weather aspects are predicted to change as a result of climate change, including the frequency and intensity of cyclones, heatwaves and floods (acute events) and changes in temperature, wind patterns and average rainfall (chronic effects). For example, cyclones are a natural phenomenon in tropical regions and are predicted to become more severe, but less frequent, under current climate change scenarios. Severe cyclones have significant broadscale effects, with recovery times of at least 10 to 20 years.	Almost certain	Major	VERY HIGH
Artificial light: Growth in shipping, recreational use and urban and industrial development is likely to continue to increase the amount of artificial light. The main known issue is the effect on turtle hatchlings' orientation, including where artificial light leads to misdirection, aggregation and increased predation. Current hotspots for elevated light near turtle nesting beaches include the Woongarra coast, Gladstone and Mackay. Some local scale projects at these locations are progressing to reduce impacts. Other impacts include effects on fish behaviour, including on juvenile fish and the orientation of pelagic species around vessel lights, and potential effects on seabird behaviour.	Almost certain	Moderate	HIGH

Potential threats — Ecosystem	Likelihood	Consequence	Risk
Atmospheric pollution: Projected increases in urban and industrial development are likely to increase contribution of atmospheric pollution at a local scale, including potential for more frequent impacts from coal dust at loading ports and smoke from increased bushfire activity. Atmospheric pollution may affect some values into the future. However, effects are expected to be minor. The contribution of gases, such as carbon dioxide, to climate change is excluded here as this is encompassed under climate change threats.	Possible	Minor	LOW
Barriers to flow: Artificial barriers in the Catchment continue to affect estuarine systems and connectivity. There are concerns that fisheries productivity is reduced by reduced connectivity and freshwater flow.	Almost certain	Moderate	HIGH
Behaviours impacting heritage values: Only assessed for heritage values			
Damage to reef structure: Chronic low-level damage across a large spatial scale remains likely due to poor anchoring practices, diving and snorkelling, marine debris, poorly-secured equipment, and reef-walking. At a local scale, impacts could be serious over a small area. While supporting infrastructure (reef protection markers and public moorings) has increased, domestic tourism, domestic migration to Queensland, and recreational vessel ownership have also been increasing. Large marine debris items persist in the Region which may cause damage.	Almost certain	Moderate	HIGH
Damage to sea floor: Trawl effort remains stable and at levels of activity that pose limited risk to shallow (< 90 m) habitats at a Reef-wide scale, given existing protection through zoning. Local effects may be higher in intensely trawled areas. Anchoring by ships may have localised impacts but is generally spatially restricted through Designated Shipping Areas and in designated anchorages.	Almost certain	Minor	MEDIUM
Discarded catch: The discard of non-retained catch from fishing activities is predicted to occur continuously, with combined broadscale consequences for populations of species commonly caught. Depredation of catch can contribute to the amount of discard from a fishing activity. Although equipment such as bycatch reduction devices assists animals to escape from fishing gear, these and other interactions have associated risk of stress and injury (immediate and post-release effects). The phase-out of gillnet fishing by 2027 will reduce the amount of discard from this particular method. Increasing independent data validation is likely to improve understanding of this threat.	Almost certain	Moderate	HIGH
Disposal of dredge material: The disposal of dredge material is not continuous but occurs more than once a year. The frequency and volume of disposal of maintenance dredge material in the Region is likely to remain relatively stable and spatially restricted based on current management. Disposal of capital dredge material is negligible. The disposal and resuspension of sediment affects the condition of values at a local scale. Uncertainty around the broader effects on the Region's values remains.	Likely	Minor	MEDIUM
Dredging: While maintenance dredging is expected to occur at least one or more times per year, capital dredging is not expected to occur annually and only at priority ports. The consequence for biodiversity within the footprint of the capital dredging site would be serious and possibly irreversible.	Likely	Minor	MEDIUM
Exotic species: Biosecurity strategies and management measures help reduce the risk of new incursions, although potential pathways for (re) introduction of non-native species remain. Increases in shipping, recreational visitation to islands, and island development are relevant. There have been some advancements in detection and prevention of exotic species since 2019. Some activities facilitate outbreaks of existing infestations. Consequences depend on the exotic species but are likely to be serious in a small area, such as adjacent to a marina or port, or on an island. Competition with, or predation of, native species is common.	Likely	Minor	MEDIUM
Extraction from spawning aggregations: While several fish spawning aggregations are protected, some fishing effort is targeted at unprotected aggregations and many inshore spawning aggregations are not protected. Targeting of spawning aggregations can have implications for recruitment and future population sizes of the species. Effectiveness of protected spawning aggregations are generally considered under other extraction threats.	Almost certain ↑	Moderate	HIGH

Potential threats — Ecosystem	Likelihood	Consequence	Risk
Extraction of herbivores: Herbivorous fishes and molluscs are not the primary target of most commercial and recreational fishing. The aquarium supply industry collects some species, a modest trochus harvest fishery is still in place, and there is some spearfishing take. Current take of herbivorous fish is low and is unlikely to become common. Traditional hunting of green turtles and dugongs is currently managed in some areas under Traditional Use of Marine Resource Agreements, and the number of agreements is likely to continue to increase. Although not continuous throughout the year, traditional hunting is likely to occur several times a year with potential effects at a small scale. Discards of herbivores occur in the trawl fishery (see Discarded catch).	Likely	Minor	MEDIUM
Extraction of particle feeders: Commercial, recreational and traditional fisheries that extract particle feeders are projected to continue, with potential for the trawl fishery effort to increase under current management arrangements. Management actions since 2019 have not been successful in the longer-term rebuilding of the saucer scallop stock. Existing efforts to improve data collection and reporting in coral harvest fishery are expected enhance understanding of the risk level of this threat to coral reef habitats.	Almost certain	Moderate	HIGH
Extraction of predators: Trends in fishing effort are predicted to remain stable, except for net fishing. Harvest strategies are now in place to manage catch of many predators. The phase-out of gillnet fishing and a ban on commercial take of hammerhead sharks are likely to reduce some impacts. However, extraction of predators is likely to remain continuous throughout the year. Some shark species extracted through the East Coast Inshore Fin Fish Fishery have life history traits that lend themselves to sustainable exploitation. A range of other top predators are slow breeding and extraction is likely to have at least moderate consequences, with effects at a wider level likely to require recovery periods of five to 10 years for most species. The network of no-take zones has already benefited populations of some predators. However, for larger, more mobile predators, benefits are limited. Contemporary research demonstrates that existing protections on some spawning aggregations are not effective at capturing peak spawning activity, and protection measures for Spanish mackerel have been insufficient to rebuild stocks.	Almost certain	Moderate	HIGH
Foundational capacity gaps: Only assessed for heritage values.			
Fragmentation of cultural knowledge: Only assessed for heritage values.			
Genetic modification: Manipulation and modification of coral and symbiont genetics is an accelerating area of research. Contemporary studies are exploring ways to increase the resilience of reefs to high sea temperatures, decreased ocean pH and other stressors. The current planned controlled in-situ trials mean this will occur more than one time in a year, but not continuously. Potential negative impacts of in-situ trials and, therefore, overall risk, are not well understood. Positive impacts of increasing resilience of Reef species at a moderate to major scale is ultimately the intended outcome of many trials. Major impacts could occur when modified organisms are released into the wild or attempts to influence genotype frequencies are implemented, though a consequence (negative or positive) at this scale remains unlikely under the current program with current management measures.	Likely ↑	Minor	↑ MEDIUM
Grounding large vessel: Despite projected increases in shipping, it is considered that current management of shipping, including the vessel traffic service, significantly reduces the likelihood of groundings. They are, therefore, not predicted to occur every year but possibly once in 10 years. Cruise ships and superyachts are an increasing presence in the Region. Groundings can have extremely serious impacts on biodiversity at a local scale with long recovery periods.	Possible	Moderate	MEDIUM
Grounding small vessel: Small vessel (<50 m) groundings are expected to occur multiple times in a year. These events are likely to be concentrated in areas of high use, such as the Whitsundays, where self-drive bareboats are common. As recreational vessel ownership has increased and skillset requirements for skippers for seafarers and domestic commercial vessel operators has decreased, the likelihood of groundings may increase. At a local scale, the impacts of groundings are generally minor. Although most vessels are small in size, the potential for ecosystem-level consequence of cumulative damage caused by groundings of small vessels remains.	Almost certain	Minor	MEDIUM

Potential threats — Ecosystem	Likelihood	Consequence	Risk
Illegal activities — other: Illegal activities, such as entering a protected or restricted area, illegal release of industrial discharge, shipping outside designated shipping areas and operating without a permit are almost certain. The consequence of the activity will vary greatly depending on its type and location.	Almost certain	Minor	MEDIUM
Illegal fishing and extraction: Greater uptake of vessel monitoring systems has reduced likelihood of commercial fishing offences. While the numbers of detected offences are significant, especially in relation to recreational fishing, they have remained stable despite increases in vessel registration. Increasing illegal activity could have major consequences, particularly for sensitive areas and species. The consequence is likely to be major at a broad scale. Declining global fish stocks are likely to increase the demand on Australian fisheries. This, in turn, will increase the incentive for illegal foreign and domestic fishing activity.	Almost certain	Major	VERY HIGH
Incidental catch of species of conservation concern: Death of discard and incidentally caught species of conservation concern across all fishing activities remains likely and could have major consequences for a population. Turtle excluder devices and bycatch reduction devices have significantly reduced the incidental catch of turtles in the Queensland trawl fishery. The planned phase-out of gillnet fishing by 2027 is likely to reduce incidental catch of species of conservation concern and efforts to implement independent data validation in commercial fisheries will improve understanding of the likelihood of this threat.	Likely ↓	Major	HIGH ↓
Incompatible uses: Only assessed for heritage values			
Marine debris: Ocean currents transport debris around the world's oceans making the Region vulnerable to debris from both local and more distant sources. Given the rapid increase in plastic production globally, the longevity of this material and the disposable nature of plastic items, plastic marine debris is likely to persist into the future and be present at a broad scale within the Region. While knowledge on distribution and movement of marine debris of all sizes continues to grow, less is known about the frequency, geographic extent and broadscale effects of its interactions with the Region's species.	Almost certain	Moderate	HIGH
Modifying coastal habitats: The potential expansion and intensification of agricultural activities and continued growth in urban and industrial development makes the likelihood of vegetation clearing and modifying supporting terrestrial habitats almost certain. The consequence to the Region's values is likely to be major over a broad scale. Modification and loss of coastal ecosystems reduces their ability to provide important ecosystem services (including for marine species and habitats). Coastal development that modifies coastal habitats may diminish natural scenic values in certain locations. The integrity of the Region's outstanding universal value is not guaranteed by the existing safeguards managing Catchment and Reef. The ecosystem services provided by the Catchment will almost certainly be affected, at varying scales. The approval of new coalmines in the Catchment can also further exacerbate the effects of climate change related threats. This threat is closely aligned with the threats of nutrient runoff, pesticide runoff and sediment runoff.	Almost certain	Major	VERY HIGH
Noise pollution: Current vessel use, projected increases in shipping, port development and recreational boat ownership means underwater anthropogenic noise is likely to be more-or-less continuous in the Region. Little is known about the effects of noise on the Region's species, but evidence from elsewhere indicates that effects can be broadscale with serious consequences close to some noise sources. Improved understanding of its effects in the Region may change the future risk rating of this threat.	Almost certain	Minor	MEDIUM
Nutrient runoff: Ongoing improvements in Catchment management are likely to reduce nutrient loads in land-based runoff in the future. However, there is likely to be a significant lag time between changes in agricultural practice and measurable water quality improvements in the Region. It is projected that nutrients will continue to enter and remain in the Region well into the future with potentially major consequences on biodiversity. This threat is closely aligned with modifying coastal ecosystems, nutrient runoff pesticide runoff and sediment runoff.	Almost certain	Major	VERY HIGH

Potential threats — Ecosystem	Likelihood	Consequence	Risk
Ocean acidification: The ocean pH of Reef waters is decreasing and projections indicate this will almost certainly continue. Even relatively small changes in ocean pH reduces the capacity of corals and other calcifying organisms to build skeletons and shells, which in turn reduce their capacity to create habitat.	Almost certain	Catastrophic	VERY HIGH
Outbreak of crown-of-thorns starfish: The presence of an active outbreak on the Reef at any given time is considered almost certain, potentially resulting in continuing coral mortality at a wider scale. Increased capacity and improvements to prioritisation in the control program has been shown to be successful in suppressing the extent of coral loss from crown-of-thorns starfish. Additional fishing measures and accruing benefits from no-take zones continue to protect natural predators of crown-of-thorns starfish. Reductions in nutrient loads in land-based runoff may reduce the number of juvenile crown-of-thorns starfish that reach adulthood.	Almost certain	Moderate ↓	HIGH ↓
Outbreak of disease: The causes of disease are difficult to ascertain but are likely to be varied. Increased susceptibility is caused by stress from both acute and chronic influences. Elevated disease levels in inshore reefs impacted by major floods in 2019 have contributed to declines in inshore coral cover. Consequences will vary depending on the disease and duration of outbreak but could have major effects at a broad scale. For example, stony coral tissue loss disease is yet to be detected in the Region but has had a major impact in Caribbean reefs.	Likely	Major	HIGH
Outbreak of other species: Changes in ecological processes as a result of other impacts may cause population explosions of some species. Considering outbreaks and blooms to date, the risk would be significant to a sensitive population or community at a local scale. However, there is a high level of uncertainty and the risk may increase in the future.	Likely	Minor	MEDIUM
Pesticide runoff: Pesticides pose potentially serious consequences to some estuarine, seagrass and freshwater ecosystems. Ongoing use of pesticides in the Catchment means the Region will almost certainly continue to receive pesticides via land-based runoff. Concentration levels of pesticides in the Region vary, and for many areas are below those expected to cause significant risk to marine organisms. However, some locations are at higher risk. The effect of ongoing low-level pesticide exposure on the inshore Reef area is a knowledge gap. This threat is closely aligned with modifying coastal ecosystems, nutrient runoff pesticide runoff and sediment runoff.	Almost certain	Moderate	HIGH
Sea-level rise: Sea level increases are expected to continue into the future. This will have a noticeable effect on coastal and shallow-water habitats and species at a broad scale.	Almost certain	Major	VERY HIGH
Sea-temperature increase: The average annual sea surface temperature is almost certain to continue to rise. Regardless of climate scenario, average sea surface temperatures will continue to increase to levels not previously recorded, bringing more extreme events such as marine heatwaves. Higher temperatures will affect the nature of the entire ecosystem over a broad scale (for example, through its effect on the process of symbiosis within corals).	Almost certain	Catastrophic	VERY HIGH
Sediment runoff: Although improved agricultural land management practices and some restoration of riparian vegetation in some Catchment areas has continued to reduce sediment input, high anthropogenic sediment loads will continue to be transported to, and remain in, the Region. Improvements in agricultural land management practices may take some time to become evident in water quality within the Region due to the lag time of sediments passing through the ecosystem and into sinks within the marine system. Projected increased rainfall variability may also contribute to sediment loads through the erosion of top soils during floods. Consequences of sedimentation for marine life will depend on the concentration and duration of exposure, however, there are likely to be major effects on biodiversity. This threat is closely aligned with modifying coastal ecosystems, nutrient runoff, pesticide runoff and sediment runoff.	Almost certain	Major	VERY HIGH
Spill — large chemical: There is a projected increase in the number of ships carrying ammonia cargo and hydrogen fuel into the Region. Chemical tankers are highly regulated and a large chemical spill is unlikely. However, the effects on biodiversity could be extremely serious and possibly irreversible at a local scale. Consequences would vary depending on the type and amount of spill and are considered major given current management and response plans.	Unlikely	Major	MEDIUM

Potential threats — Ecosystem	Likelihood	Consequence	Risk
Spill — large oil: While shipping is projected to increase, recent improvements in management make the potential for a large oil spill unlikely. The physical smothering of plants and animals, combined with oil toxicity and its chemical reactions with water, mean a large spill is likely to have serious and persistent effects for several years.	Unlikely	Major	MEDIUM
Spill — small: Small chemical and oil spills are almost certain to occur frequently in the Region. Projected increases in the number of ships and other vessels are likely to increase the likelihood of small spills in the future. There could be some effects on sensitive marine life in the area of the spill, with consequences depending on size and type of spill. It is possible that unintentional pollution may be created over the next decade by trials of new Reef intervention approaches— neither likelihood nor consequence for this aspect are well understood at present.	Almost certain	Insignificant	LOW
Terrestrial discharge: Projected increases in urban, industrial and mining developments in the coastal zone (within five kilometres of the coastline) and on islands will make point-source discharges, such as sewage and stormwater, almost certain in the future. As regulations require sewage to be treated, sewage discharge is likely to be only a small component of the nutrient load entering the marine environment and have only minor effects. Discharges of wastewater from industrial development and mining that could have irreversible effects over a small area of the Region are possible, but are not expected to occur annually. The occurrence and impact of a range of firefighting and pharmaceutical compounds entering the Region is not well known.	Almost certain	Minor	MEDIUM
Vessel strike: Continuing growth in shipping and recreational boating will increase the potential for vessel strikes on wildlife. Surface-breathing animals are most at risk (for example, humpback whales). Capital build projects, such as ports and other infrastructure, increase localised vessel use in coastal and island areas that contain important habitat for marine turtles, dugongs and inshore dolphins. The consequences of vessel strike may be more significant in some locations and for some species, than others.	Likely	Minor	MEDIUM
Vessel waste discharge: Increases in vessel traffic and the continued unavailability of onshore pump-out facilities means there is likely to be more vessel-based sewage and wastewater discharge in the future. Effects on biodiversity are expected to be minor under current management arrangements.	Almost certain	Minor	MEDIUM
Wildlife disturbance: Projected increases in population, tourism and expected associated increases in recreational vessel ownership are likely to lead to an increase in disturbance of wildlife from the presence of boats, drones, snorkelling and diving activities, and access to islands. These increases may cause some localised effects (for example, on seabirds and shorebirds).	Almost certain	Minor	MEDIUM

Risks to heritage values

Table A8.2 considers the risks to the Region's heritage values (Indigenous, historic and other) but excludes natural heritage values (as ecosystem values are covered by the assessment in Table A8.1). Indigenous and natural heritage values are intrinsically linked; assessment of the natural heritage aspect of this is covered by Table A8.1. The heritage risk assessment in Table A8.2 includes consideration of the Region's world heritage attributes (Appendices 3 and 4), other than those associated with ecosystem values.

Table A8.2 **A risk assessment for each potential threat to the Region's heritage values (Indigenous, historic, and other)**

A full description for each of the identified threats is provided in Appendix 6. An arrow indicates the direction of change since 2019

Potential threats — Heritage values	Likelihood	Consequence	Risk
Acid sulfate soils: Disturbance of acid sulfate soils may affect historic heritage places or values in a small area. Impacts may erode subsistence lifestyles of local Traditional Owners or corrode artefacts.	Possible	Moderate	MEDIUM
Altered ocean currents: Changes to the ecosystem could have flow-on effects to Indigenous heritage values, especially if species that have cultural significance for Indigenous customary practice, lore, storylines and songlines are affected. Any changes in ocean currents are likely to have only minor effects on historic heritage values, such as shipwrecks.	Almost certain	Moderate	HIGH
Altered weather patterns: Changes to the ecosystem could have flow-on effects to Indigenous heritage values specifically culturally important sites (including sacred sites) and places of Indigenous significance. It is likely that historic heritage sites, features, and their associated artefacts in the path of a severe cyclone will be damaged, potentially seriously. Heritage sites may also be impacted by coastal erosion associated with more intense and frequent disturbances. These may affect the aesthetic attributes contributing to the Reef's outstanding universal value, as well as economic and social values of the Region and adjacent Catchment.	Almost certain	Major	VERY HIGH
Artificial light: Artificial light can impact on turtle hatchlings' orientation in the nesting season. Such impacts could have flow-on effects on Indigenous cultural values, for example, totems, storylines and traditional hunting. Reduced dark sky area and lowered visibility of stars (from skyglow effects) may affect the aesthetic attributes contributing to the Reef's outstanding universal value, as well as economic and social values of the Region and adjacent Catchment. This threat is unlikely to significantly affect historic heritage values.	Almost certain	Moderate	HIGH
Atmospheric pollution: Changes to the ecosystem by human-caused haze and deposition of particulate matter, such as coal dust, bushfire smoke or terrigenous dust, may affect the aesthetic attributes contributing to the Reef's outstanding universal value, as well as economic and social values of the Region and adjacent Catchment. The contribution of gases, such as carbon dioxide, to climate change is excluded here as this is encompassed under other threats, such as sea-temperature increase. This threat is unlikely to significantly affect historic heritage values.	Possible	Minor	LOW
Barriers to flow: Changes to the ecosystem of the Region and Catchment could have flow-on effects to Indigenous heritage values specifically connectivity crucial to some totem species and could interrupt the flow of storylines across the landscape. This threat is unlikely to significantly affect historic heritage values.	Almost certain	Moderate	HIGH
Behaviour impacting heritage values: Growing population and recreational use means people exhibiting undesirable behaviours at Indigenous and historic heritage sites that affect the site's intangible and tangible cultural heritage values are likely to occur more than once in a year. The likelihood of impact may be higher at sites where visitors are unaware of the site's local Indigenous cultural significance or desired behavioural guidelines from Traditional Owners. Severity and longevity of impact varies depending on the nature, frequency and intensity of the undesirable presence or behaviour. Minimising the risk of foundational capacity gaps and fragmentation of cultural knowledge may reduce the impact of behaviours through increased First Nations self-agency and participation in management, improved knowledge sharing, and greater awareness of heritage values.	Likely ↑	Moderate	HIGH ↑

Potential threats — Heritage values	Likelihood	Consequence	Risk
Damage to reef structure: Changes to reef structure may affect the underwater aesthetic attributes contributing to the Reef's outstanding universal value, especially in high visitation locations. Damage to features that are culturally significant to Traditional Owners is also possible. Undiscovered historic heritage sites (including wrecks) and features may also be damaged. If an interaction occurs at an individual heritage place, the consequences are likely to be serious, or even irreversible.	Almost certain	Moderate	HIGH
Damage to seafloor: Effects are likely to be localised. Depending on the location of the damage, Indigenous culturally significant sites (including sacred sites, burial sites and sites that have storylines associated with them) could be affected. It is possible that undiscovered historic heritage sites (including wrecks) and features could be damaged. If an interaction occurs, the consequences are likely to be serious, or even irreversible. Changes to the seafloor may affect the underwater aesthetic attributes contributing to the Reef's outstanding universal value.	Possible	Moderate	MEDIUM
Discarded catch: While bycatch reduction devices and turtle excluder devices in the trawl fishery have reduced deaths of some Indigenous culturally important species (including marine turtles), risks remain for a range of other species. If discarded catch floats or is washed ashore it can affect natural beauty. This threat is unlikely to significantly affect historic heritage values.	Almost certain	Moderate	HIGH
Disposal of dredge material: The disposal and resuspension of significant volumes of sediment could affect the aesthetic attributes (above and below the water) contributing to the Reef's outstanding universal value. Declining water clarity can affect the ability to perform some Indigenous cultural practices. While it is possible that additional sediment into the system by disposal or resuspension may impede discovery of previously unknown historic heritage sites and features, it is not likely to affect heritage values over a wider area.	Likely	Minor	MEDIUM
Dredging: Environmental impact assessment processes for dredge campaigns aim to avoid disturbance of heritage sites from dredging. However, some risk remains for unrecorded sites of Indigenous cultural significance, such as burial sites and sacred sites, and unrecorded historic heritage sites. While in progress, dredging can also affect the aesthetic values of an area.	Likely	Minor	MEDIUM
Exotic species: The consequence of changes to the ecosystem on heritage values would depend on the species and the heritage value affected. Serious effects on Indigenous heritage values at a local scale may occur. The effects of exotic species on historic maritime heritage is a knowledge gap.	Likely	Minor	MEDIUM
Extraction from spawning aggregations: Unsustainable extraction may affect the aesthetic attributes contributing to the Reef's outstanding universal value. Depending on the species affected, Indigenous heritage values may be impacted. Local depletions may also affect social and economic values of the Region. This threat is unlikely to affect historic heritage values.	Almost certain ↑	Moderate	HIGH
Extraction of herbivores: Although not continuous throughout the year, traditional hunting (particularly of dugongs and green turtles) is likely to occur several times a year with potential effects at a small scale. Traditional hunting is thought to be largely sustainable with positive effects on Indigenous heritage values. There is intention to implement more Traditional Use of Marine Resources Agreements to cover more of the Reef, reducing the likelihood and impacts of herbivore extraction at a broader scale. This threat is unlikely to significantly affect historic heritage values.	Likely	Insignificant	LOW
Extraction of particle feeders: Changes to the ecosystem could have flow-on effects to Indigenous cultural practices. This threat is unlikely to significantly affect historic heritage values.	Almost certain	Moderate	HIGH
Extraction of predators: Changes to the ecosystem could have flow-on effects for Indigenous cultural practices. In addition, the exploitation of some targeted predators that are totems for Traditional Owners will affect the Indigenous heritage values of relevant Sea Country estates. This threat is unlikely to significantly affect historic heritage values.	Almost certain	Moderate	HIGH

Potential threats — Heritage values	Likelihood	Consequence	Risk
Foundational capacity gaps: Indigenous heritage values are compromised by different levels of access and agency of First Nations people to manage Country and adapt to climate change threats. Particularly where power dynamics are uneven, and persistent inequalities and inequities exist within Reef management and society more broadly. While remoteness is a factor, limitations in skills, equipment and safe transport will also affect capacity building. Potential impacts of capacity gaps include those on the enduring connection Traditional Owners have with their land and Sea Country, the maintenance of culture, and ability to transfer knowledge to younger generations. Local and international awareness of capacity gaps emphasises the major consequences of this threat to the Region's Indigenous heritage values. This threat is unlikely to significantly affect historic heritage values.	Likely	Major ↑	↑ HIGH
Fragmentation of cultural knowledge: Factors affecting this threat are closely aligned with the foundational capacity gaps (refer above). Availability of specialist skills in historic heritage preservation is thought to be stable.	Likely	Major	HIGH
Genetic modification: The effect of interventions, including genetic modification, on Indigenous heritage values is unknown. Movement and modification of biological material within and between different Sea Country may impact on intangible Indigenous cultural values. This threat is unlikely to significantly affect historic heritage values.	Likely ↑	Minor	↑ MEDIUM
Grounding — large vessel: Many reefs have strong cultural value to Traditional Owners connected by song and storylines and, in some cases, they are sacred sites. The destruction and damage caused by a ship grounding could have significant and long-term effects on Indigenous heritage values. A ship grounding is likely to be rare at a site of historic heritage significance, but it could have major consequences. Changes to the environment by a grounding will affect the aesthetic attributes contributing to the Reef's outstanding universal value, as well as economic and social values of the Region and adjacent Catchment.	Possible	Moderate	MEDIUM
Grounding — small vessel: The effect of a small vessel grounding will have similar impacts on the Region's heritage values as a large vessel grounding, at varying scales.	Almost certain	Minor	MEDIUM
Illegal activities — other: The likelihood of an illegal activity affecting Indigenous or historic heritage values and the consequence of its effect will vary greatly depending on the type of activity and location and the heritage values affected. The extent of damage (replaceable or irreversible loss of a heritage value) increases the consequence of its effect. Monitoring of looting, souveniring, vandalism and other activities remains difficult due to limited availability of information on location and condition for many heritage sites. For this reason, the level of risk of intentional and unintentional damage is unclear. Given the size of the Region and ongoing human use, the likelihood of this threat is almost certain, at varying scales.	Almost certain	Moderate	HIGH
Illegal fishing and extraction: Illegal fishing and extraction activities directly affect Traditional Owners' ability to practice customary lore, use their cultural tools and technology, and follow cultural observances. This threat is unlikely to significantly affect historic heritage values.	Almost certain	Major	VERY HIGH
Incidental catch of species of conservation concern: Many species of conservation concern are of cultural significance to Traditional Owners as either a food source or totem, or for customary practice. The planned phase-out of gillnet fishing by 2027 is likely to reduce incidental catch of species of conservation concern. This threat is unlikely to significantly affect historic heritage values.	Likely ↓	Major	↓ HIGH

Potential threats — Heritage values	Likelihood	Consequence	Risk
Incompatible uses: The volume and variety of uses occurring in the Region continues to affect the capacity of Traditional Owners to sustain their cultural practices and fulfil their customary responsibilities. Commercial and recreational fishing can have localised effects causing changes to customary practice if Traditional Owners have to fish or collect in non-traditional areas. Similarly, tourism operations can be affected by fishers (commercial and recreational) or vice versa, depending on management rules. Structures associated with tourism, ports and other activities can affect the scenic beauty of an area, as can commercial and recreational vessels. Economic and social impacts are almost certain as climate change impacts are more frequent, affecting the potential redistribution of users into different or concentrated locations. This threat is unlikely to significantly affect historic heritage values.	Almost certain	Moderate	HIGH
Marine debris: Some marine animals and birds of Indigenous cultural significance can become entangled in, or killed by, marine debris. Debris also washes up in culturally important areas and sacred sites. On rare occasions, debris (such as discarded fishing nets) could become entangled on submerged historic heritage sites, potentially degrading their heritage value. Changes to the environment will affect the aesthetic attributes contributing to the Reef's outstanding universal value, as well as economic and social values of the Region and adjacent Catchment.	Almost certain	Moderate	HIGH
Modifying coastal habitats: Indigenous cultural observances, customs, storylines and songlines can be lost through changes to the coastal environment. Damage to or loss of irreplaceable culturally significant sites and associated artefacts of historic and Indigenous value has major consequences. Changes to the coastal habitats affect the aesthetic attributes contributing to the Reef's outstanding universal value, as well as economic and social values of the Region and adjacent Catchment. At a local scale, the number of ports and marinas has remained stable over the past 5 years, but maintenance of these facilities can have an impact on nearby heritage values.	Almost certain	Major	VERY HIGH
Noise pollution: Little is known about the effects of noise on the Region's species, including for species that have particular cultural significance to Traditional Owners. Effects on auditory experiences may affect an area's natural beauty. Improved understanding of noise effects may change the future risk rating of this threat. This threat is unlikely to significantly affect historic heritage values.	Almost certain	Minor	MEDIUM
Nutrient runoff: Effects of nutrient runoff on ecosystem values and decreases in water clarity will impact Indigenous heritage values as well as the underwater natural beauty of the World Heritage Area. This threat may affect underwater historic heritage sites through altered chemical processes, but the level of risk in the Region remains a knowledge gap.	Almost certain	Major	VERY HIGH
Ocean acidification: The effects of ocean acidification will have catastrophic consequences for reef building and the Region's values (natural, Indigenous and historic heritage values). Changes to ocean chemistry may accelerate deterioration of tangible heritage sites and artefacts. Coral reefs are one of the fundamental attributes contributing to the Reef's outstanding universal value. Changes to the environment will affect the aesthetic attributes contributing to the Reef's outstanding universal value, as well as economic and social values of the Region and adjacent Catchment.	Almost certain	Catastrophic	VERY HIGH
Outbreak of crown-of-thorns starfish: As with other threats that are likely to seriously affect coral reefs, continued outbreaks will diminish the Reef's outstanding universal value. The decline in coral reef health will have consequent effects on the natural and Indigenous heritage values. This threat is unlikely to significantly affect historic heritage values.	Almost certain	Moderate ↓	HIGH ↓
Outbreak of disease: Outbreaks of disease, such as in corals and turtles, can diminish Indigenous heritage values through affecting cultural practices, customs and lore. This threat is unlikely to significantly affect historic heritage values.	Likely	Major	HIGH
Outbreak of other species: Little is known of the potential effects of outbreaks or blooms of other species on Indigenous cultural values, but any declines in ecosystem health will have consequent effects on Indigenous heritage values. This threat is unlikely to significantly affect historic heritage values.	Likely	Minor	MEDIUM

Potential threats — Heritage values	Likelihood	Consequence	Risk
Pesticide runoff: Changes to the ecosystem could have flow-on effects to Indigenous heritage values. Bioaccumulation of toxic components of pesticides will have additional adverse effects if this makes some species unsafe for consumption as part of Indigenous cultural practices. This threat is unlikely to significantly affect historic heritage values.	Almost certain	Moderate	HIGH
Sea-level rise: Changes to the ecosystem could affect coastal and shallow-water Indigenous heritage sites, as well as cause changes to custom. Loss of access to fish traps, burial sites (which may be in coastal sand dunes), or rock art located in beach caves will have adverse consequences for Indigenous cultural practices. Rising sea levels is also likely to affect coastal and shallow-water historic heritage sites, including through storm surges and tidal changes. Rising sea levels may affect the aesthetic attributes contributing to the Reef's outstanding universal value, as well as economic and social values of the Region and adjacent Catchment.	Almost certain	Major	VERY HIGH
Sea-temperature increase: Changes to the ecosystem will simultaneously affect the Indigenous heritage values of the Region. Changes to the environment will affect the aesthetic attributes contributing to the Reef's outstanding universal value, as well as economic and social values of the Region and adjacent Catchment. On a smaller scale, increased sea temperatures could accelerate the natural degradation of historic heritage sites.	Almost certain	Catastrophic	VERY HIGH
Sediment runoff: Increases in turbidity will decrease the underwater natural beauty of the World Heritage Area. Declines in the environment caused by increased sediments will affect the Indigenous heritage values of the Region. Increased sediments can affect underwater historic heritage values.	Almost certain	Major	VERY HIGH
Spill — large chemical: Changes to the ecosystem could have flow-on effects to Indigenous heritage values. A spill that had severe effects on the local environment could have extremely serious and possibly irreversible effects on Indigenous cultural practice, observances, story and song lines, and places of cultural significance at a local scale. A spill will affect the aesthetic attributes contributing to the Reef's outstanding universal value. Also, it is likely that the economic and social values of the Region and adjacent Catchment will be adversely affected. In addition, a large chemical spill close to a historic heritage site (specifically a wreck) could present a serious risk to its values.	Unlikely	Major	MEDIUM
Spill — large oil: The physical smothering of plants and animals, combined with oil toxicity and its chemical reactions with water, mean a large oil spill would likely have serious and persistent effects on some natural and Indigenous heritage values, such as coral reefs, seabirds and turtles. It would also affect the natural beauty of the area, in the short term. Aesthetic attributes contributing to the Reef's outstanding universal value, as well as economic and social values of the Region and adjacent Catchment would be affected. It is expected that a large spill would rarely affect a historic site or feature.	Unlikely	Major	MEDIUM
Spill — small: Scenic beauty above and below the water may be slightly affected in small local areas. However, there is unlikely to be serious consequences for the Region's Indigenous and historic heritage values from small chemical and oil spills.	Almost certain	Insignificant	LOW
Terrestrial discharge: Changes to the ecosystem could have localised flow-on effects on some Indigenous heritage values. For example, elevated concentrations of heavy metals in culturally significant species, such as dugongs and turtles, or concentrations of bacteria unsafe for human immersion, could place Indigenous cultural values and practices at further risk. This threat may affect underwater historic heritage sites through altered chemical processes, but the level of risk in the Region remains a knowledge gap.	Almost certain	Minor	MEDIUM
Vessel strike: Some of the species that contribute strongly to the Reef's outstanding universal value, such as dugongs, turtles, dolphins and whales, are most at risk. As these species also have cultural significance for Traditional Owners, there is likely to be local effects on Indigenous cultural heritage. This threat is unlikely to significantly affect historic heritage values.	Likely	Minor	MEDIUM

Potential threats — Heritage values	Likelihood	Consequence	Risk
Vessel waste discharge: The likely minor effects on the natural environment will have flow-on effects on Indigenous heritage values. This threat may affect underwater historic heritage sites through altered chemical processes, but the level of risk in the Region remains a knowledge gap.	Almost certain	Minor	MEDIUM
Wildlife disturbance: Projected increases in population, tourism and associated recreational vessel ownership, access to islands, drone use, snorkelling and diving activities are likely to lead to an increase in disturbance of wildlife. Changes to animal behaviour caused by the presence of boats or people can change the nature of Traditional Owner customary practice and change storylines. Disturbances may affect the aesthetic attributes contributing to the Reef's outstanding universal value. Also, it is likely that the economic and social values of the Region and adjacent Catchment will be adversely affected. This threat is unlikely to significantly affect historic heritage values.	Almost certain	Minor	MEDIUM

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