GREAT BARRIER REEF MARINE MONITORING PROGRAM

SYNTHESIS REPORT
2021–22

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Front cover photography: Data logger being retrieved from the water during routine water quality monitoring (© Dr J. Mellors, James Cook University/TropWater).

The Great Barrier Reef Marine Park Authority acknowledges the continuing Sea Country management and custodianship of the Great Barrier Reef by Aboriginal and Torres Strait Island Traditional Owners whose rich cultures, heritage values, enduring connections and shared efforts protect the Reef for future generations.

DISCLAIMER

Comments and questions regarding this document are welcome and should be addressed to:

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Acknowledgement

The Great Barrier Reef Marine Monitoring Program (MMP) is a collaboration between the Great Barrier Reef Marine Park Authority, Australian Institute of Marine Science (AIMS), James Cook University, and Cape York Water Partnership, with important contributions from Traditional Custodians, the Reef Joint Field Management Team, Seagrass-Watch and community volunteers.

We thank our long-term partners and collaborators for their dedication to monitoring, evaluation and synthesis of science about the Great Barrier Reef. We also acknowledge the Australian Institute of Marine Science's Long-Term Monitoring Program for providing information that is integrated into our annual technical reports.

We would also like to thank our partners in the Paddock to Reef Integrated Monitoring, Modelling and Reporting program, of which the MMP is a component, for ongoing collaboration. Finally, we acknowledge the contextual information, including river discharge data, provided by the Queensland Government (Department of Natural Resources, Mines and Energy) and climate data sourced from the Australian Bureau of Meteorology.

Executive summary

The Great Barrier Reef (the Reef) is more than just coral reefs in clear, blue offshore waters. The Great Barrier Reef Marine Park (Marine Park) includes the inshore region, which stretches along the coast of Queensland and sustains diverse ecosystems (Browne *et al*. 2012, Carter *et al*. 2021). It has a vital role to play in the Great Barrier Reef World Heritage Area, harbouring extensive high value areas of seagrass meadows and coral reefs (Great Barrier Reef Marine Park Authority 2019). These are responsible for providing a critical link between the coastal and offshore marine regions of the Reef by:

1. supporting unique biodiversity, coastal and wetland habitats, iconic species and socio-cultural values

2. providing irreplaceable nursery and feeding grounds for many species of fish, prawns, turtles and dugongs

3. protecting the coastal region and our shores from erosion

4. sustaining our community lifestyles and livelihoods.

The health of inshore ecosystems has high significance and their proximity to the coast makes them more vulnerable to exposure from land-based runoff and pollution, exacerbated by highly modified adjacent catchments and coastal development (Waterhouse *et al*. 2016). Ensuring that the quality of water entering the inshore region has minimal impact on the health, resilience and sustainability of the Reef requires continuous monitoring. Since 2016–17, repeated disturbances such as marine heatwaves and tropical cyclones have had a considerable and widespread impact on the health of ecosystems and water quality of the inshore region. High summer water temperatures caused coral bleaching and subsequent mortality of corals in Cape York, Wet Tropics and Burdekin regions[1] (Hughes *et al*. 2017, Thompson *et al*. 2018), while Tropical Cyclone Debbie in 2017 severely impacted coral communities and seagrass meadows in the Mackay-Whitsunday region. Seagrass meadows in the Reef intertidal and estuarine habitats were the most severely affected with abundance declining to nearly zero (McKenzie *et al*. 2018). Chronic effects of reduced water quality caused by accumulation of fine sediments also resulted in a slow recovery of the coral communities and seagrass meadows (Thompson *et al*. 2023), even though the Mackay-Whitsunday region has been relatively free of severe disturbances in recent years. This demonstrates that while inshore ecosystems have shown capacity to recover after severe disturbance events, their health remains vulnerable and it may take many years for complex communities to re-establish.

In the monitoring season of 2021–22 (1 October 2021 – 30 September 2022), no significant acute disturbances affected the inshore Reef. There was limited cyclone activity for the Reef with only one cyclone, ex-Tropical Cyclone Tiffany, which crossed the Cape York coast in

[1] The Great Barrier Reef Region consists of the Great Barrier Reef Marine Park along with the Great Barrier Reef Catchment Area, made up of six Natural Resource Management (NRM) regions, each representing catchments with similar climate and bioregional setting, with boundaries extending into the adjacent marine area. The MMP uses these six NRM regions: Cape York, Wet Tropics, Burdekin, Mackay-Whitsunday, Fitzroy and Burnett-Mary.

early January 2022. However, the season was characterised by relatively late rainfall events in April and May 2022 in the most northern and southern regions. Overall, rainfall and river discharge were just above the long-term median for the Reef. The northern regions (Cape York, Wet Tropics and Burdekin) had discharges around the long-term median, while the Mackay–Whitsunday region discharge was around half of the long-term median and the Fitzroy region was 1.5 times above the long-term median. The Burnett–Mary region had very high discharge in the 2021–22 monitoring year at nearly nine times above the long-term median (Figure 1).

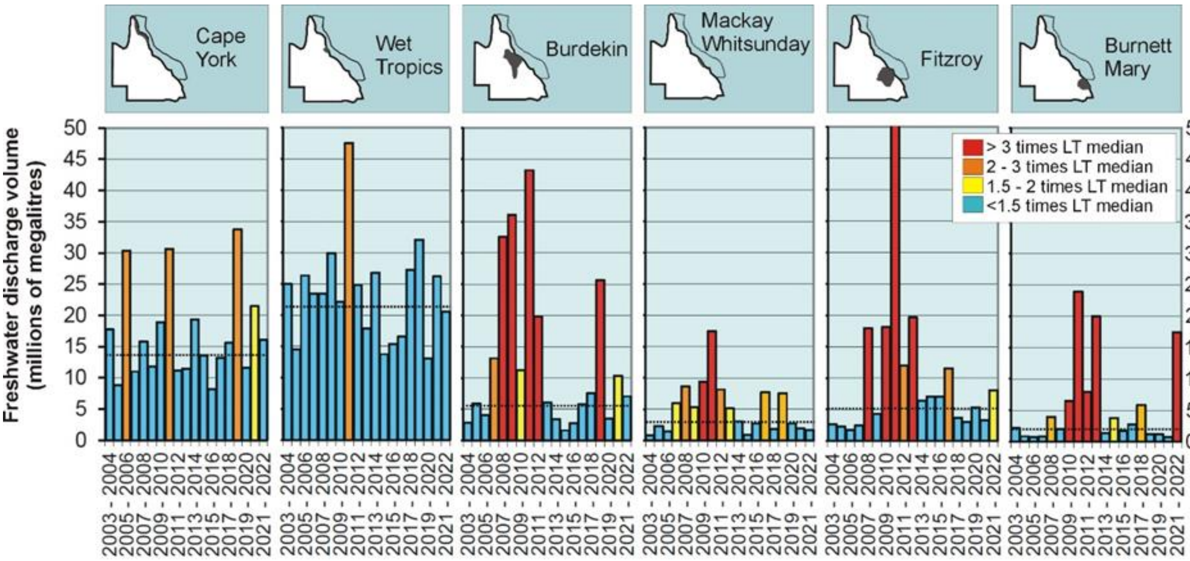

Figure 1. Corrected annual water year (1 October to 30 September) discharge from each region for 2003–04 to 2021–22 (image extracted from Moran *et al*. 2023).

Sea-surface temperature over the 2021–22 summer was above average for most of the summer across the Marine Park. The inshore areas in the north and central sectors, which include the Wet Tropics, Burdekin and Mackay-Whitsunday regions, were the most severely affected with temperatures close to three degrees Celsius above average in early March (Figure 2). Marine heatwaves affected inshore coral reefs mainly in the Burdekin region, but seagrass meadows in most regions experienced intertidal temperatures that were more than half a degree higher than the previous reporting period (Thompson *et al*. 2023, McKenzie *et al*. 2023), exceeding long-term averages.

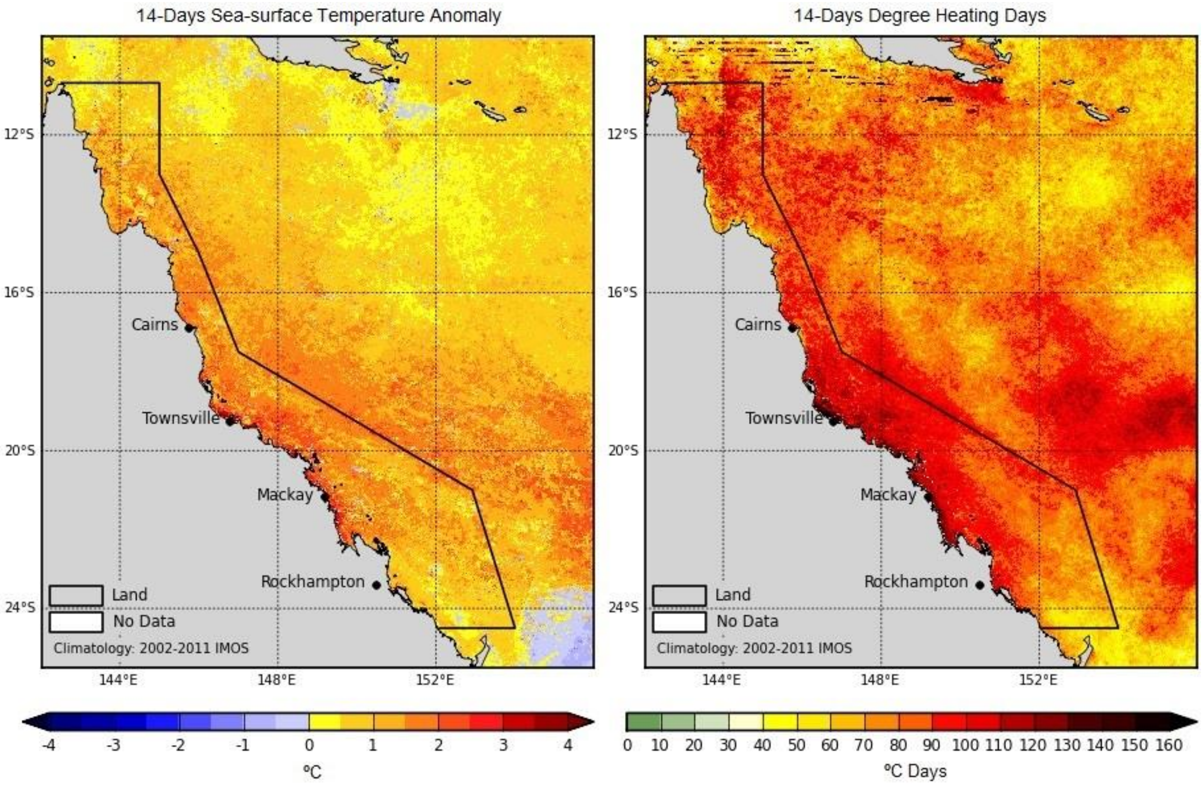

Figure 2. Sea-surface temperature (SST) anomaly (left) and annual degree heating days (right) estimates for the Reef. SST anomaly is the difference between SST values and the monthly long-term mean SST (2002-2011) from 1–15 March 2021, based on the 14-day Integrated Marine Observing System (IMOS) climatology mosaic. Annual degree heating day accumulation over the summer period (1 December to 31 March) for 4km^2 pixels based on temperatures exceeding the 14-day IMOS climatology mosaic. Data extracted from the Australian Bureau of Meteorology ReefTemp website.

The effects of the environmental conditions experienced in the 2021–22 wet/summer season might not have been fully detected in the current monitoring season as seagrass monitoring occurred prior to the summer period and there can be time lags in the responses of coral and seagrass communities. It is noteworthy that some results suggest that the annual water quality indices were influenced by the relative lateness of the most significant flood events that occurred in the 2021–22 season. The long-term water quality scores (adjusted to be less sensitive to year-to-year variations) showed a continuous trend of improvement in some of the indicators. The long-term results demonstrate that, while it is difficult to quantitatively assess the benefits of improved land management practices as a direct result of the Reef 2050 Water Quality Improvement Plan (Reef WQIP), improvements in water quality are beneficial for the health and resilience of inshore ecosystems. Therefore, continuous monitoring is essential to determine if trends in stability and improvement are broad-reaching and sustained.

Key results for the 2021–22 monitoring season are summarised below.

Water Quality

- Annual condition index scores were ‘good’ in Cape York and ‘moderate’ in the Wet Tropics, Burdekin and Mackay-Whitsunday regions (Figure 3). Scores were generally similar to the 2020–21 monitoring year, which is likely related to similar amounts of river discharge in both monitoring years.

- Long-term index scores (insensitive to year-to-year variability) continued a four-year trend of improvement in the Wet Tropics, Burdekin and Mackay-Whitsunday regions (Figure 4).
- Chlorophyll *a*, total suspended solids and phosphate met local water quality guideline values in most regions.
- Particulate phosphorus met water quality guideline values in Wet Tropics and Burdekin regions but exceeded guidelines in Mackay-Whitsunday region.
- Nitrate/nitrite, particulate nitrogen and Secchi depth did not meet water quality guideline values in most regions.
- Most water quality indicators are showing trends of improvement or stability over the last five years, in contrast with trends of degradation in condition from 2008 to 2015 in many regions.
- Remote sensing analysis is used to characterise the Reef into three water types, depending on their water quality characteristics. These range from 'Reef WT1' representing highly turbid waters with potentially high nutrient concentrations, to 'Reef WT3' representing less turbid waters with limited nutrients. In the 2021–22 wet season, the visible satellite images indicate that only three per cent of the Reef area was exposed to Reef WT1 and included mainly inshore areas. Only 17 per cent of the Reef was exposed to Reef WT2 and 61 per cent of the Reef was exposed to Reef WT3 (Figure 5).
- Building on these methods, the area exposed to a potential risk in the 2021–22 monitoring year was spatially limited with only 12 per cent of the Reef (waters) exposed to a potential risk resulting from poor water quality, representing an area of approximately 43,600 square kilometres. However, approximately 82 per cent of seagrasses were exposed to a potential risk, in contrast to only 12 per cent of coral reefs.

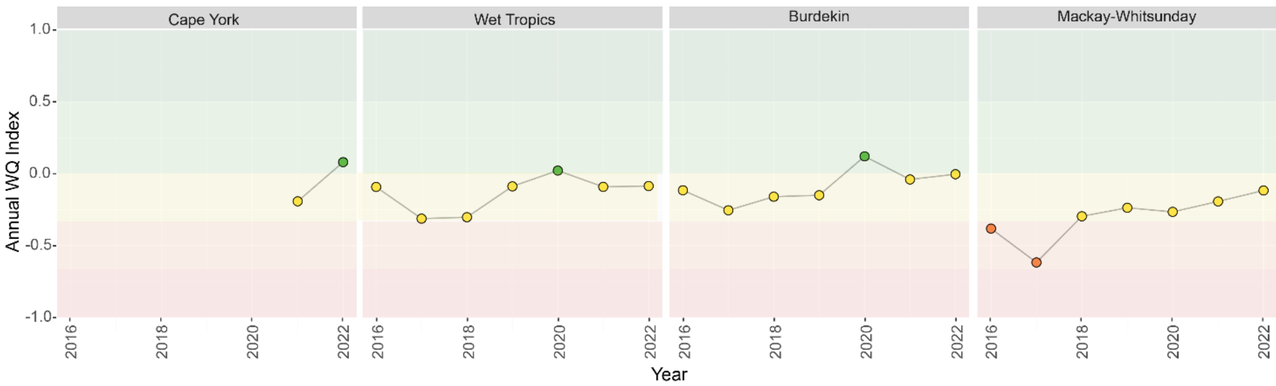

Figure 3. Trends in the regional Annual Water Quality (WQ) Index scores for the Cape York, Wet Tropics, Burdekin and Mackay-Whitsunday regions. The Index includes three indicators: water clarity, particulates and productivity. Values are

indexed scores scaled from -1.0 to 1.0 and graded: ■ = very good (1 to 0.5), ■ = good (0.5 to 0), ■ = moderate (< 0 to -1/3), ■ = poor (< -1/3 to -2/3), ■ = very poor (< -2/3 to -1). Note scores are unitless. Data source: Moran *et al*. 2023.

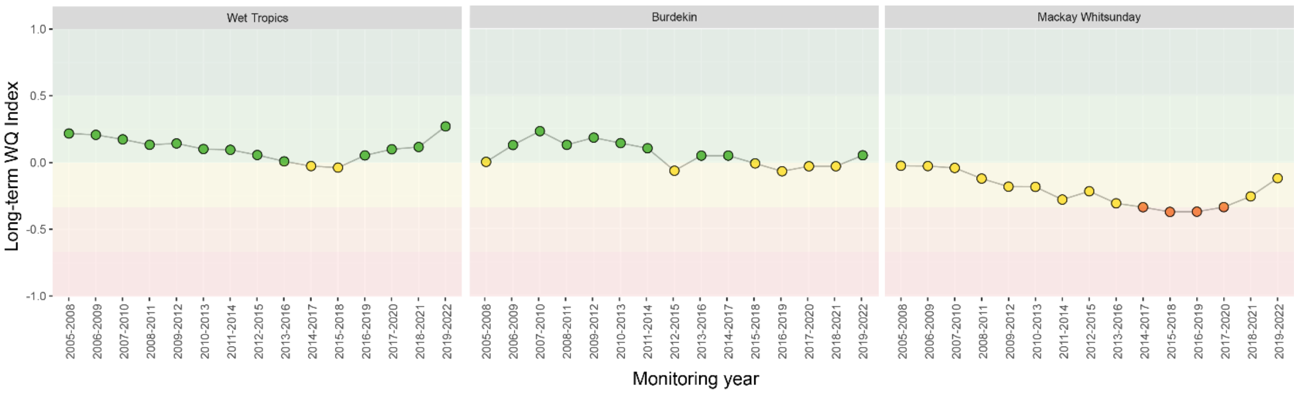

Figure 4. Trends in the regional Long-term Water Quality Index scores for the Wet Tropics, Burdekin and Mackay-Whitsunday regions. The index includes five indicators: water clarity, nitrate/nitrite, particulate nitrogen, particulate phosphorus and chlorophyll *a*. Long-term data are not available for Cape York. Values are indexed scores scaled from -1.0 to 1.0 and graded: ■ = very good (1.0 to 0.5), ■ = good (0.5 to 0.0), ■ = moderate (< 0.0 to -1/3), ■ = poor (< -1/3 to -2/3), ■ = very poor (< -2/3 to -1.0). Note scores are unitless. Data source: Moran et al. 2023.

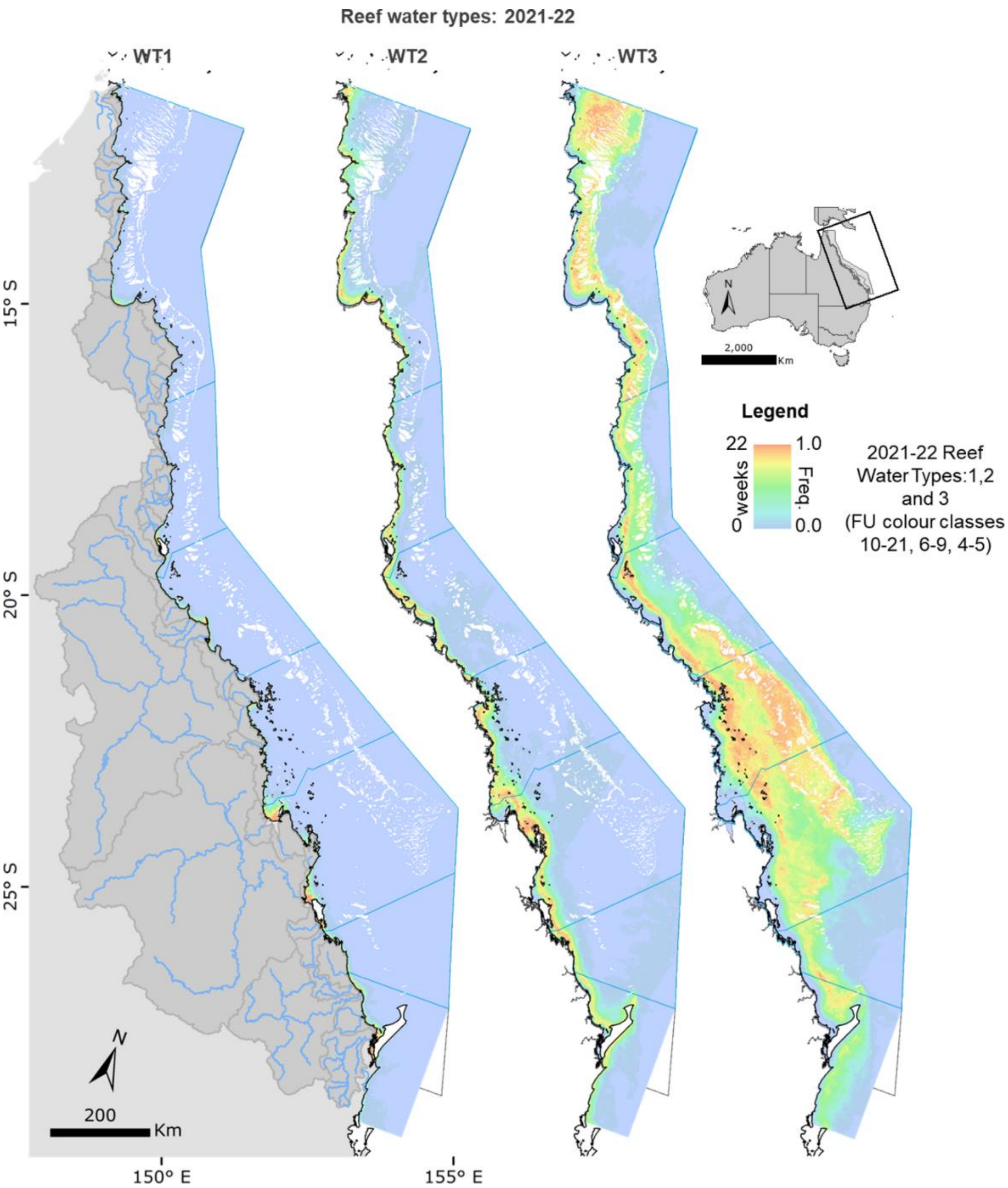

Figure 5. Map showing the frequency of Reef WT1, WT2 and WT3 in the 2021–22 wet season based on the available (non-cloudy) satellite images. The highest frequency is shown in orange and the lowest frequency is shown in blue. These maps are used in the exposure assessment to represent the spatial likelihood of exposure of each of the wet season water types in 2021–22. Image extracted from Moran *et al*. 2023.

Seagrass conditions

- Seagrass condition has shown signs of recovery in the northern regions (Cape York, Wet Tropics and Burdekin) but scores remained around average (moderate). In the Mackay-Whitsunday, the index grade improved from ‘poor’ to ‘moderate’. In the southern regions (Fitzroy and Burnett-Mary), seagrass deteriorated and remained in ‘poor’ condition (Figure 6)

- Seagrass Index scores across Cape York increased slightly in 2021–22 due to higher scores in both the abundance and resilience indicators.
- In the Wet Tropics, overall seagrass condition improved, driven by significant improvements in abundance in the northern meadows and resilience in the southern meadows.
- Seagrass abundance improved in the Burdekin region as it recovered from the effects of heavy rainfall and above-average discharge from rivers in early 2019.
- Seagrass condition improved in the Mackay-Whitsunday region, driven primarily by a substantial increase in the resilience indicator at Reef intertidal habitats.
- Seagrass Index scores for the Fitzroy and Burnett-Mary declined and seagrass remained in a poor state in 2021–22, with the abundance indicator declining to 'very poor' condition.

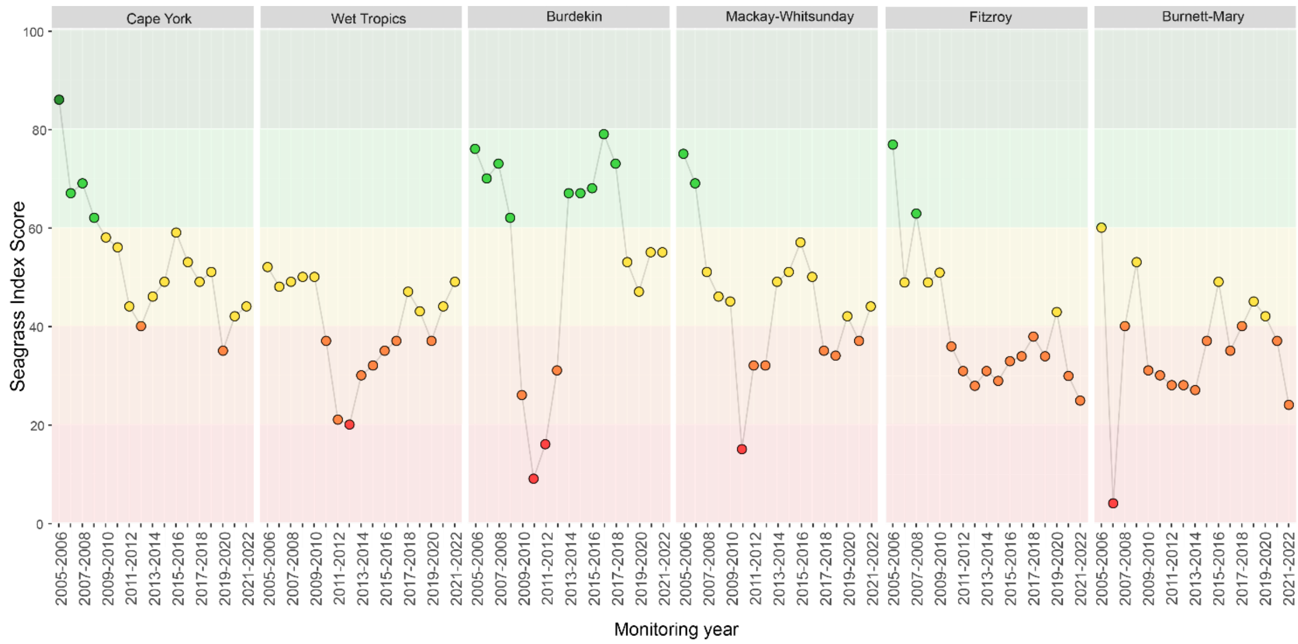

Figure 6. Temporal trend in regional Seagrass Index scores from 2005–06 to 2021–22. Values are indexed scores scaled from 0–100 and graded: ■ = very good (81–100), ■ = good (61–80), ■ = moderate (41–60), ■ = poor (21–40), ■ = very poor (0–20). Note scores are unitless. Data source: McKenzie *et al*. 2023.

Coral conditions

- Coral condition remains 'moderate' in the northern regions and 'poor' in the southern regions (Figure 7).
- In the Wet Tropics, Coral Index scores have remained stable since 2016, but variation within sub-regions exist.
- The Coral Index score continues to decline in Burdekin region, likely driven by increases in macroalgae in the region.
- Marginal improvement in the Coral Index score in Mackay-Whitsunday region was detected. This observed recovery was mainly driven by high densities of juvenile corals at some reefs even though the overall score remained 'poor'.
- In Fitzroy region, high cover of macroalgae and low densities of juvenile corals are hindering recovery at some reefs.

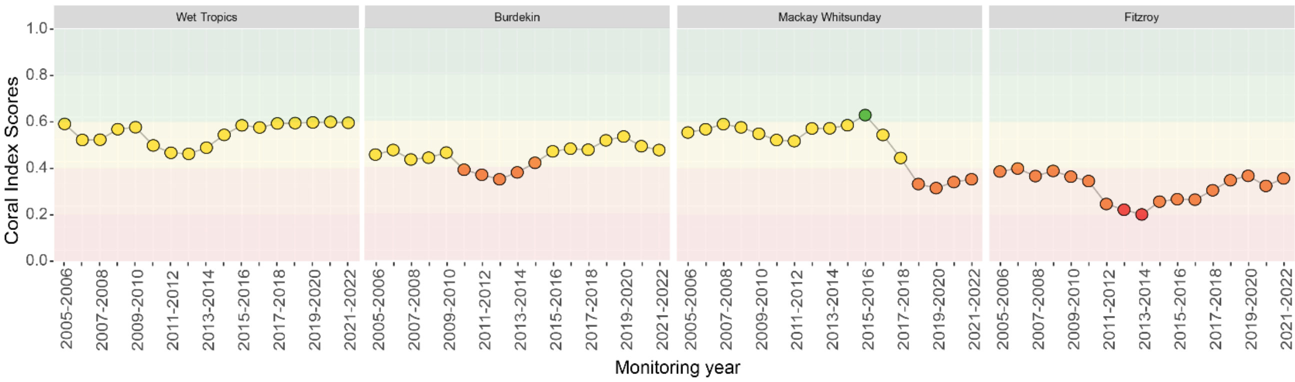

Figure 7. Temporal trend in regional Coral Index scores from 2005–06 to 2021–22. Values are indexed scores scaled from 0.00–1.00 and graded: ■ = very good (0.81–1.00), ■ = good (0.61–0.80), ■ = moderate (0.41–0.60), ■ = poor (0.21–0.40), ■ = very poor (0.00–0.20). Note scores are unitless. Data source: Thompson *et al*. 2023.

Introduction

Improving water quality is one of our major strategies for mitigating climate change impacts on the Reef and sustaining our coastal way of life.

Poor water quality is a major threat to marine ecosystems around the world and poses one of the highest risks to many coastal and inshore Reef ecosystems (Great Barrier Reef Marine Park Authority 2019 and supporting references therein). Increased sediments and low light from flood events can negatively impact and cause mortality of coral and seagrasses at large scales, decreasing the viability of these ecosystems and risking their replacement with barren, muddy and unstable areas. Increased nutrients, largely from agricultural activities but also other coastal land uses including the development of urban areas, can increase algal growth, blocking light and space for the growth of corals and jeopardising the structural and ecological integrity of these inshore coral reefs. These inshore areas include places we know and appreciate on a regular basis. They are often major tourism attractions and culturally significant places, such as the Whitsunday Islands, Magnetic Island, Green Island, Low Isles, the Keppel Islands, the Flinders Island Group and many other locations supporting inshore coral reefs and seagrass meadows. These inshore ecosystems help trap incoming sediment from land-based runoff entering the Reef lagoon. They provide irreplaceable habitats for commercial, recreational and culturally important animals, and protect our shores by assisting with coastal stabilisation and acting as long-term storage of blue carbon.

Ongoing monitoring of excess nutrients and pollutants entering the Reef is crucial for understanding the impacts of poor water quality on coastal and inshore marine ecosystems. Chronic impacts of poor water quality can reduce the potential for these ecosystems to survive pressures from climate change and negatively impact Reef resilience.

Three reasons why we should monitor and protect the inshore region:
- It provides rich nursery and feeding grounds for many species of fish, prawns, turtles, and dugongs
- It protects our shores from erosion providing coastal stability
- It sustains our community lifestyles and livelihoods.

Land-based run-off with associated pollutants, mainly from agricultural activities, is the greatest contributor to poor water quality in the Reef. Reduced water quality is primarily due to pollutants such as nutrients, fine sediment and pesticides entering the Reef through the catchments (Schaffelke *et al*. 2017). Changes in land use patterns and deforestation over the past 200 years of European settlement have affected the health of coastal and inshore ecosystems, particularly corals and seagrass meadows, due to increased nutrients and sediments trevelling from rivers to the Reef (Waterhouse *et al*. 2017). A decline in water quality is associated with reduced Reef resilience by contributing directly to coral diseases (Haapkylä *et al*. 2011), algal blooms and lower coral and seagrass growth, abundance and recovery (Brodie *et al*. 2019). It also negatively impacts the health of other Reef fauna, including important cultural, recreational and commercial species of fish, prawns, turtles and dugong (Great Barrier Reef Marine Park Authority 2019).

Great Barrier Reef Marine Monitoring Program

Only a relatively small amount (about 7 per cent) of the entire Great Barrier Reef Marine Park and World Heritage Area is attributed to coral reefs, with the rest consisting of a diverse range of marine habitats, including seagrass, mangroves, sand, algal and sponge gardens, and inter-reefal communities (Great Barrier Reef Marine Park Authority 2023). This exhibits the inter-connectedness and inter-reliance of these habitats on the Reef's overall resilience, particularly in relation to climate change and the potential for more severe and cumulative impacts. The Reef represents 10 per cent of global coral reefs (Great Barrier Reef Marine Park Authority 2023) and its seagrass meadows are estimated to represent substantially more, between 13 and 22 per cent (McKenzie et. al. 2022), making both resources globally significant.

Since Reef resilience has been compromised by human-induced global warming, actions to reduce the threats posing the highest risks have never been more time-critical (Great Barrier Reef Marine Park Authority 2019). Water quality improvement has an important role in increasing ecosystem resilience and recovery from disturbances. Implementation of the Queensland Government's Reef 2050 Water Quality Improvement Plan 2018 (Reef 2050 WQIP) contributes to improving the outlook of the Reef by reducing pollutant loads entering the coastal and inshore areas. The Reef 2050 WQIP is integrated as a major component of the Reef 2050 Long-Term Sustainability Plan (Reef 2050 Plan) and is supported by a robust monitoring and evaluation program, the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Paddock to Reef Program).

The Great Barrier Reef Marine Monitoring Program (MMP) is one line of evidence used to report progress towards the Reef 2050 WQIP and forms an essential part of the Paddock to Reef Program. The MMP provides the evidence base to assess and describe the condition of inshore coral and seagrass ecosystems and inshore water quality. It is used to demonstrate any long-term improvements (or declines) that occur, including those resulting from the implementation of the Reef 2050 WQIP and other policy interventions. It provides critical information for the Reef Water Quality Report Cards used to assess the long-term effectiveness of the Reef 2050 WQIP.

The MMP is therefore an internationally significant program, as well as being essential for effective management of the Reef. The MMP ensures the most up-to-date information about these two crucial habitats in the inshore Reef, where a significant proportion of seagrass meadows exist and where our coastal ecosystems connect with the Reef as a whole. The MMP links with Queensland's management programs in relation to water quality (a critical environmental parameter) via continual monitoring and reporting in its annual reports, to the Reef Water Quality Report Card and through other media.

The objectives of the MMP are to:

- assess temporal and spatial trends in inshore marine water quality and link pollutant concentrations to end-of-catchment loads
- monitor, assess and report the condition and trend of inshore coral reefs and seagrass meadows in relation to declines in water quality and the extent, frequency and intensity of acute and chronic impacts.

The MMP currently has three core sub-programs:

1. Inshore marine water quality monitoring
2. Inshore coral reef monitoring
3. Inshore seagrass monitoring, which have been conducted since 2005.

Water quality and climate change

Land-based runoff to the inshore Reef is mainly delivered during the wet season, often forming distinct flood plumes in the coastal zone that occasionally reach midshelf and offshore regions of the Reef lagoon (Waterhouse *et al*. 2023). The current rate of climate warming is leading to lower overall rainfall punctuated by high intensity wet season rainfall events (Bureau of Meteorology 2022). This may lead to more suspended sediments and pollutants flowing into the Reef lagoon. The area of the Reef affected by land-based runoff has increased substantially because of changing land management practices, to the extent that fine terrestrial sediment is reaching midshelf reefs for the first time in their geological history (Lough *et al*. 2015) The effect of elevated concentrations of nutrients, suspended sediments and pesticides is likely slowing regeneration of coastal ecosystems with consequent impact on their long-term resilience. Imposed over the episodic impacts of flooding is the threat of marine heatwaves over the wet season (Bureau of Meteorology 2022). If climate predictions are realised there are likely to be continued and increasing negative consequences on inshore ecosystems.

In this context, continued monitoring is critical to enable detection and reporting of any pollutant load reductions at the end of catchments, and subsequent improvements in coastal and inshore habitats, under the Reef 2050 WQIP. Successes in improving water quality must be quantifiable and clearly indicate the overall outcomes for Reef health and resilience.

The intention of this MMP Synthesis Report is to facilitate a more accessible synthesis and interpretation of the outcomes of the three 2021–22 annual reports addressing water quality entering the Reef and its impacts on the resilience and condition of coral and seagrass habitats of the inshore Reef. The introduction identified the importance of this inshore region, and perspective is necessary when discussing the Reef. A summary of the methods and results of monitoring undertaken between 1 October 2021 and 30 September 2022 (the 2021–22 monitoring season) is outlined below. The Annual Technical Reports for water quality (Moran *et al*. 2023), seagrass (McKenzie *et al*. 2023) and coral (Thompson *et al*. 2023) underpin this synthesis report. Detailed methods, results and further information are available in the Annual Technical Reports, and Quality Assurance and Quality Control Manuals, which are published and available to the public on the Great Barrier Reef Authority's E-Library website (https://elibrary.gbrmpa.gov.au). Further synthesised results can also be found in the MMP Dashboard, available through the Reef Knowledge System (https://reefknowledgesystem.gbrmpa.gov.au/dashboards/marine-monitoring-program).

Methods

This section briefly describes the field methods used in the MMP to collect data on inshore marine water quality, and condition of coral and seagrass (Figure 8). A comprehensive list of water quality and ecosystem health indicators measured under the MMP are in this section. A subset of these indicators is used to calculate the inshore marine water quality, seagrass and coral indices scores. Specific and detailed information on data analyses and calculation of the scores, synthesis and integration of data can be found in each of the annual reports, which are referenced below. It is noteworthy that values of the calculated coral and seagrass scores mentioned here are directly incorporated into the Reef Water Quality Report Card. In contrast, the Water Quality Index scores reported here are a specific tool developed by AIMS for the MMP to visualise trends in the suite of water quality variables (Moran *et al*. 2023).

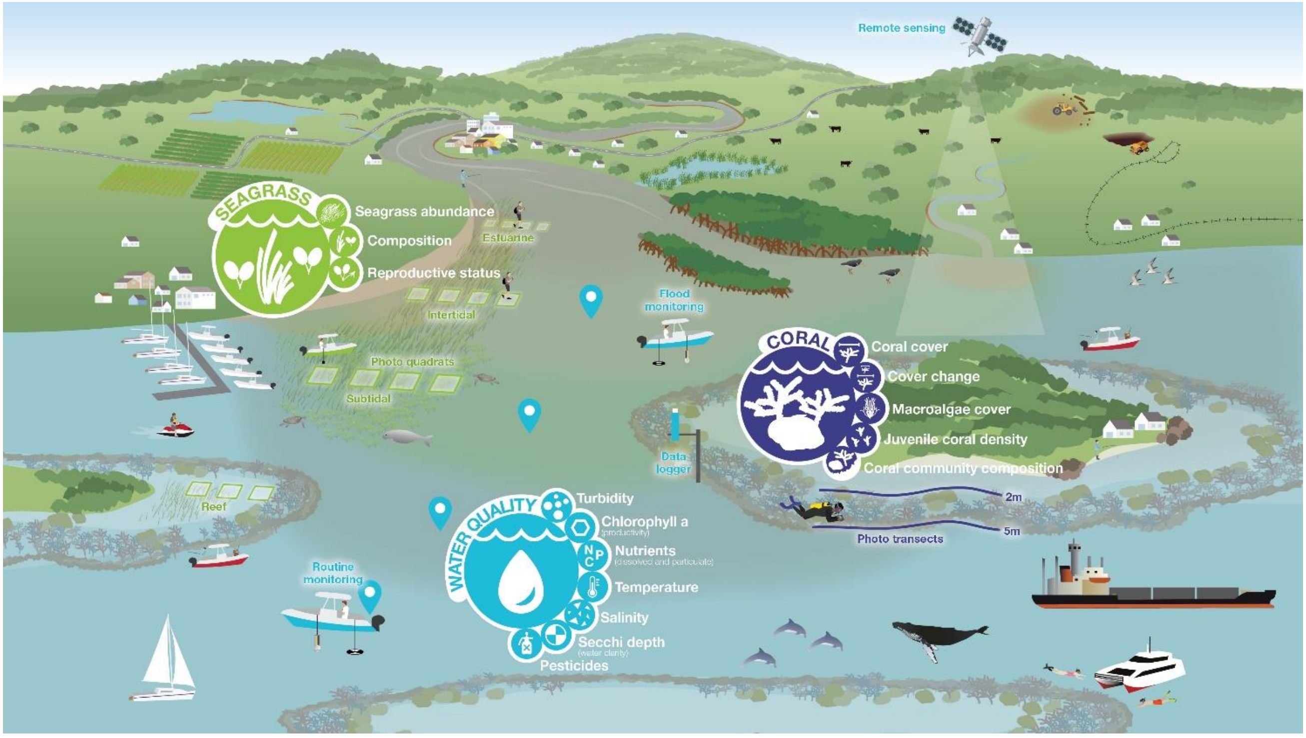

Figure 8. Conceptual diagram representing the components monitored by the Marine Monitoring Program.

Water quality monitoring

Water quality monitoring is carried out in the inshore waters of the Reef to assess changes over time in concentrations of relevant water quality indicators during wet and dry seasons (Figure 9). In addition, specific monitoring of flood plumes (resulting from river flood events) also forms part of the MMP. Detailed information on inshore marine water quality monitoring and data analyses can be found in Moran *et al*. (2023).

Monitoring at inshore sites includes the following parameters:

- concentration of nutrients and total suspended solids, turbidity and Secchi depth as a proxy for water clarity
- concentration of chlorophyll *a* as proxy for productivity
- *in-situ* temperature and salinity
- remote sensing analysis to determine spatial and temporal variation in coastal water quality, especially during the wet season, and the exposure risk of inshore coral and seagrass ecosystems to terrestrial run-off.

These indicators are used to calculate the Water Quality Indices, measured against established water quality guideline values (Great Barrier Reef Marine Park Authority 2010). Different water quality parameters are used to calculate the Water Quality Indices, which communicate the long-term trend (insensitive to year-to-year variability) and annual condition (sensitive to year-to-year variability) of water quality relative to guideline values (Moran *et al*. 2023).

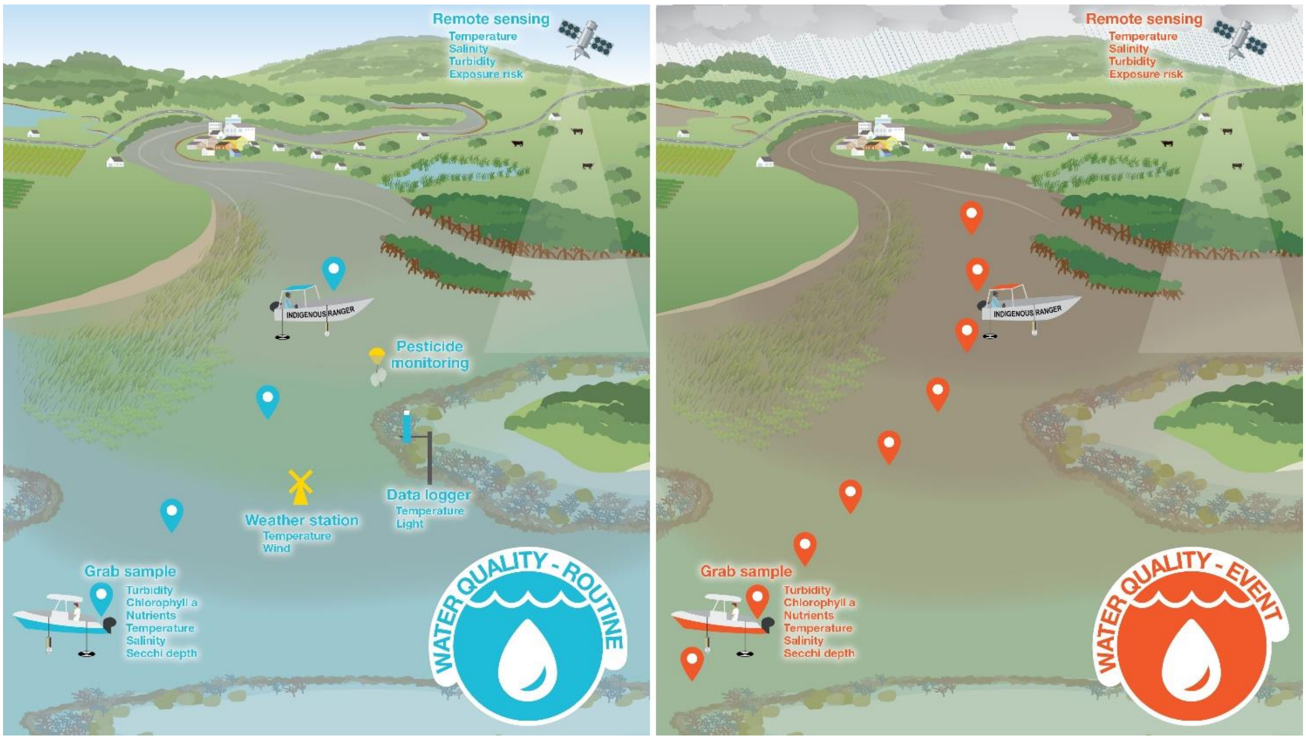

Figure 9. Water quality monitoring is routinely undertaken during wet and dry seasons (left), along permanent transects located from river mouths to open coastal areas. Additionally, monitoring of flood plumes is conducted as required during flood events (right).

Remote sensing

Satellite imagery is used to interpret where and when three specific water types, reflecting different water quality conditions, are present in the Reef during the wet season (22 weeks from November to May):

- Reef WT1—brownish, turbid waters, which are rich in sediment and dissolved organic matter from river flood plumes, typically found inshore in enclosed and open coastal waters.
- Reef WT2—less turbid part of flood plumes, which are greenish waters rich in algae and dissolved organic matter, typically found in open coastal and midshelf waters.
- Reef WT3—greenish-blue waters with suspended sediment slightly above ambient conditions and enriched with nutrients, typically found offshore towards the open sea.

Satellite imagery and modelling outputs are then linked with *in situ* monitoring to estimate the exposure of inshore areas to end-of-catchment loads from rivers through exposure maps and assessment. The exposure assessment estimates the magnitude and likelihood of exposure to pollutants mapped through Reef WT1, WT2 and WT3. By overlaying the exposure maps with information on the spatial distribution of coral reefs and seagrass meadows, the areas and percentages of these ecosystems that may experience exposure to pollutants during the wet season can be identified (Moran *et al*. 2023). The exposure categories are not validated against ecological health data and represent relative potential risk categories for seagrass and coral reef ecosystems. Category I (no or very low risk) represents waters with ambient or detectable but low pollutant concentrations and therefore low risk of any detrimental ecological effect. The areas and percentages of ecological communities affected by the different categories of exposure were calculated as a relative measure between regions and the long-term average.

Seagrass monitoring

Monitoring is conducted in all six regions and covers each major seagrass habitat types where possible: estuarine, coastal intertidal, coastal subtidal, reef intertidal and reef subtidal (Figure 10). Detailed information on inshore seagrass monitoring and data analyses can be found in McKenzie *et al*. 2023.

In summary, monitoring occurred in 69 sites across 30 locations assessed during the 2021–22 monitoring season. This sampling strategy covered 14 coastal, four estuarine and 12 reef locations (two or three sites at each location). Reef intertidal sites in the Burdekin and Wet Tropics were paired with a subtidal site (McKenzie *et al*. 2023).

At each location, apart from subtidal sites, sampling included two sites nested within 500 metres of each other. Subtidal sites were not always replicated within locations. Intertidal sites were defined as a 5.5 hectare area within a relatively homogenous section of a representative seagrass community/meadow. Monitoring occurred at sites in the late dry season (September–November 2021) and late wet season (March–April 2022). In each site, two indicators were assessed:

- seagrass abundance—an assessment of the average percentage cover of seagrass per monitoring site in relation to the Seagrass Abundance Guidelines (McKenzie 2009)

- resilience—an assessment of reproductive effort, species trait, relative meadow extent and density of seeds in the seed bank, which are used to infer capacity of a meadow to resist or recover following a disturbance event.

These indicators are weighed equally and used to calculate the Seagrass Index score.

Figure 10. Seagrass meadows are monitored in coastal and reefal habitats of the inshore region.

Coral reef monitoring

Monitoring of inshore coral reef communities occurs yearly at reefs adjacent to four regions: Wet Tropics, Burdekin, Mackay-Whitsunday and Fitzroy. No reefs in Cape York region are included due to logistic and occupational health and safety issues relating to diving in coastal waters in this region. In addition, there are few coral reefs in inshore waters of the Burnett-Mary region, and therefore there are no established monitoring sites in this area. Detailed information on inshore coral reef monitoring and data analyses can be found in Thompson *et al*. 2023.

Thirty reefs are monitored at two metre and five metre depth, with an additional eight inshore reefs monitored at a single depth under the AIMS Long-Term Monitoring Program. All are included in the annual assessment of coral condition. Coral monitoring for the 2021–22 report occurred between April and June 2022 allowing detection of any impacts from disturbances common in the wet season, such as bleaching and cyclones.

At each monitoring site, five 20 metre-long transects were deployed and five indicators assessed (Figure 11):

- hard and soft coral covers
- number of hard coral juvenile colonies (up to 5 centimetres diameter)
- proportion (percentage) of macroalgae cover
- rate of change in coral cover (as an indication of the recovery potential of the reef following a disturbance)
- coral community composition.

These indicators were weighed equally and used to calculate the Coral Index score.

Figure 11. The status of inshore coral reefs is assessed along permanent transects to monitor benthic cover and coral recruitment.

Regional summaries

This section expands on the condition and trends of water quality, seagrass and coral at a regional-level, and explores linkages to catchment run-off and other environmental pressures. It further presents results from flood monitoring and the effects of flood plumes on water quality and condition of inshore habitats.

Cape York

The Eastern Cape York catchment region covers an area of 45,500 square kilometres, divided into four focus regions: Pascoe River, Stewart River, Normanby Basin and Endeavour Basin (Moran *et al*. 2023). *In situ* water quality monitoring was conducted in 21 sites, sampled four to six times per year during ambient conditions, while seagrass was monitored in six locations (Figure 12). Corals are not monitored by the MMP in Cape York.

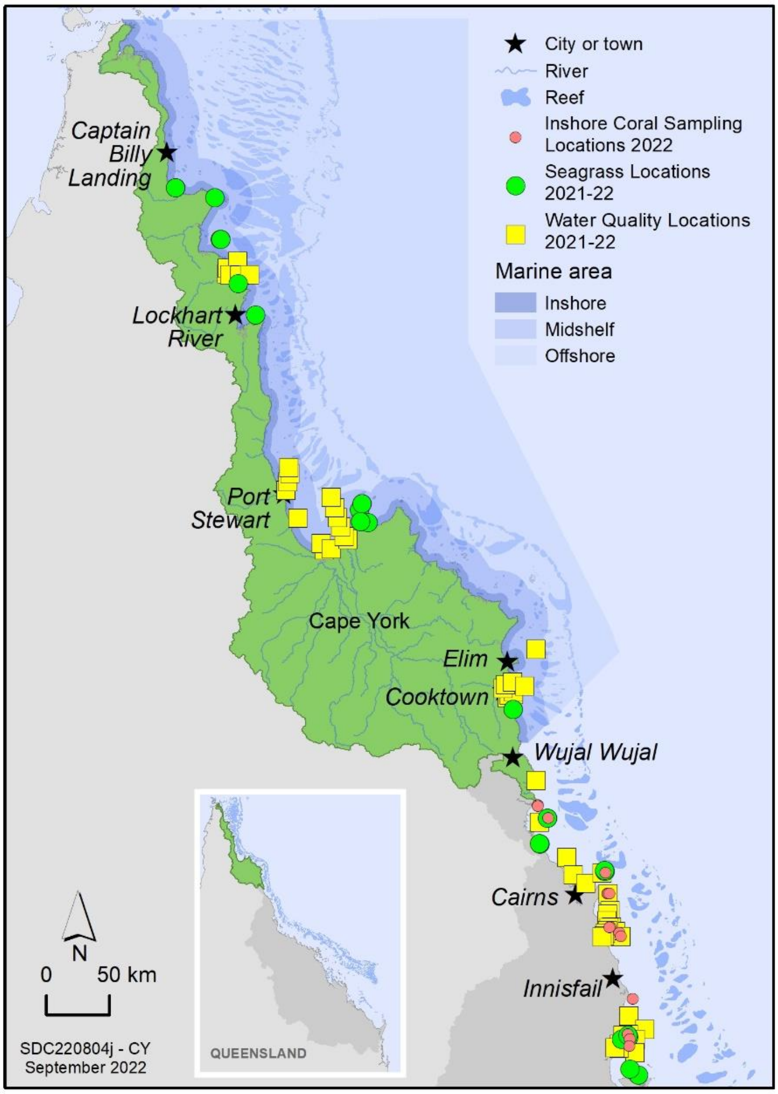

Figure 12. Water quality and seagrass sampling sites in the Cape York NRM region shown with water body boundaries. Note coral monitoring is not conducted in Cape York.

Environmental conditions

Cape York was the only region directly impacted by a tropical cyclone in the 2021–22 wet season. A tropical low formed in the northern Coral Sea on 8 January 2022, which quickly developed into the category 2 Tropical Cyclone (TC) Tiffany on 9 January 2022. TC Tiffany reached Cape York Peninsula near Cape Melville north of Cairns, rapidly weakened and crossed Princess Charlotte Bay at category 1 intensity. However, the system brought heavy rainfall across the Cape York Peninsula (Courtney and Boterhoven 2022).

Wet season rainfall across the basins of Cape York was close to the long-term average for the region. Annual discharge from rivers in the Cape York region were also close to the long-term average. There were above average discharges (1.5 times above the median) from the Pascoe and Lockhart Rivers late in the wet season.

Sea-surface temperature in Cape York was slightly above average, however intertidal temperature was the warmest since monitoring was established in the region (McKenzie *et al*. 2023).

Water quality

The Annual Condition Water Quality Index score for the Cape York region was 'good' for the 2021–22 monitoring year (Figure 13).

Rainfall was generally consistent over the wet season but there were several small to moderate discharge events late in the wet season and in the early dry season. As a result of the relative lateness of these discharge events in 2021–22 monitoring year, water quality conditions were generally documented to be in moderate to good condition. However, this is likely influenced by the timing of these events compared with most of the sampling effort which is constrained to the wet season throughout Cape York, due to logistical constraints associated with strong south-east trade winds in the dry season. Overall, the annual Water Quality Index score for each sub-region was 'moderate', except for the Annan-Endeavour sub-region, which scored 'very good'.

Key results:

- Chlorophyll *a* concentration, total suspended solids (TSS), phosphate (PO_4) and particulate phosphorus (PP) met the water quality guideline values at most sites for all Cape York sub-regions.
- Nitrogen Oxides (NO_x) exceeded the guideline values at most sites and sub-regions.
- Secchi depth did not meet the minimum guideline values at most sites and sub-regions. However, monitoring occurred primarily during the wet season and mean averages are compared against annual guidelines.
- A 'very good' annual Water Quality Index score at the Annan-Endeavour sub-region was likely influenced by the timing of the major discharge in that region late in the wet season, after most of the wet season monitoring efforts had been completed.
- Flood plumes and terrestrial runoff affected mainly enclosed coastal areas of Cape York.
- Approximately 14 per cent of the Cape York region was exposed to a potential risk, including a 17 per cent increase of the coral reef area was exposed to the lowest category of risk.

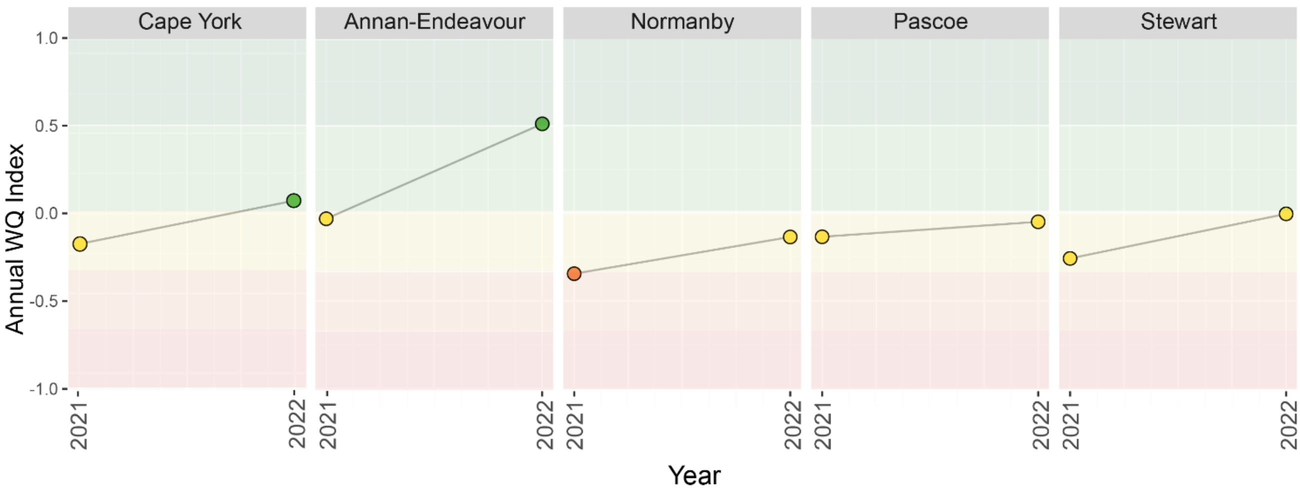

Figure 13. Temporal trends in the Annual Water Quality Index for the Cape York region.

Seagrass

During the 2021–22 monitoring year, the Seagrass Condition Index score for the Cape York region improved slightly since the previous reporting period, with the overall grade remaining 'moderate' (Figure 14).

The abundance indicator declined slightly between 2020–21 and 2021–22. Losses occurred at reef subtidal habitats and some reef intertidal habitats where sites lost close to half their percentage cover. There were slight improvements in the resilience indicator, partly a consequence of higher reproductive effort and seed banks in coastal habitats, such as Bathurst Bay (McKenzie *et al*. 2023). Both indicators remain in a moderate state (yellow band), with scores in 2021–22 marginally below long-term averages. The Seagrass Condition Index score in 2021–22 was the fourth lowest over the last decade.

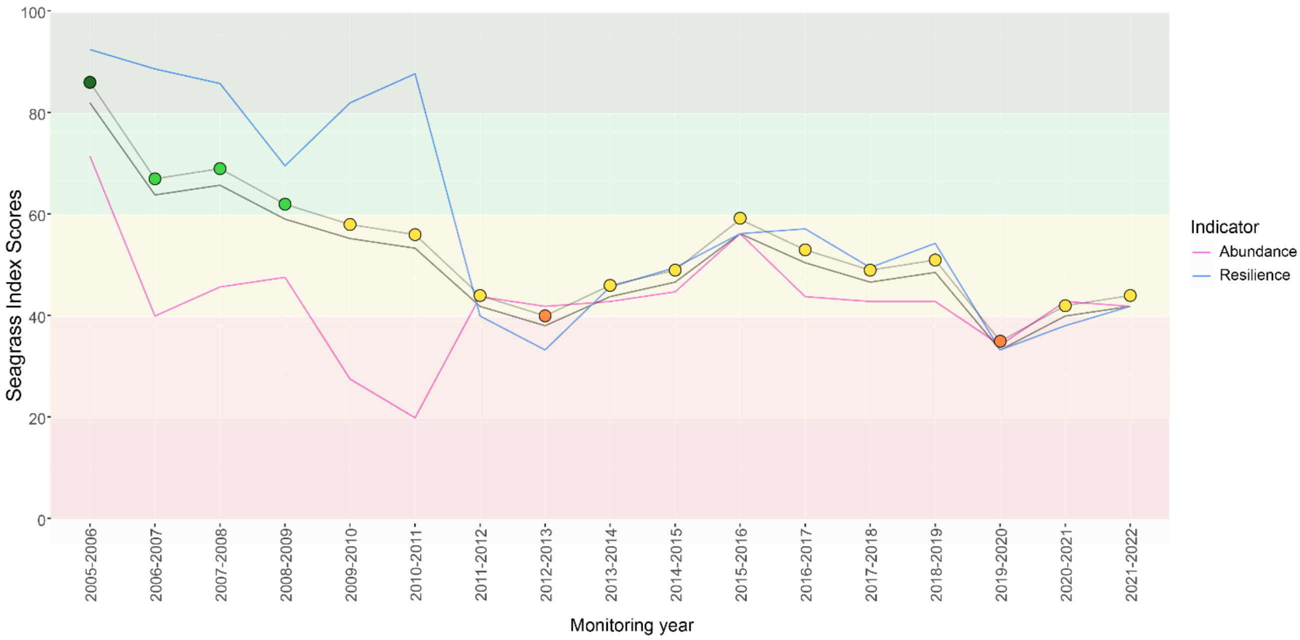

Figure 14. Seagrass Condition Index scores for the Cape York region from 2005–06 to 2021–22. Black line with circles represents the index score and values are scaled from 0–100 and graded: ■ = very good (81–100), ■ = good (61–80), ■ = moderate (41–60), ■ = poor (21–40), ■ = very poor (0–20). Blue and pink lines represent the indicators that inform the index score. Note, scores are unitless. Data source: McKenzie *et al*. 2023.

Coral

The MMP does not monitor inshore coral communities in Cape York region.

Wet Tropics

The Wet Tropics region covers about 22,000 square kilometres, extending from the Daintree forests of the north to the sugarcane land delta of the Herbert River catchment in the south and west to the dry rangelands of Mount Garnet (Terrain 2015). For reporting purposes, this region is divided into three focus regions (Barron-Daintree, Russell-Mulgrave-Johnstone and Herbert-Tully) with results of water quality and coral conditions presented separately. *In situ* water quality monitoring was conducted in 17 sites, sampled three to ten times per year during ambient conditions. Seagrass was monitored in six locations (Figure 15) in the late wet and late dry seasons, while corals were monitored in 12 sites in the dry season by the MMP and two sites by AIMS' Long-Term Monitoring Program (often in the wet season).

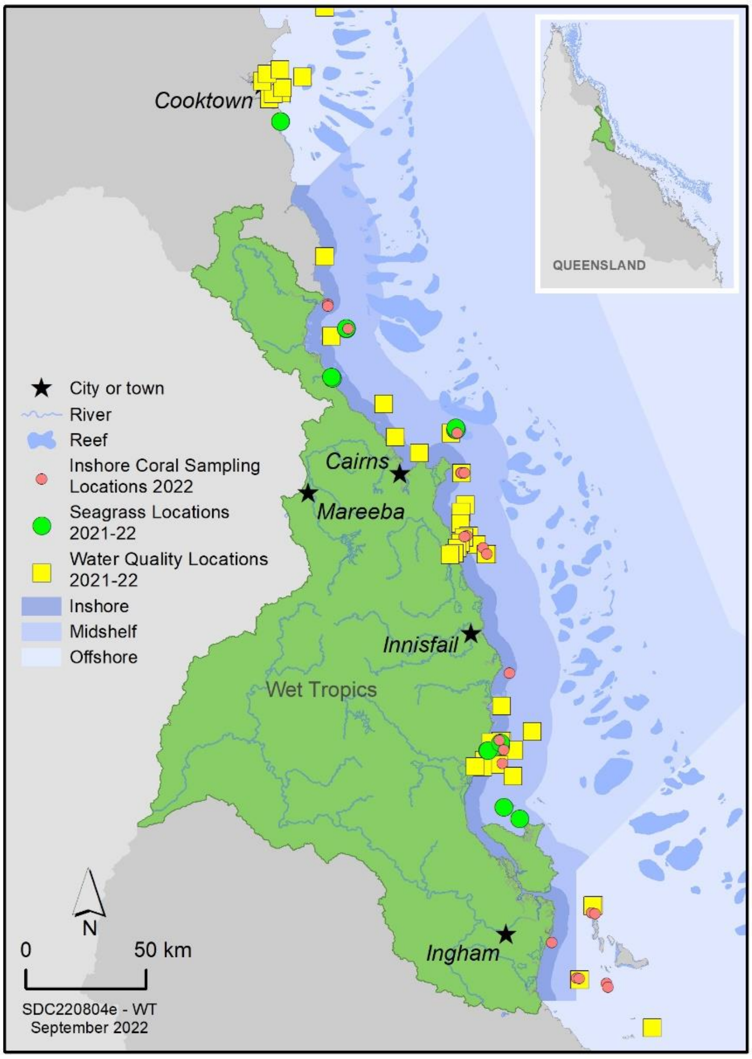

Figure 15. Map showing sampling sites in the Wet Tropics region. Note that water quality sites shown include flood event monitoring sites in addition to routine monitoring sites.

Environmental conditions

There were three main flood events influencing the Wet Tropics region during the 2021–22 wet season in March, April and May. Discharge from the Daintree, Mossman, Barron, Russell-Mulgrave and Johnstone basins was slightly higher or close to the long-term median. In contrast, river discharge in the Tully basin was slightly less than the long-term median. Annual rainfall was slightly lower than average across the Wet Tropics. However, the largest discharge events in the region occurred late in April, followed by another in early May, after the wet season.

Sea-surface temperatures were above average and thermal stress might have led to an increase in coral disease incidence in the Russell-Mulgrave-Johnston and Barron-Daintree sub-regions (Thompson *et al*. 2023).

Water quality

The Annual Water Quality Index score for the Wet Tropics region was 'moderate' for the 2021–22 monitoring year, but variations were detected among the sub-regions. The Barron-Daintree sub-region was scored 'good', while the Russell-Mulgrave-Johnstone and Herbert-Tully were scored 'moderate' (Figure 16).

Discharge from the Barron-Daintree Basin was 1.3 times higher than the long-term median, while discharge in the Russell-Mulgrave-Johnstone and Herbert-Tully basins was close to the long-term median (Moran *et al*. 2023). Of the three focus regions within the Wet Tropics, the Barron-Daintree Basin commonly contributed the lowest discharge and consistent loads compared to the two focus regions to the south (Russell-Mulgrave-Johnstone and the Herbert-Tully).

Key results:

- Chlorophyll *a* concentration, TSS and PO_4 met the water quality guideline values in all sub-regions and continue to improve.
- NO_x exceeded the guideline values in all sub-regions but is improving in the Herbert-Tully sub-region.
- Secchi depth did not meet the minimum guideline values but an improving trend was detected in all sub-regions.
- Flood plumes and terrestrial runoff affected mainly enclosed coastal areas of the Wet Tropics.
- Only 15 per cent of the Wet Tropics area was exposed to a potential risk, and only inshore waters and habitats (mostly seagrass meadows) were exposed to the highest potential risk.

The Long-term Water Quality Index showed an improving trend over the past few years in the Barron-Daintree and Russell-Mulgrave-Johnstone sub-regions, which were scored 'good'. In contrast, the Long-term Water Quality Index in the Herbert-Tully sub-region consistently scored 'poor' over the past six monitoring seasons (Figure 16).

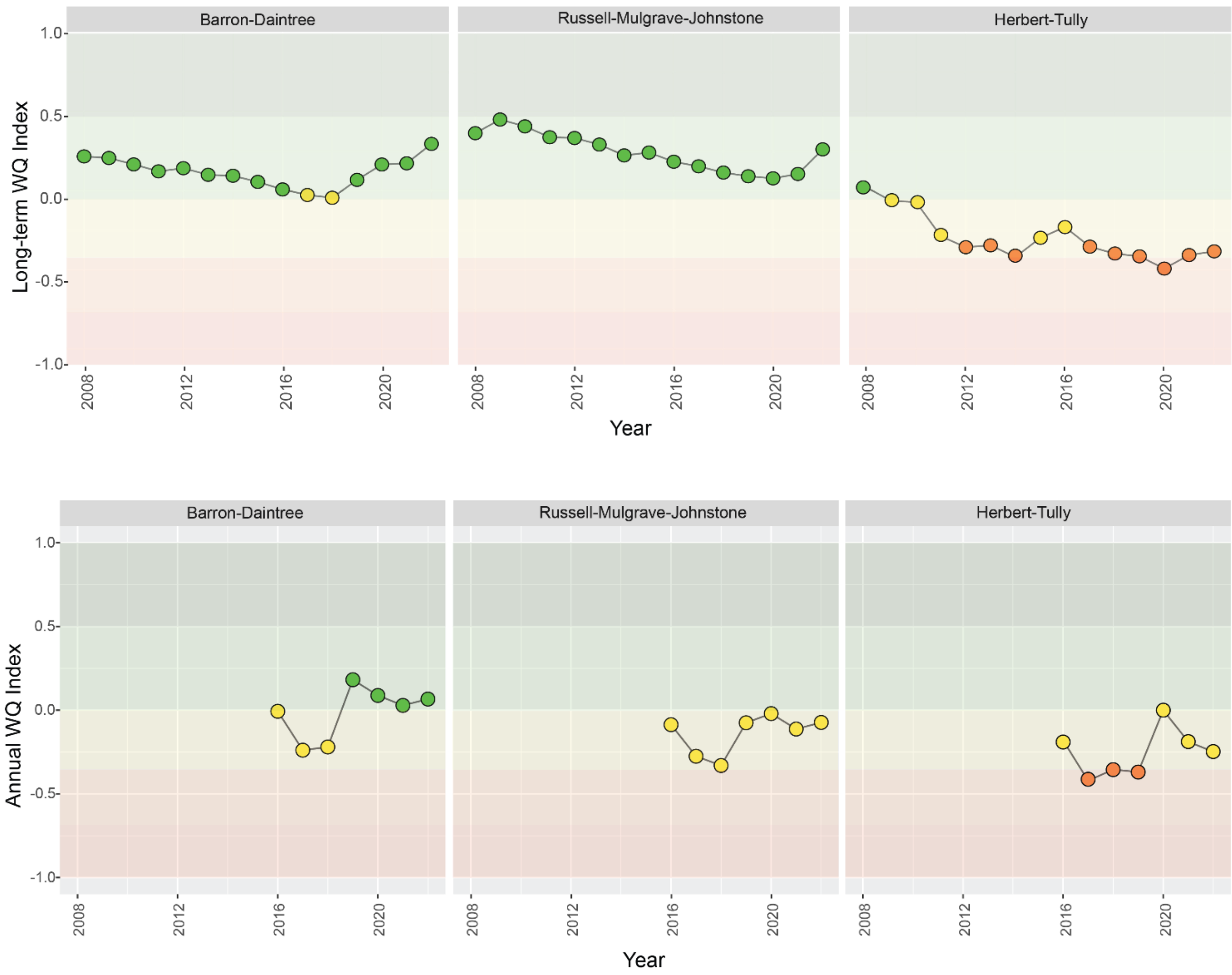

Figure 16. Temporal trends in the Long-term Water Quality Indices and Annual Water Quality Indices for the Wet Tropics sub-regions. Note that the annual index is based on the post-2015 MMP sampling design and is sensitive to year-to-year variability, whereas the long-term index is based on the pre-2015 review and it is insensitive to year-to-year variability.

Seagrass

During the 2021–22 monitoring year, the Seagrass Condition Index score for the Wet Tropics region improved but the grade remained 'moderate' (Figure 17).

Both abundance and resilience indicators improved, however northern and southern meadows were quantified and analysed separately as they diverge substantially in terms of seagrass meadow condition. While resilience was rated 'moderate' in both northern and southern sites, abundance was rated 'good' in northern sites and 'poor' in southern sites (McKenzie *et al.* 2023).

In the northern sites, seagrass abundance improved largely because of increasing trends at subtidal reef sites and mild climatic conditions. However, resilience declined in the north due to small declines in both coastal and reef intertidal habitats, and dominance of colonising species at the reef intertidal and subtidal sites at Low Isles. Seed banks declined in coastal habitats in the north in 2021–22 and there were no seeds at reef intertidal or subtidal habitats.

In the south, seagrass abundance declined slightly but was the third highest score in the southern area since monitoring commenced. The decline was due to reductions in abundance in the reef subtidal habitat. The declines were a legacy of losses that occurred from 2009 to 2011, the result of multiple years of severe weather, above-average rainfall and elevated discharge. Recovery of seagrass meadows post-2011 was challenged, particularly in the south, by unstable substrates, chronic poor water quality compared to the north (high turbidity and light limitation) and limited recruitment capacity. However, resilience increased and was the highest level recorded to date in the southern area. This was due predominantly to large increases in the resilience score at reef intertidal sites where there were reproductive structures of foundational species for the first time since 2017–18 (McKenzie *et al*. 2023).

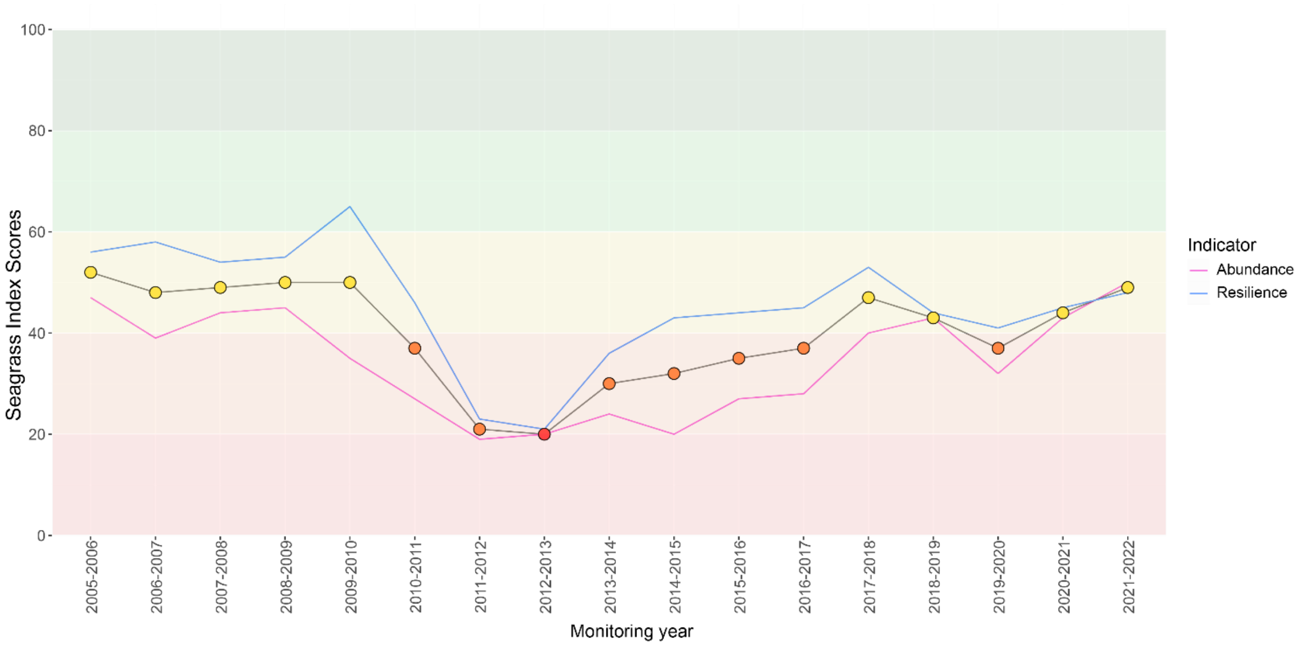

Figure 17. Seagrass Condition Index scores for the Wet Tropics region from 2005–06 to 2021–22. Black line with circles represents the index score and values are scaled from 0–100 and graded: ■ = very good (81–100), ■ = good (61–80), ■ = moderate (41–60), ■ = poor (21–40), ■ = very poor (0–20). Blue and pink lines represent the indicators that inform the index score. Note, scores are unitless. Data source: McKenzie *et al.* 2023.

Coral

Barron-Daintree

The coral community condition was 'moderate' (Figure 18). Most indicators showed signs of improvement from the previous monitoring season, with the exception of macroalgae. Coral cover across the region increased from 40 per cent to 50 per cent in the 2021–22 monitoring year, with the rate of this increase reflected in the 'good' score for cover change. Macroalgal cover remains high at Snapper North, hindering improvements of this indicator. Although the juvenile coral indicator falls in the 'poor' category, the density of juveniles has improved in Snapper South and Low Isles.

Figure 18. Temporal trend in Coral Index scores for the Barron-Daintree sub-region from 2005–06 to 2021–22. Values are indexed scores scaled from 0.0–1.0 and graded: ■ = very good (0.81–1.00), ■ = good (0.61–0.80), ■ = moderate (0.41–0.60), ■ = poor (0.21–0.40), ■ = very poor (0.00–0.20). Note, scores are unitless. Data source: Thompson *et al*. 2023.

Russell-Mulgrave-Johnstone

The Coral Index score has fluctuated between 'good' and 'moderate' since the start of the MMP (Figure 19). The slight decline in the 2021–22 monitoring season reflects declines in all indicators except for coral cover. Coral cover increased at most reefs. Macroalgal cover remains low, except at the western Franklands, where dense macroalgal mats persist. Presence of crown-of-thorns starfish remained at outbreak level at High Island and the Frankland Group.

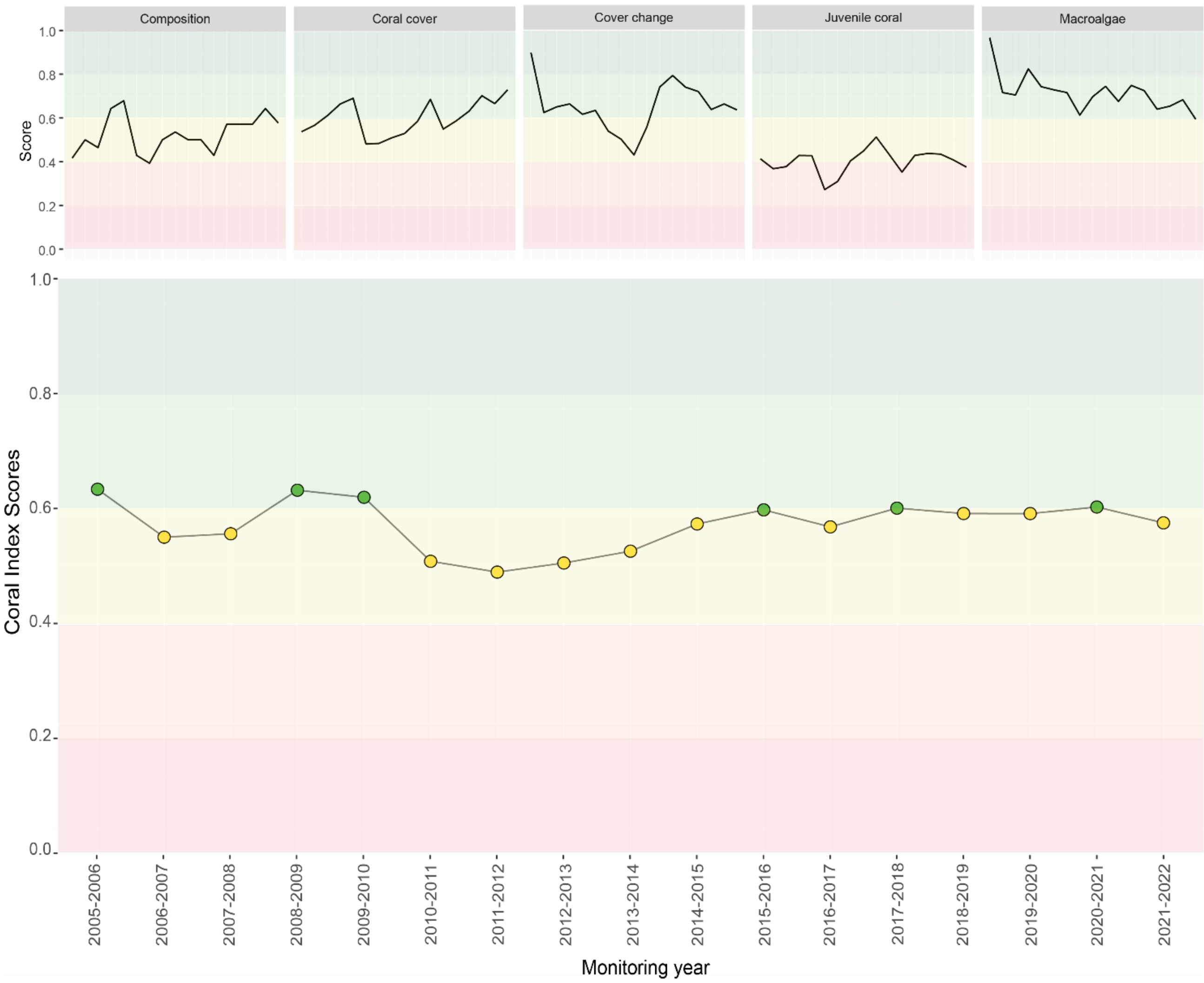

Figure 19. Temporal trend in Coral Index scores for the Russell-Mulgrave-Johnstone sub-region from 2005–06 to 2021–22. Values are indexed scores scaled from 0.0–1.0 and graded: ■ = very good (0.81–1.00), ■ = good (0.61–0.80), ■ = moderate (0.41–0.60), ■ = poor (0.21–0.40), ■ = very poor (0.00–0.20). Note, scores are unitless. Data source: Thompson *et al*. 2023.

Herbert-Tully

The Coral Index score has improved significantly since monitoring started in 2005, but declined slightly in 2021–22 from ‘good’ to ‘moderate’ (Figure 20). Despite this decline, coral cover continues an upward trajectory. The declining trend in juvenile coral is due mainly to strong cohorts of *Turbinaria,* which recruited in the years following Tropical Cyclone Yasi in 2011, growing out of the juvenile size classes (Thompson *et al*. 2023). Unfortunately, high cover of macroalgae remains persistent on reefs around Bedarra and Dunk islands. While remaining high, the decline in cover change and the above median level of disease suggest that the rate of coral cover increase has been suppressed by the cumulative pressures of thermal stress in 2020 and 2022 and above median river discharge in 2021 (Thompson *et al*. 2023).

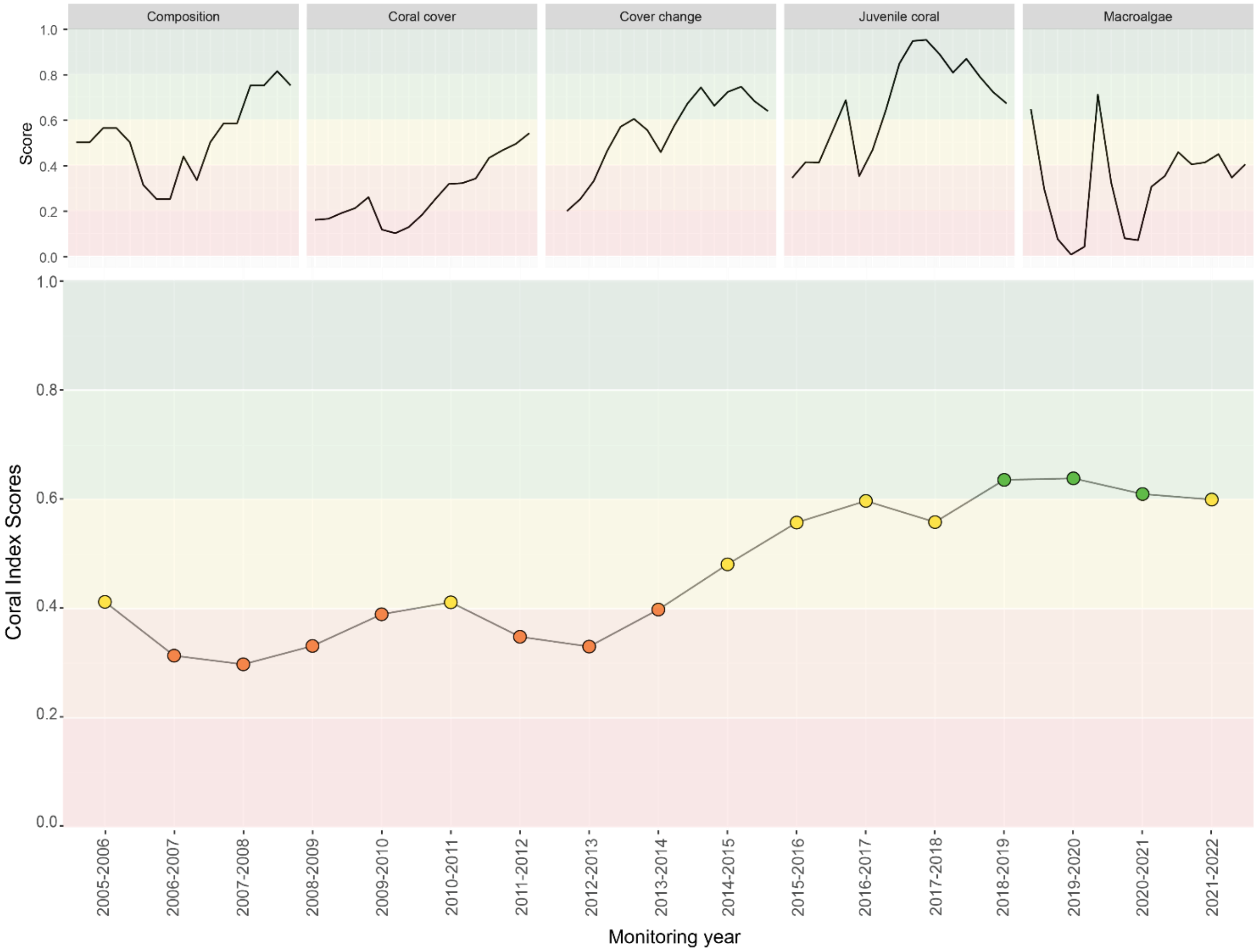

Figure 20. Temporal trend in Coral Index scores for the Herbert-Tully sub-region from 2005–06 to 2021–22. Values are indexed scores scaled from 0.0–1.0 and graded: ■ = very good (0.81–1.00), ■ = good (0.61–0.80), ■ = moderate (0.41–0.60), ■ = poor (0.21–0.40), ■ = very poor (0.00–0.20). Note, scores are unitless. Data source: Thompson *et al*. 2023.

Burdekin

Located in north-eastern Queensland, the region covers eight per cent of the state. It spans a great variety of landscapes, with a land area of approximately 134,000 square kilometres and 12,000 square kilometres of Sea Country. The Burdekin River catchment is the second biggest in the state and is the main catchment in the region, along with the adjoining smaller coastal catchments of the Don River, Haughton River, Ross River and Crystal Creek at the most northern extent.

In situ water quality monitoring was conducted in six sites, sampled seven times per year during ambient conditions. Seagrass was monitored at four locations in the late wet and late dry seasons, while corals were monitored in 15 sites in the dry season (Figure 21).

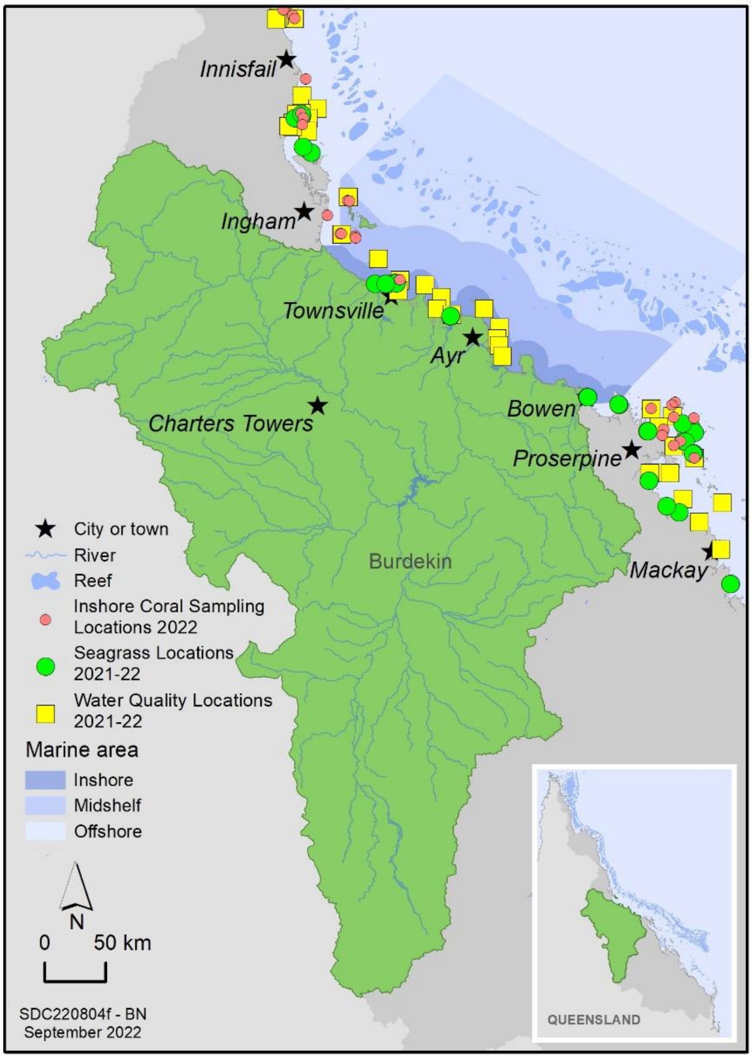

Figure 21. Map showing sampling locations in the Burdekin region. Note that water quality sites shown include flood event monitoring sites in addition to routine monitoring sites.

Environmental conditions

The combined discharge and loads calculated for the 2021–22 monitoring year from the Burdekin and Haughton basins were around 1.2 times the long-term median, after a very low discharge year in 2020–21. Wet season rainfall across the Burdekin basins was below the long-term average, but there was elevated rainfall in May 2022.

The Burdekin region experienced the highest thermal stress in the 2021–22 monitoring year, with sea-surface temperatures well above average. Inshore areas around Townsville had the highest heat stress accumulation, with some areas reaching temperatures close to 3 degrees Celsius above average and accumulating up to 140-degree heating days.

Water quality

The Annual Condition Water Quality Index for the Burdekin region scored ‘moderate’ for the 2021–22 monitoring year (Figure 22), which was similar to 2020–21.

The total discharge for the Burdekin region was 1.2 times the long-term median. It is noteworthy that dry and wet season results did not show significant seasonal difference, primarily driven by heavy rainfall and large discharge events in the early dry season, May 2022 (Moran *et al*. 2023).

Key results:

- Chlorophyll *a* concentration, PP, and PO_4 met the water quality guideline values and continue to improve.
- NO_x exceeded the guideline values but is also showing an improving trend over the past few years.
- Secchi depth did not meet the minimum guideline values but has been stable over the past two monitoring seasons.
- Flood plumes and terrestrial runoff affected mainly enclosed coastal areas of Burdekin.
- Area of the Burdekin region exposed to a potential risk reduced by 5 per cent from 2020–21 to 2021–22 monitoring years, representing a total area exposed to any potential risk to 42,976 square kilometres.

The Long-term Water Quality Index for the Burdekin region showed early signs of improvement this year after a gradual decline in condition since 2010.

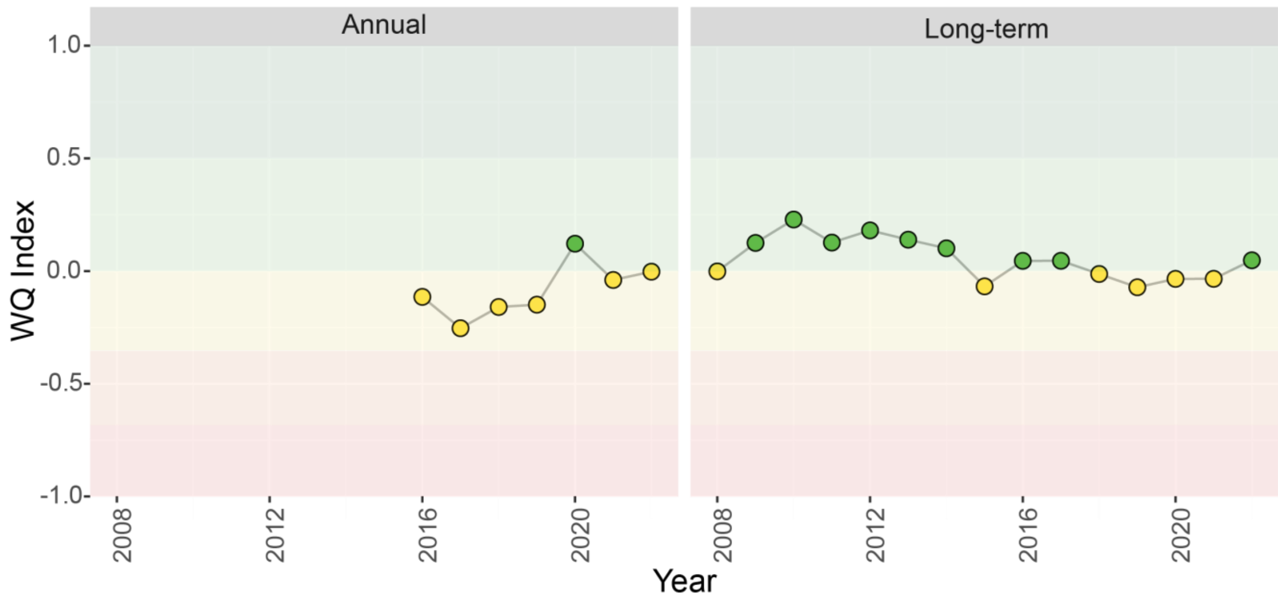

Figure 22. Temporal trends in the Annual and Long-term Water Quality Indices for the Burdekin region. Note that the annual index is based on the post-2015 MMP sampling design and is sensitive to year-to-year variability, whereas the long-term index is based on the pre-2015 review, and it is insensitive to year-to-year variability.

Seagrass

Overall seagrass condition remained unchanged from the previous year, and condition remained 'moderate' for both indicators informing the Seagrass Condition Index (Figure 23).

Seagrass abundance increased slightly. The low abundances at some sites were likely the legacy from the losses observed in 2019, due to heavy rainfall and flooding of the Burdekin River coupled with unusually large discharges from the smaller creeks and rivers entering Cleveland Bay.

Seagrass resilience reduced marginally but remained 'moderate'. Patterns of resilience were inconsistent among habitat types. For example, in coastal intertidal habitats reproductive effort declined but remained around average levels and seed density in the seed bank was the highest on record. This occurred late in the wet season. Reproductive effort and seed banks remained very low in reef intertidal habitats and were absent in subtidal habitats.

Since monitoring was established, seagrass meadows of the Burdekin region have demonstrated high resilience particularly through their capacity for recovery. This may reflect a conditioning to disturbance (large seed bank and high species diversity) but may also reflect the nature of the disturbances, which are episodic and dominated by wind events and Burdekin River flows.

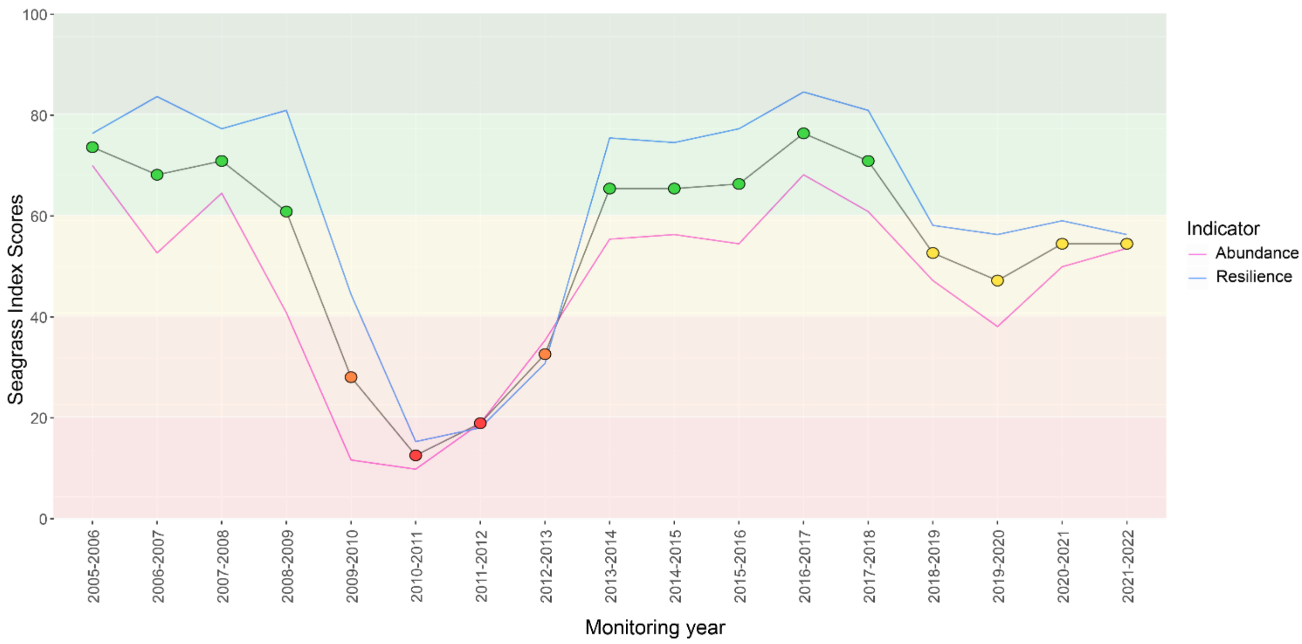

Figure 23. Seagrass Condition Index scores for the Burdekin region from 2005–06 to 2021–22. Black line with circles represents the index score and values are scaled from 0–100 and graded: ■ = very good (81–100), ■ = good (61–80), ■ = moderate (41–60), ■ = poor (21–40), ■ = very poor (0–20). Blue and pink lines represent the indicators that inform the Seagrass Condition Index score. Note, scores are unitless. Data source: McKenzie *et al.* 2023.

Coral

The Coral Index remained in the 'moderate' condition range, having declined from a peak in 2019–2020 (Figure 24). The primary pressure to have influenced coral communities between 2020–21 and 2021–22 surveys was a marine heat wave during early 2022. Although surveys in 2022 were undertaken over the dry season in June and July, bleached or partially bleached corals were observed at most reefs.

The Coral Index score has fluctuated between 'moderate' and 'poor' since the start of the MMP. The slight decline from the 2020–21 monitoring year was driven primarily by declines in scores for macroalgae and juvenile coral. Coral cover has improved, which captures the ongoing recovery of hard coral communities following a period punctuated by high discharge from the region's catchments and exposure to physical damage from storms and cyclones between 2009 and 2012 (Thompson *et al*. 2023). The cover change indicator score for the region has remained 'moderate' with a slight upward trend indicating recovery from the 2020 bleaching event and an ongoing positive balance between losses and gains in cover in 2021–22.

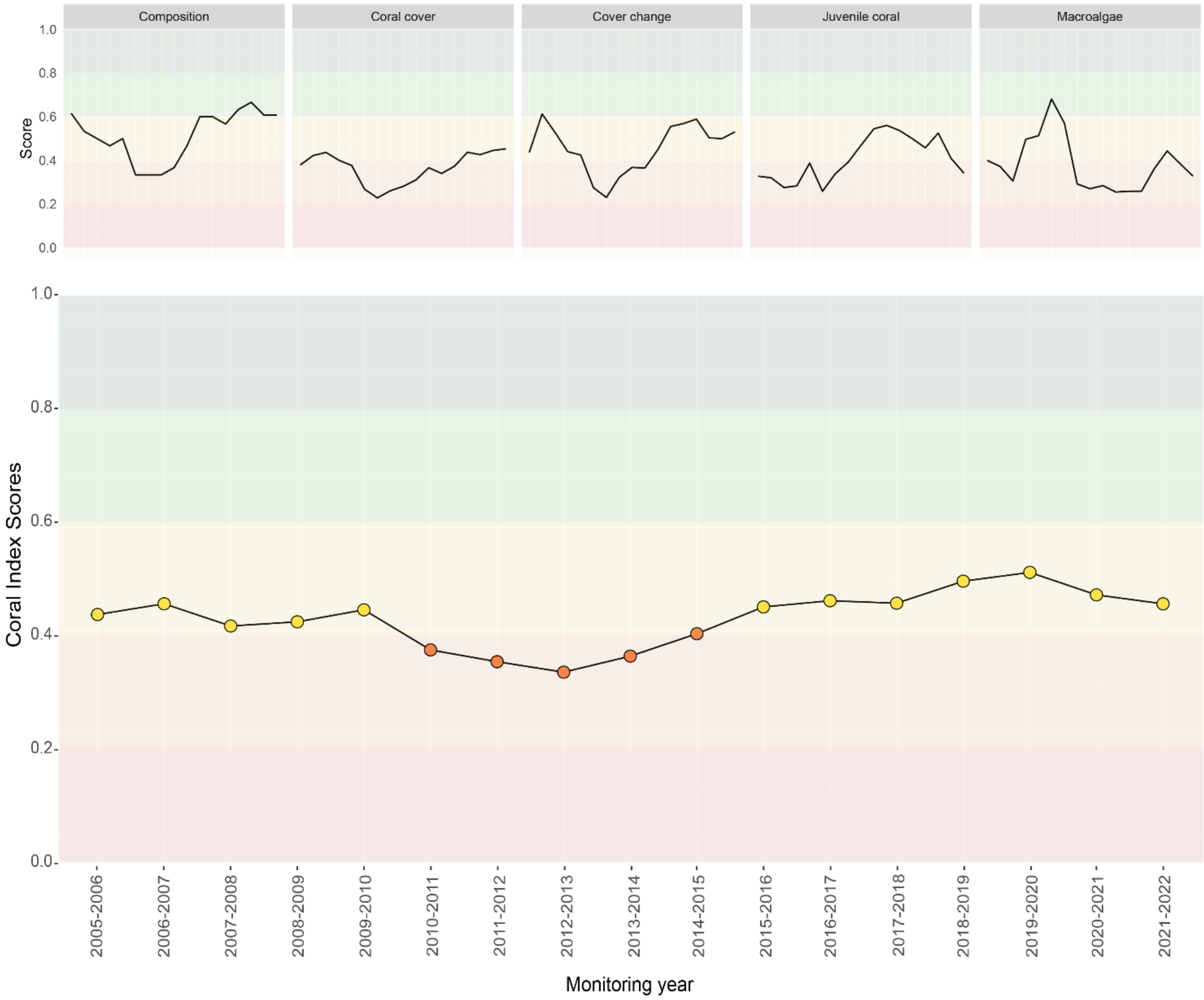

Figure 24. Temporal trend in Coral Index scores for the Burdekin subregion from 2005–06 to 2021–22. Values are indexed scores scaled from 0.0–1.0 and graded: ■ = very good (0.81–1.00). ■ = good (0.61–0.80), ■ = moderate (0.41–0.60), ■ = poor (0.21–0.40), ■ = very poor (0.00–0.20). Note, scores are unitless. Data source: Thompson *et al*. 2023.

Mackay-Whitsunday

The Mackay-Whitsunday region comprises an area of 9,300 square kilometres and extends from south of Bowen to Clairview. The region extends from the western boundary of the Clarke Connors Range, shrouded in high altitude rainforests, across the expansive cane fields and grazing lands of the coastal lowlands (Reef Catchments 2014). The region comprises four major river basins, the Proserpine, O'Connell, Pioneer and Plane basins. It is also potentially influenced by runoff from the Fitzroy River during extreme events or through longer-term transport and mixing (Lønborg *et al*. 2016).

In situ water quality was monitored in five sites under ambient conditions up to five times a year. Seagrass condition was monitored in 10 locations up to twice a year, once in the late dry season and once in the late wet season. Coral communities were assessed in seven sites at two and five metres in the dry season by the MMP, and a further two sites by the Long-Term Monitoring Program (Figure 25).

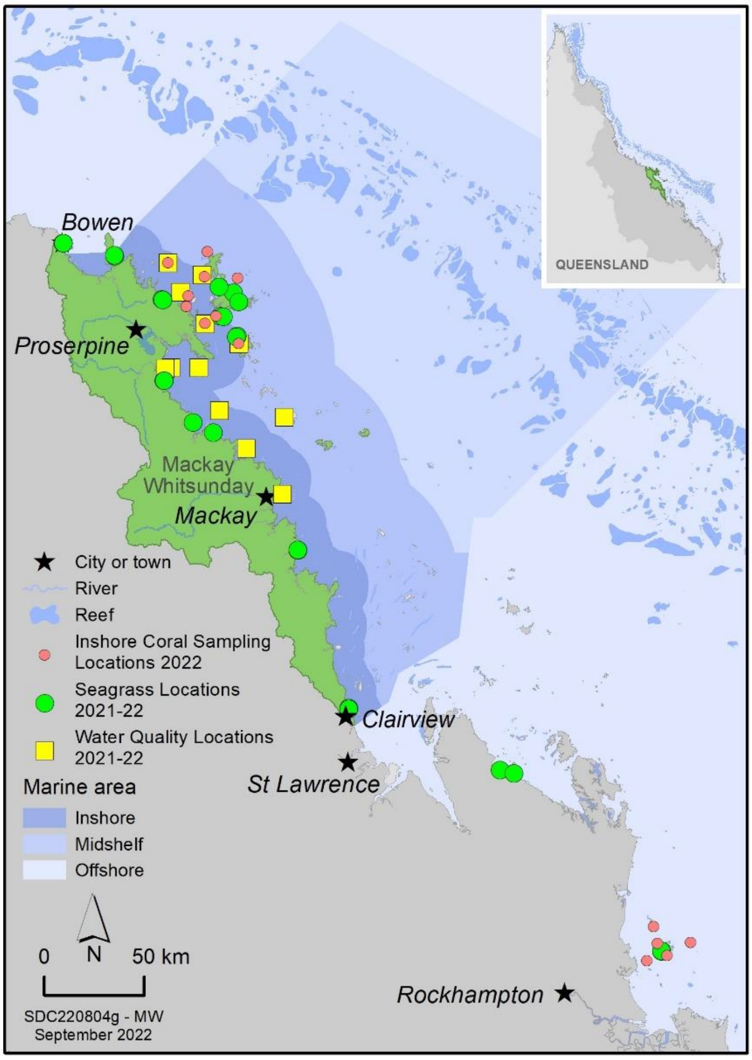

Figure 25. Map showing sampling sites in the Mackay-Whitsunday region. Note that water quality sites shown include flood event monitoring sites in addition to routine monitoring sites.

Environmental conditions

The combined discharge and loads calculated for the 2021–22 monitoring year from the Proserpine, O'Connell, Pioneer and Plane rivers were around half of the long-term median values, and were among the lowest recorded over the past decade. Wet season rainfall across the Mackay-Whitsunday region was below the long-term average for the third year in a row.

Sea-surface temperature was above average, particularly in the inshore Mackay-Whitsunday region where temperatures were up to 3 degrees Celsius above average in January 2022.

Water quality

The Annual Condition Water Quality Index for the Mackay-Whitsunday region scored 'moderate' for the 2021–22 monitoring year (Figure 26), with a slight improvement since 2020–21.

The total discharge for the Mackay-Whitsunday region was around half of the long-term median values and were amongst the lowest recorded over the past decade (Moran *et al*. 2023)

Key results:

- Concentrations of five water quality variables (NO_x, PO_4, PP, Secchi depth and Chlorophyll *a*) did not meet guideline values.
- Concentrations of PN and TSS met guideline values.
- All water quality variables showed a trend of improvement or stability since 2017.
- The area exposed to a potential risk reduced from 21 per cent to 15 per cent. However, only 1 per cent of the region was in the highest exposure category.

The Long-term Water Quality Index has shown signs of improvement over the last two years, following a decline in condition since 2008.

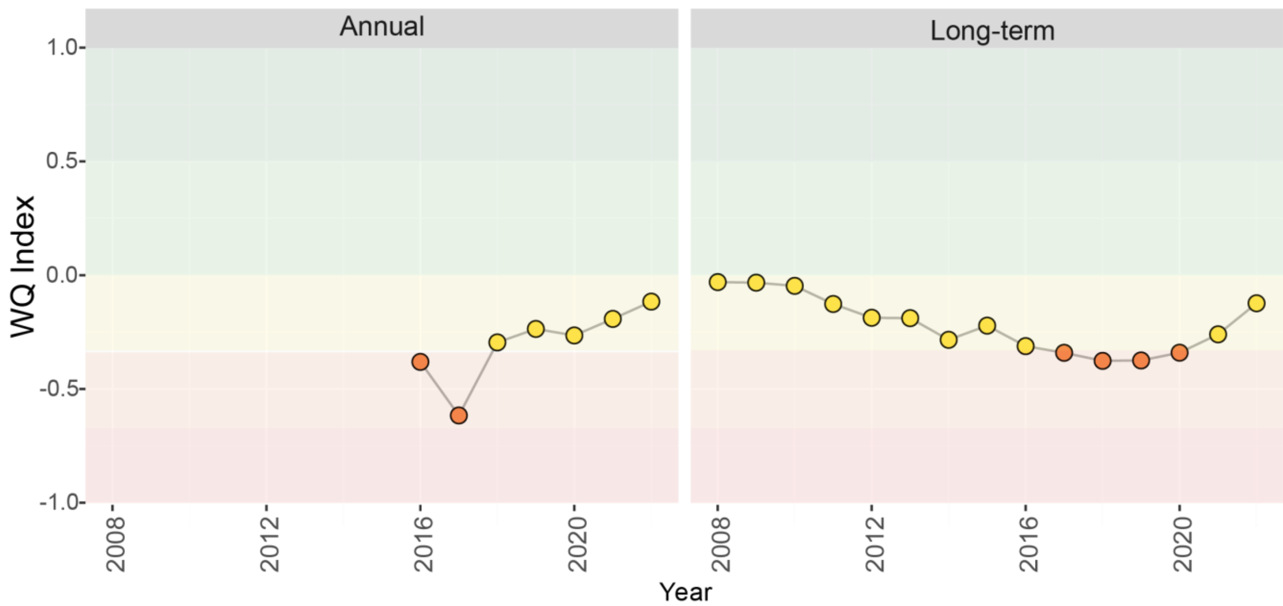

Figure 26. Temporal trends in the Annual and Long-term Water Quality Indices for the Mackay-Whitsunday region. Note that the annual index is based on the post-2015 MMP sampling design and is sensitive to year-to-year variability, whereas the long-term index is based on the pre-2015 review, and it is insensitive to year-to-year variability.

Seagrass

Inshore seagrass meadows across the Mackay-Whitsunday region improved in overall condition in 2021–22 to 'moderate'. Nevertheless, abundance scores remained 'poor', while the 'resilience' indicator increased to 'moderate' (Figure 27).

The seagrass abundance score decreased slightly again in 2021–22, with losses at 40 per cent of sites. There were small increases and small declines in abundance at sites within all habitat types, with overall declines in coastal intertidal habitats and reef subtidal habitats.

The overall resilience score for the Mackay-Whitsunday region was moderate following a substantial improvement from 'poor' in 2020–21. The resilience score increased at several sites. There were large improvements in resilience at reef intertidal habitats where reproductive structures were observed for the first time and at subtidal habitats. Despite these improvements in the resilience score, seed banks declined to the lowest levels since 2010–11 at estuarine sites and since 2013–14 in coastal habitats, and remained absent in reef habitats.

Up until 2016–17, the Mackay-Whitsunday regional seagrass condition had been improving from 2010–11, when it reached its lowest level since monitoring commenced. After this time, the recovery trend abated and dropped to 'poor' as a consequence of Tropical Cyclone Debbie in March 2017. Since then, the index has fluctuated between 'poor' and 'moderate' with recovery fluctuating across the region. Based on the long-term trend, it seems that the recovery potential of seagrass in this region is being undermined by a combination of local pressures and chronic impacts.

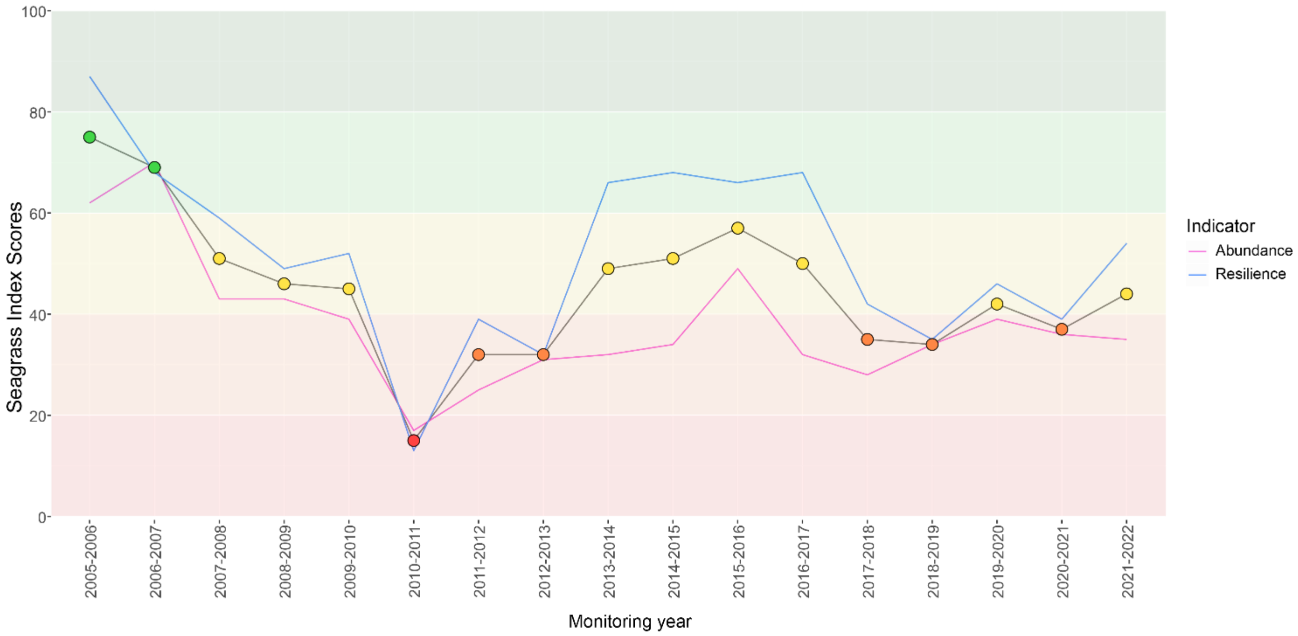

Figure 27. Seagrass Condition Index scores for the Mackay-Whitsunday region from 2005–06 to 2021–22. Black line with circles represents the index score and values are scaled from 0–100 and graded: ■ = very good (81–100), ■ = good (61–80),

= moderate (41–60), = poor (21–40), = very poor (0–20). Blue and pink lines represent the indicators that inform the Seagrass Condition Index score. Note, scores are unitless. Data source: McKenzie *et al.* 2023.

Coral

The Coral Index score remained ‘poor’, even though a slight increase in condition can be observed as the region slowly recovers after Tropical Cyclone Debbie in 2017 (Figure 28). Major improvements were detected in the juvenile coral indicator, which is now within the ‘moderate’ range, while all other indicators remain in the ‘poor’ range.

Persistent high turbidity resulting in limited light availability and accumulation of fine sediment hinders growth of fast-growing corals, particularly at 5 metre sites. Consequently, coral cover and cover change indicators, which are influenced by losses or growth of fast-growing *Acroporidae* corals, continue in the ‘poor’ range. Nevertheless, these scores show an upward trend.

Finally, macroalgal cover has increased at most sites, which drove the macroalgae indicator score down between 2020–21 and 2021–22 monitoring years.

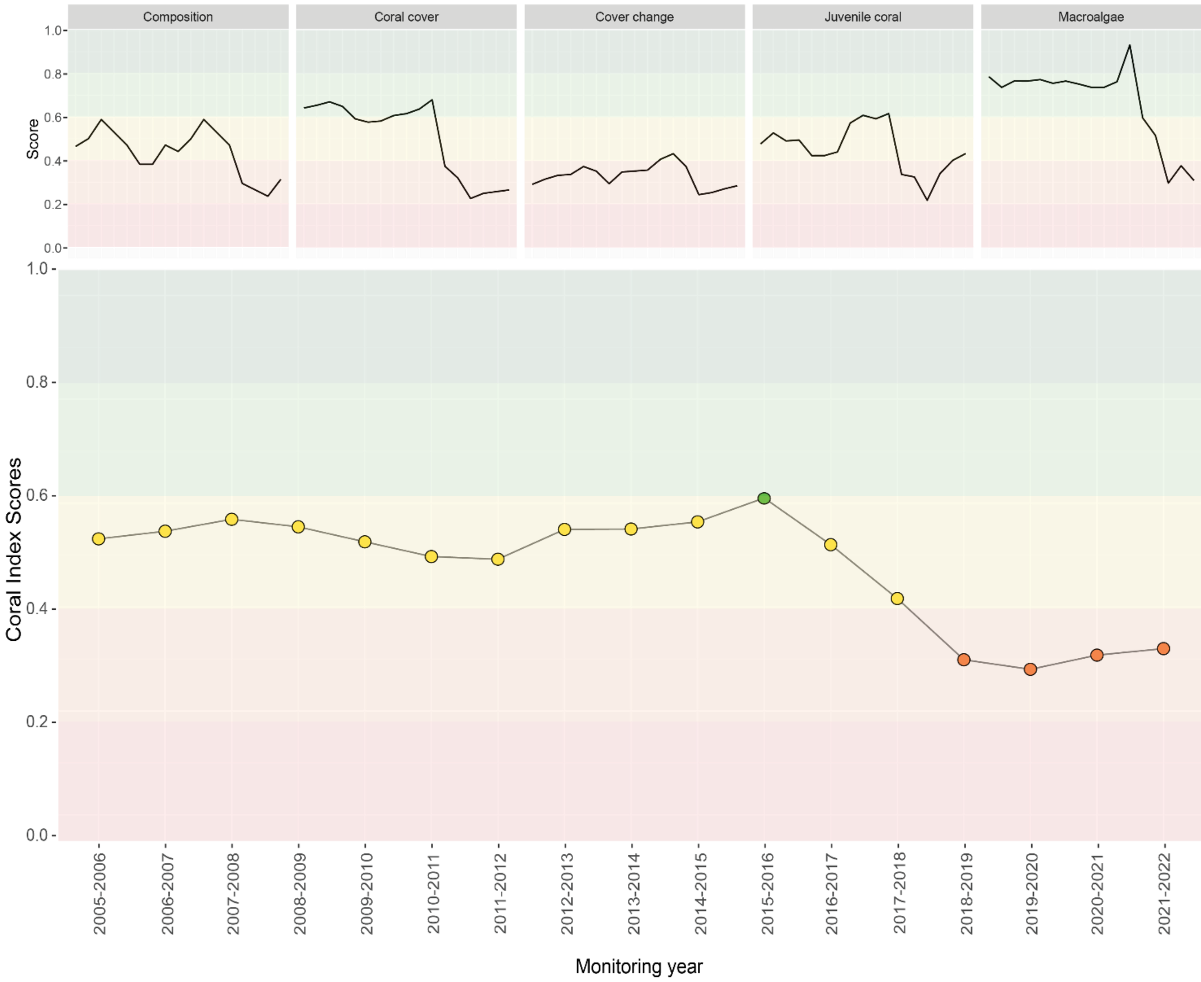

Figure 28. Temporal trend in Coral Index scores for the Mackay-Whitsunday region from 2005–06 to 2021–22. Values are indexed scores scaled from 0–1 and graded: = very good (0.81–1.00), = good (0.61–0.80), = moderate (0.41–0.60), = poor (0.21–0.40), = very poor (0.00–0.20). Note, scores are unitless. Data source: Thompson *et al.* 2023.

Fitzroy

The Fitzroy region is the largest NRM region by area in the Great Barrier Reef. It covers most of what is known as Central Queensland. The principal city is Rockhampton, with Gladstone and Emerald as other major cities (Figure 29). It covers approximately 158,000 square kilometres, of which 117,000 square kilometres are land used for agricultural production. Fitzroy is the largest river catchment within the Reef region and all water run-off flows into the Fitzroy River and eventually into the Reef lagoon (Lewis *et al*. 2021).

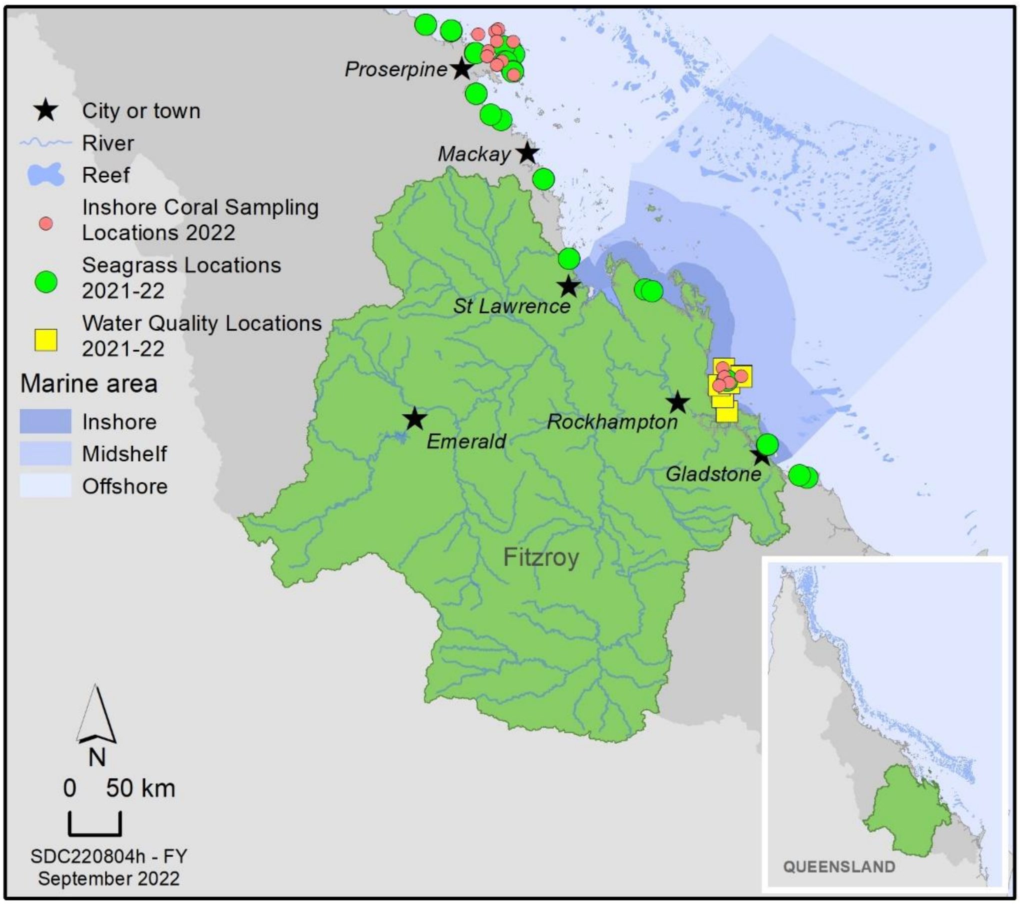

Figure 29. Map showing sampling sites in the Fitzroy region. Note that water quality locations are monitored by the Fitzroy Basin Marine Monitoring Program.

Environmental conditions

In the 2021–22 monitoring year, river discharge from the Fitzroy River was more than 1.5 times the annual median and exposure to turbid water (Reef WT1 and WT2) was above the long-term average (Moran *et al*. 2023).

Sea-surface temperature was above average, but heat stress was not as severe as in the northern parts of the inshore Reef.

Water quality

The MMP monitored water quality in the region from 2005 to 2014. Monitoring in the region ceased in 2015. However, since 2020 water quality monitoring has been conducted by the Fitzroy Basin Marine Monitoring Program for inshore water quality. This water quality program is funded in partnership by the Australian Government's Reef Trust and Great Barrier Reef Foundation, and the AIMS. Results can be found in Appendix A.

Seagrass

The Seagrass Condition Index score for the Fitzroy region remained 'poor' for the 2021–22 monitoring year and both indicators declined. Abundance declined to 'very poor' while resilience remained 'poor' (Figure 30).

Seagrass abundance declined at all locations and habitats on average across the region in 2021–22. The largest declines were in the coastal habitats in Shoalwater Bay. Meadow extent declined to the lowest level since monitoring began at the estuarine sites in Gladstone Harbour. Abundances remained very low at the reef intertidal sites. However, there was an increase in the proportion of foundational species, which are persistent and aid recovery of a meadow, to the highest level on record.

Overall resilience in the Fitzroy region was 'poor' but the trend varied among habitats and sites. Resilience declined slightly in estuarine habitats in Gladstone. At coastal habitats, resilience declined sharply at one site, but increased at the other to the highest level in 12 years due to an increase in reproductive effort. In reef intertidal habitat, resilience increased to the highest level in 13 years at one site due to an improvement in species composition, but declined at the other.

Inshore seagrass meadows across the region continued to decline for the second year in a row. This follows a gradual recovery from 2012–13 to 2019–20 from multiple years of climate-related impacts which, like Mackay-Whitsunday, are more recent than in other regions. There are local-scale impacts and processes that are driving declines in indicators at some sites, while others within the same habitat improve. The Fitzroy region also has the fewest number of sites, so changes in one site can have a greater influence on the score compared with other regions.

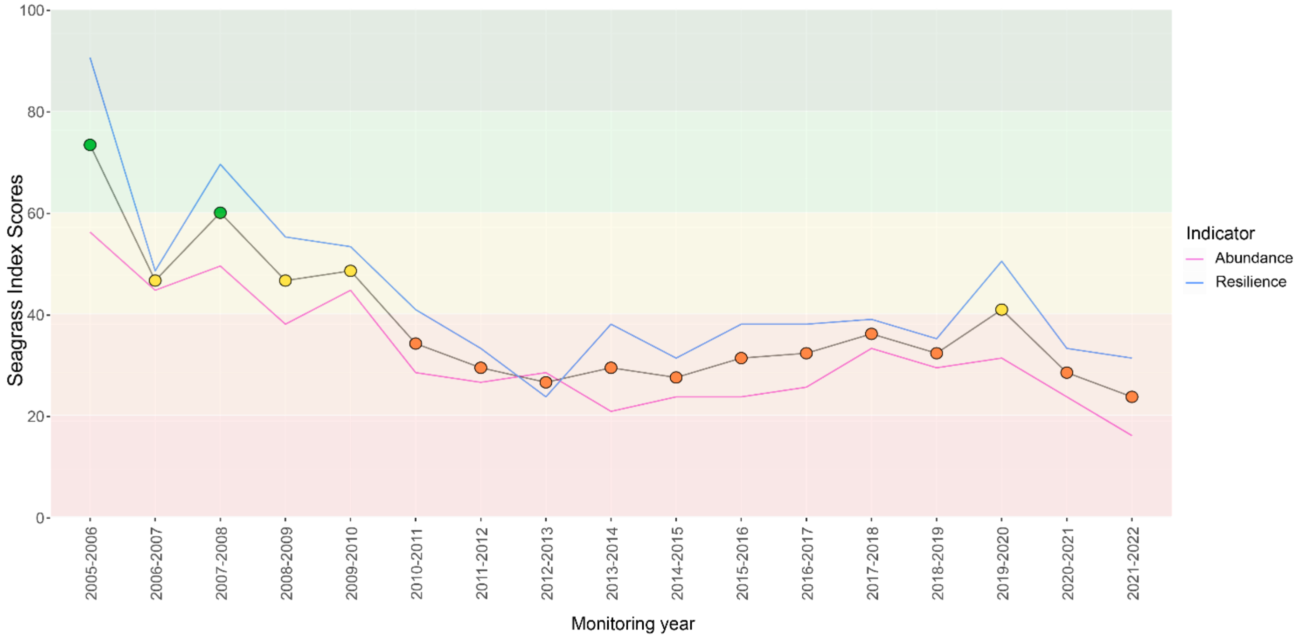

Figure 30. Seagrass Condition Index scores for the Fitzroy region from 2005–06 to 2021–22. Black line with circles represents the index score and values are scaled from 0–100 and graded: ■ = very good (81–100), ■ = good (61–80), ■ = moderate (41–60), ■ = poor (21–40), ■ = very poor (0–20). Blue and pink lines represent the indicators that inform the Seagrass Condition Index score. Note, scores are unitless. Data source: McKenzie *et al*. 2023.

Coral

The Coral Index score in the Fitzroy region remains 'poor' despite resuming the general improvement in scores since 2014, when the index score dipped into the 'very poor' range (Figure 31).

Across the region, coral cover and cover change indicators were in the 'moderate' range. These two indicators were the most influential in the increase in the Coral Index from 2020–21 to 2021–22. The improvement in the cover change score is noteworthy as this is the first time since 2009 that the rate of coral cover increase has reached modelled expectations over the four-year running mean. It has occurred during a period without major flooding of the Fitzroy. However, the continued 'very poor' score for macroalgae and the further decline in juvenile coral demonstrate ongoing impediments to the resilience of coral communities.

Figure 31. Temporal trend in Coral Index scores for the Fitzroy region from 2005–06 to 2021–22. Values are indexed scores scaled from 0–1 and graded: ■ = very good (0.81–1.00), ■ = good (0.61–0.80), ■ = moderate (0.41–0.60), ■ = poor (0.21–0.40), ■ = very poor (0.00–0.20). Note, scores are unitless. Data source: Thompson *et al*. 2023.

Burnett-Mary

The Burnett-Mary region covers an area of approximately 56,000 square kilometres of land and 11,000 square kilometres of sea, and includes the major coastal towns of Bundaberg, Hervey Bay, and Maryborough (Figure 32). The adjacent coastal area, from north to south, includes the Baffle, Kolan, Burnett, Burrum and Mary River catchments and the northern part of the Noosa River catchment. The predominant land use in these catchments is grazing and forestry is the second most common land use (Coppo *et al*. 2014).

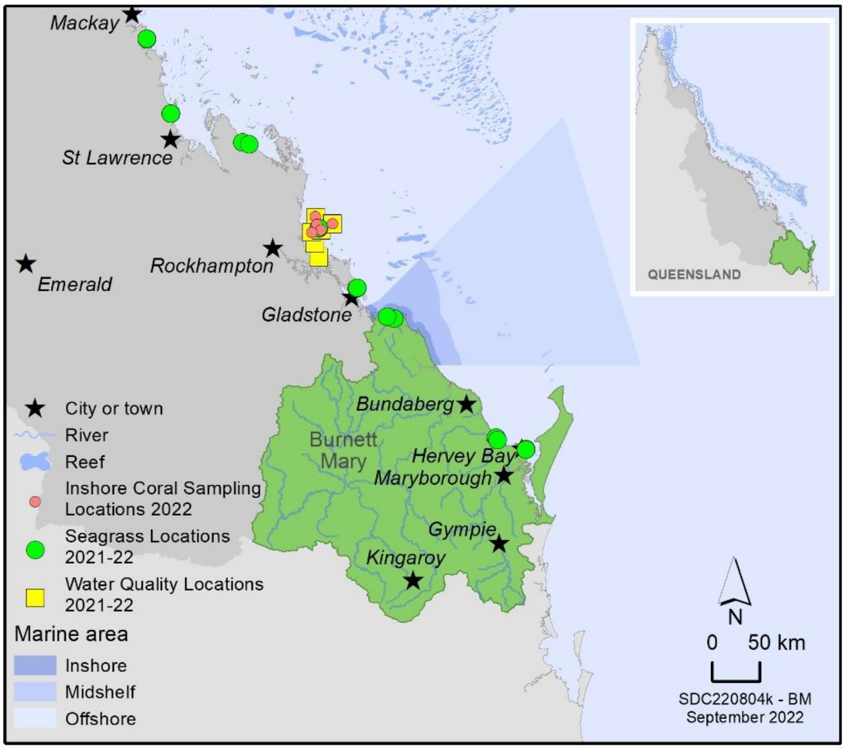

Figure 32. Map showing sampling sites in the Burnett-Mary region.

Environmental conditions

Extreme weather events affected the Burnett-Mary region in the 2021–22 monitoring year. Annual river discharge was nine times greater than the long-term median and was affected by late periods of elevated rainfall in May 2022, after the wet season.

Sea-surface temperatures were slightly warmer than the long-term average, however intertidal temperatures were higher than the previous monitoring period (McKenzie *et al*. 2023). Maximum intertidal within-canopy temperature exceeded 35 degrees Celsius for a total of 12 days, representing a four-fold increase over the 2020–21 monitoring year.

Water quality

The MMP does not conduct *in situ* water quality monitoring in the Burnett-Mary region.

Seagrass

The Seagrass Condition Index score declined in the 2021–22 monitoring year but remained in the ‘poor’ range. Abundance and resilience indicators declined as well (Figure 33).

The seagrass abundance indicator declined to a ‘very poor’ grade for the first time since 2013–14. Abundances declined in both estuarine and coastal habitats, in a trend continuing since 2015–16 in estuarine habitats and since 2019–20 in coastal habitats. Meadow spatial extent in estuarine habitats also declined to the lowest level since 2008.

The resilience indicator declined to ‘poor’ overall due to a large change in resilience in the coastal meadows at Burrum Heads, where abundance fell below the threshold indicative of low resistance and there were no reproductive structures observed. In contrast, resilience improved slightly at estuarine sites, where the score was buoyed by flowering in recent years, which indicates capacity to have formed a seed bank. However, seeds had been depleted at estuarine sites by late in the wet season of 2021–22.

The decrease in the Seagrass Condition Index in 2021–22 to the second lowest on record was based on surveys prior to elevated discharge in March when further declines were likely to have occurred in vulnerable meadows. The region has a history of variable seagrass condition but has shown a reasonable capacity for recovery following extreme events.

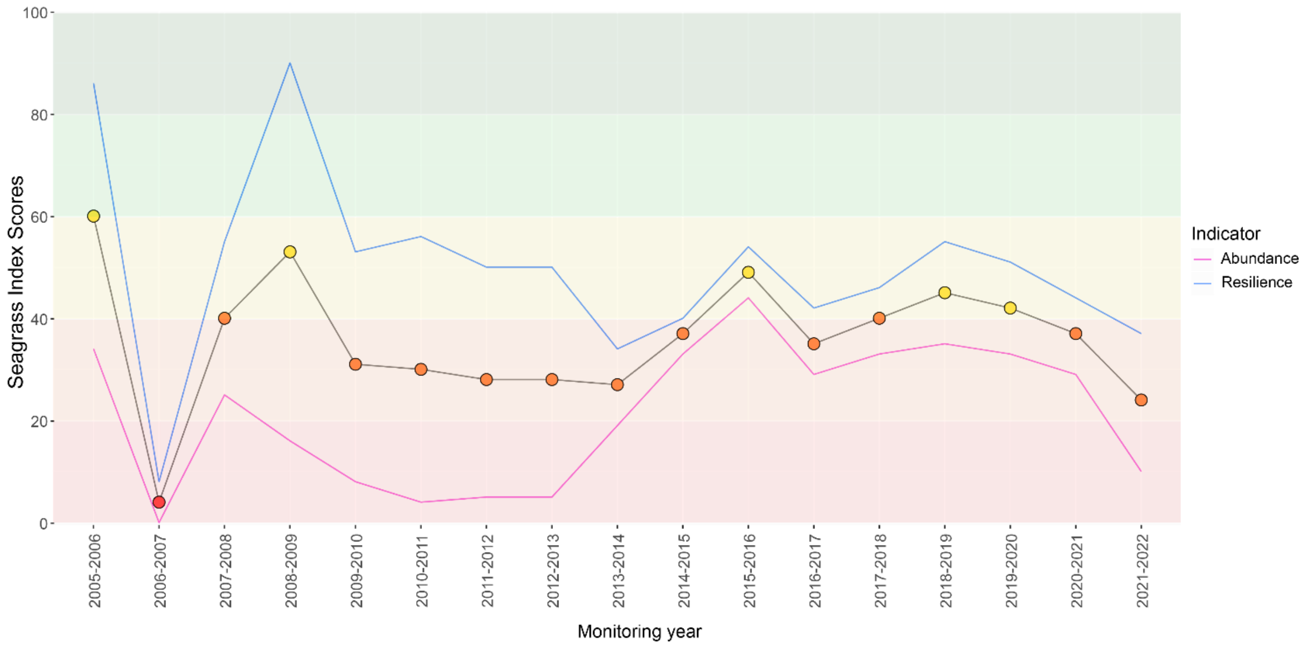

Figure 33. Seagrass Condition Index scores for the Burnett-Mary region from 2005–06 to 2021–22. Black line with circles represents the index score and values are scaled from 0–100 and graded: ■ = very good (81–100), ■ = good (61–80), ■ = moderate (41–60), ■ = poor (21–40), ■ = very poor (0–20). Blue and pink lines represent the indicators that inform the Seagrass Condition Index score. Note, scores are unitless. Data source: McKenzie *et al.* 2023.

Coral

The MMP does not conduct inshore coral monitoring in the Burnett-Mary region.

Flood monitoring

Flood event monitoring is an integral part of the MMP and is built into the water quality sub-program. The MMP assesses the magnitude, extent and duration of flood plumes, particularly following extreme events, such as heavy rainfall and cyclones. It allows a better understanding of the levels of flood influence on water quality. It also enables the Great Barrier Reef Marine Park Reef Authority and broader government to be kept up-to-date on any flood events that may affect the inshore marine ecosystem.

The 2021–22 monitoring year was marked by several reactive flood monitoring campaigns, including heavy rainfalls in late April to early May, resulting in an unseasonal wet start to the dry season. Heavy rainfall and flood plumes were mostly detected in the northern part of the Marine Park.

Cape York

Pascoe River

Most of rainfall for the Pascoe region in the 2021–22 monitoring year occurred over one major flood event from 15 to 26 April 2022. No targeted flood monitoring was conducted during the April event due to access issues. Satellite images were cloudy during the event, however a turbid plume was seen to reach over 20 kilometres to the north on 29 April.

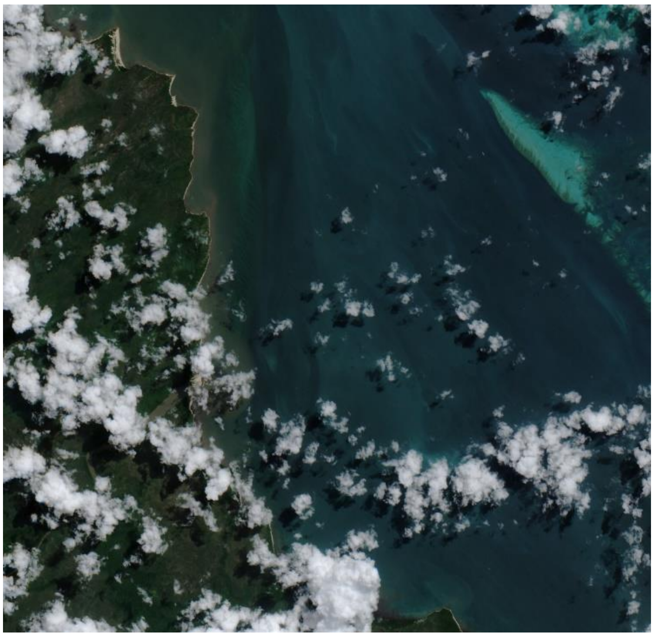

Figure 34. Sentinel-2 true colour satellite image showing flooding from the Pascoe River on 29 April 2022. Source: Sentinel Hub EO Browser, downloaded by Dr Caroline Petus, JCU TropWater. Extracted from Moran *et al*. 2023.

Normanby River

The largest flood event for the Normanby Basin over the 2021–22 wet season occurred in mid-February and was a below average magnitude flood event. The resulting flood plume, combined with flood water from the Stewart River and other coastal inlets, was estimated to have inundated over 3,500 square kilometres, including reefs in the midshelf and offshore waterbodies (based on MODIS Terra and Aqua satellite images).

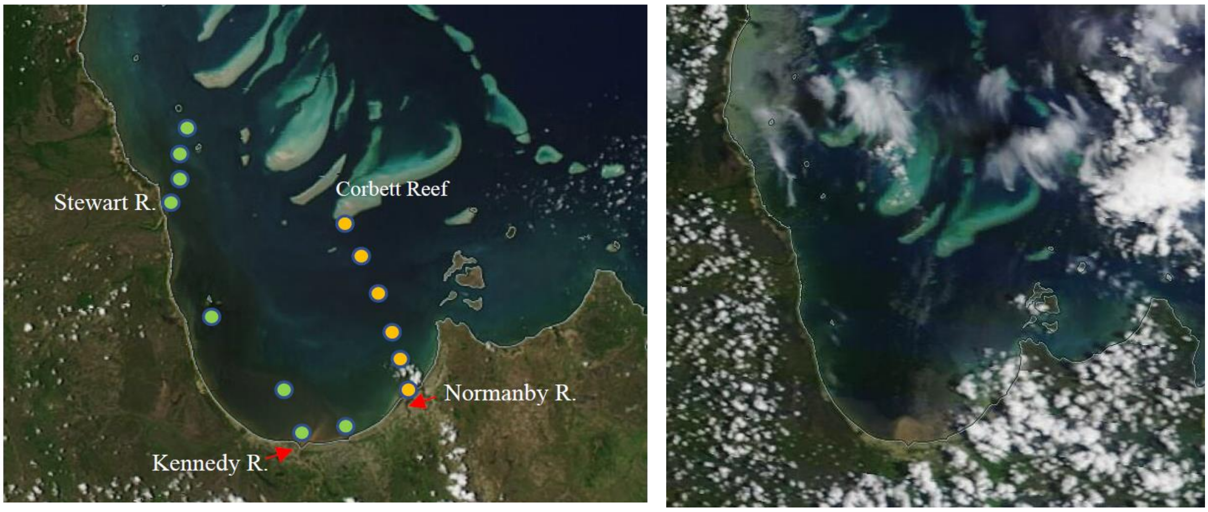

Figure 35. Satellite image of Kennedy and Normanby river flood plume on 10 February (left) and 12 February 2022 (right). Sampling occurred across the Stewart and Normanby transects on 11 and 12 February. Source: NASA MODIS Aqua and Terra.

Annan-Endeavour Rivers

The 2021–22 wet season saw slightly above average rainfall in the Endeavour Basin, with several minor floods. Most of the rain and river discharge occurred during one event in April 2022. Flood event monitoring occurred along the Annan and Endeavour transects during the first (relatively minor) event of the wet season (11 January 2022) and again during the largest event of the year on 26 April 2022.

Satellite images and water quality samples from the April 2022 flood event showed that the flood plume flowed north, inundating reefs in the midshelf waterbody, including Forrester Reef, approximately 30 kilometres to the northeast of the Endeavour River mouth.

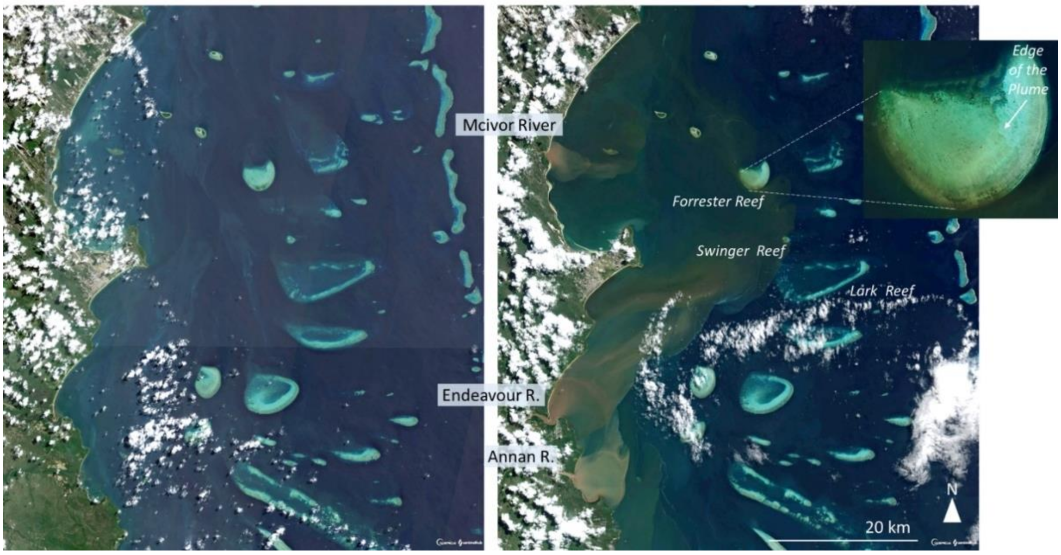

Figure 36. Sentinel-3 EO hub satellite images showing flooding from the Annan and Endeavour rivers on 26 April 2022 (right) compared with ambient conditions before the flood on 6 April 2022 (left). Source: Sentinel-3 EO Hub downloaded by Caroline Petus, James Cook University/TropWATER. Images extracted from Moran *et al*. 2023.

Wet Tropics

Tully River

The Tully River had three flow events that exceeded the minor flood level over the 2021–22 monitoring year. The largest event peaked at 7.4 metres, just below the moderate flood level of 8.0 metres on 26 April 2022. This flood plume was subject to event sampling two days after this peak.

Sites along the Tully transect were sampled and the salinity profiles showed the increasing influence of the river flood plume in the upper ~5 metres of the water column at sites closest to the river mouth. The Tully flood plume was observed to be restricted to the inshore waters and moving northwards along the coast.

Burdekin

Haughton River

The Haughton River had two flow events that exceeded the moderate flood level over the 2021–22 monitoring year. The first event peaked at 6.77 metres on 26 April 2022. The second event peaked slightly higher at 6.84 metres 11 May 2022. Flood plume event sampling was undertaken two days after this peak.

Burdekin River

There was one high flow event that peaked at 7.5 metres on 15 May 2022, just below the minor flood level (9.0 metres at the Calre gauge site). The event caused flooding above minor and moderate flood levels in some of the upstream tributaries of the Burdekin River. However, the plume stayed relatively close to the coast. Flood monitoring was conducted across the Burdekin transect during this event.

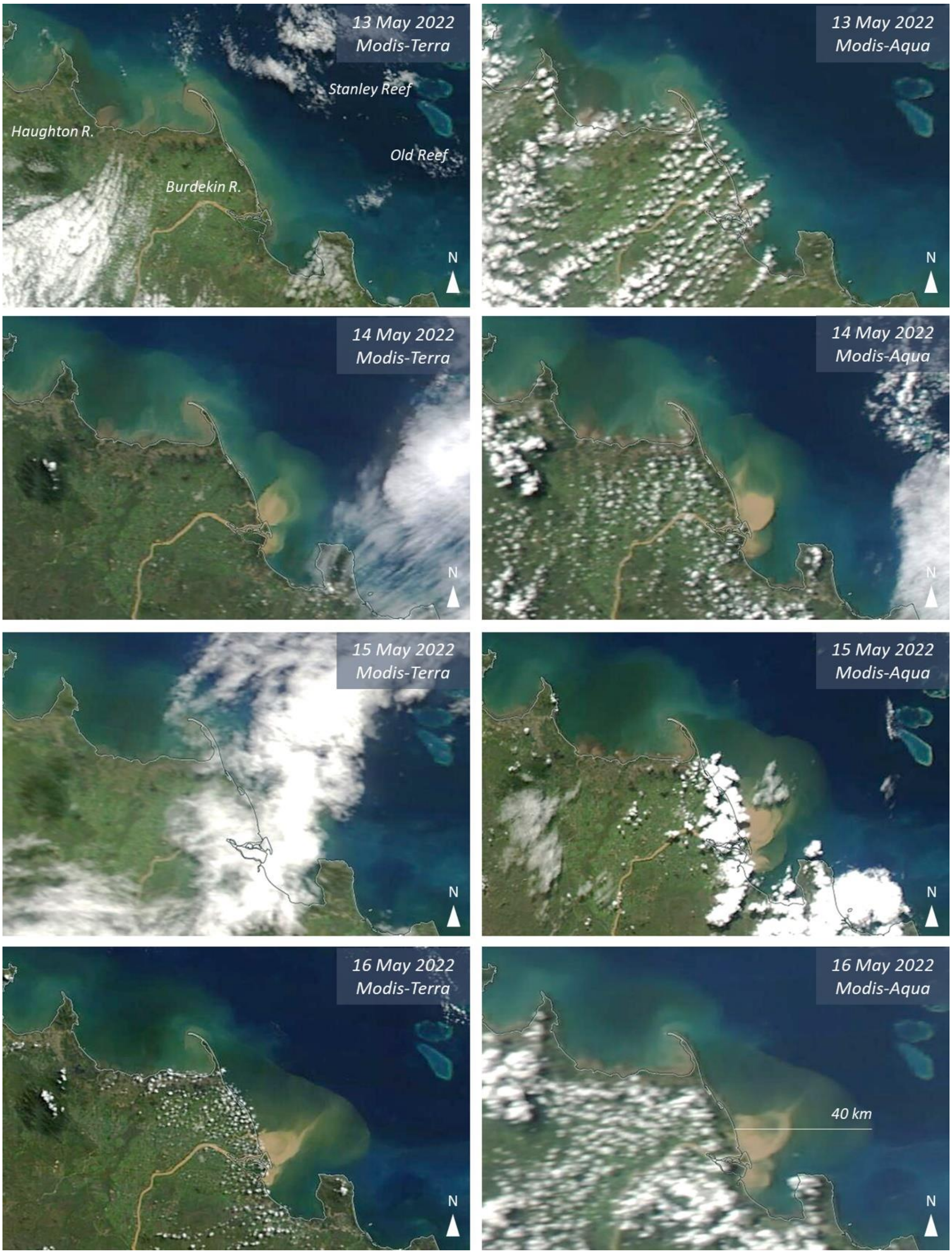

Figure 37. Satellite images showing flooding from the Burdekin and Haughton rivers. Source: MODIS Aqua and Terra downloaded by Caroline Petus, James Cook University/TropWATER. Extracted from Moran *et al*. 2023.

Discussion

Chronic poor water quality is regarded as one of the main issues negatively impacting the health of inshore ecosystems of the Reef (Great Barrier Reef Marine Park Authority 2019). Human pressure along the Queensland coast has increased disproportionately since European settlement, causing significant loss of diversity, habitat complexity and abundance of species in inshore ecosystems (Lewis *et al*. 2021). The Reef's current condition is the result of cumulative impacts of climate and other local pressures influenced by human activities, including agricultural runoff into the inshore region. However, the 2021–22 monitoring season showed some positive trends in the seagrass and coral indices in some regions, which provide an indication of the resilience of the Reef's habitats.

Inshore water quality and the condition of seagrass and corals have largely improved or remained unchanged from the previous monitoring year. However, there were regional differences detected for coral and seagrass. Seagrass condition improved in northern and central regions, while southern regions experienced a significant decline in both resilience and abundance. In contrast, condition of coral has slightly declined in the Wet Tropics and Burdekin regions, while positive signs of recovery were reported in the Mackay-Whitsunday and Fitzroy regions.

Coral condition and trend

The 2021–22 monitoring year showed that the condition of inshore coral communities have remained relatively stable or, where condition was poor, were showing signs of slow recovery. The southern regions of Mackay-Whitsunday and Fitzroy both saw increased coral index scores. In the Fitzroy Region the improvement in the cover change indicator score is noteworthy. It is the first time since 2009 that the rate of coral cover increase has reached modelled expectations over the four-year running mean on which the score is based (Thompson *et al*. 2023). Good water quality in recent years (Moran *et al*. 2023) likely contributed to recovery of coral communities in the Fitzroy region.

In the Mackay-Whitsunday region, coral communities are beginning to recover from the long-lasting impacts of severe Tropical Cyclone Debbie, which severely impacted the region in 2017 (Bureau of Meteorology 2017). Following cyclone Debbie, high turbidity coupled with high rates of sedimentation resulted in unsuitable conditions for the recruitment of some corals, particularly at deeper sites (Thompson *et al*. 2023). The improvement in juvenile coral indicator scores in recent years is a positive sign for the early recovery of coral communities at some sites. While positive signs of recovery of coral communities have been observed since the 2020–21 monitoring year, persistence of macroalgae, which have colonized some severely impacted reefs, likely continue to limit the recovery potential at these locations. This persistence of macroalgae suggests that coral communities remain vulnerable to future disturbances.

In the Wet Tropics and Burdekin regions, coral communities have demonstrated the capacity to recover following severe loss of coral due to acute disturbances such as severe Tropical Cyclone Yasi in 2011. The rate of this recovery has, however, been suppressed during periods of high turbidity, such as in the Burdekin region after the 2019 floods, and by repeated exposure to marine heatwaves.

In general, coral monitoring results show that a range of pressures, including tropical cyclones, high sea water temperatures and outbreaks of crown-of-thorns starfish and diseases impact inshore coral communities and result in declines in coral scores. Importantly, the results also highlight that recovery from such events is likely to have been supressed due exposure to chronic stress imposed by poor water quality.

Seagrass condition and trend

Seagrass condition remained largely unchanged in the 2021–22 monitoring year, with improvements in condition in the northern and central regions and declines in the southern regions of Fitzroy and Burnett-Mary.

In the Wet Tropics, the overall score was the fourth highest on average since the start of the MMP in 2005. In the northern Wet Tropics, the abundance score increased to the highest on record and was a 'good' rating. In the southern Wet Tropics, the score has been on an increasing trend since 2012–13. However, in 2021–22 abundance declined a little and was 'poor', though resilience increased to 'moderate' with the highest score on record. There was elevated discharge in 2018–19, particularly in the far north of the region from the Daintree River, but otherwise environmental conditions were relatively benign in the Wet Tropics from 2010–11 to 2021–22. The exception is water temperature, which was elevated in 2021–22 and which continues a trend for warm within-canopy temperature anomalies to be more frequent than cool within-canopy temperature anomalies in the region. Otherwise, the relatively low-pressure conditions have supported recovery across the Wet Tropics (McKenzie *et al.* 2023). Healthy seagrass meadows provide habitats and foraging grounds for hundreds of fish species, turtles and dugongs. The meadows can quickly assimilate nutrients from the water column and trap sediments within the leaves, keeping the water column clear (Coles *et al.* 2015).

River discharge in the Burnett-Mary region was up to nine times above the regional long-term average, driven primarily by floods in the Mary River. Floods of this magnitude can result in reduced seagrass abundance and reproductive effort (McKenzie *et al*. 2021) and recovery of meadows depends on size of seed banks, reproductive efforts and species diversity. Over the last five monitoring years, reproductive effort has remained below the Reef-wide baseline. It further declined in the 2021–22 monitoring season with no reproductive structures reported from any monitoring site (McKenzie *et al*. 2023). The absence of reproductive structures is an indication that seeds are not being generated, which negatively impacts capacity to recover after disturbances and reduces resilience of meadows (Collier *et al*. 2021).

Sea-surface temperature in the 2021–22 monitoring year was above the long-term average for most of the Marine Park. Coral bleaching and mortality were observed in coral communities in the Burdekin region in July, indicating that if bleaching was more widespread, it was likely that corals in other regions potentially recovered their pigmentation by the time corals were surveyed. In seagrass habitats, region-wide within-canopy temperature was higher than average in the 2021–22 monitoring year, and all sites (except Burrum Heads) had higher than average temperature. While the negative biological impacts of extreme temperature are well-document in corals (Jurriaans *et al*. 2019, Schoepf *et al*. 2021), the chronic effects of rises in temperature are relatively unknown. This is especially the case for biological processes critical to resilience of seagrasses, such as flowering, seed development, viability and germination (McKenzie *et al*. 2023). Heat waves are predicted to become more common and rising sea-surface temperatures are likely to dominate the pressures on inshore Reefs (Hughes *et al*. 2021), resulting in a decrease in resilience of habitats to other pressures, such as poor water quality.

In addition to the pressure of rising sea-surface temperature, unseasonal (late) flood events in the 2021–22 monitoring year could potentially hinder recovery of ecosystems that have been under heat stress over the summer. During dry season months, communities of seagrass and corals often get a respite from the summer impacts, with cooler temperature and reduced influenced of land-based runoff. The unusual wet start of the dry season (in April and May) caused flooding in some of the northern rivers and produced extensive flood plumes that reached offshore reefs (for example, in Cape York). In the Burdekin region, the observed plumes mostly stayed close to the enclosed coastal areas. Sporadic, large flood events can heavily impact seagrass meadows and coral reefs after flooding by causing temporary loss of these ecosystems (McKenzie *et al*. 2023, Thompson *et al*. 2023). As a result, fecundity and recruitment on both ecosystems can decline following floods due to lingering elevation of sediment, higher nutrients concentrations and associated conditions, such as reduced light.

It is important for Reef managers to understand the difference between acute and chronic risks from poor water quality on the health and resilience of inshore ecosystems. Acute risks are usually linked to large flood events and result in extensive inshore seagrass and coral areas experiencing reduced salinity along with high turbidity and nutrient concentrations. These acute impacts occur during the wet summer months, when heat waves are also likely to happen. Therefore, there is the potential for cumulative impacts from local and global factors in the short-term. These acute impacts can turn into chronic risks, caused by high turbidity and low light levels maintained by wind-driven resuspension of fine sediments, which can settle on the seafloor after large flood events (such as after Tropical Cyclone Debbie in the Mackay-Whitsunday region) (Thompson *et al*. 2023).

The latest results presented here highlight that inshore ecosystems can benefit greatly from management actions that reduce chronic stress at local levels, such as improvements in water quality. Good water quality can contribute greatly to enhancing the resilience of inshore corals and seagrasses, particularly following acute climatic disturbances, such as marine heatwaves and severe storms.

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Glossary

Coral cover indicator	One of five indicators included in the calculation of the coral index, based on the level of coral cover derived from point intercept transects.
Cover change indicator	One of five indicators included in the calculation of the coral index, derived from a comparison of the observed change in coral cover observed *in situ* in periods free from disturbance, and the change in cover predicted by modelling, averaged over a four-year period. It is an indicator of the recovery potential of coral communities due to growth.
Coral index	Average score of the five coral indicators: coral cover, cover change, community, macroalgae and juvenile coral.
Composition indicator	One of five indicators included in the calculation of the coral index, which compares the composition of hard coral communities at each reef to a baseline composition at that reef. It is an indicator of selective pressures imposed by the environmental conditions at a reef.
Macroalgal indicator	One of five indicators included in the calculation of the coral index, which considers the proportional representation of macroalgae in the algal community, based on cover estimates derived from point intercept transects. It is an indicator of competition with corals.
Juvenile coral indicator	One of five indicators included in the calculation of the coral index, which is based on an estimate of the number of hard coral colonies that have successfully survived early life cycle stages, culminating in settlement and growth through to visible juvenile corals, which can replenish coral populations.
Ecosystem health	Ecological processes, biodiversity and function of biological communities is maintained.
Guideline value	A measurable quantity (e.g. concentration) or condition of an indicator for a specific community value below which (or above which, in the case of stressors) there is considered to be a low risk of unacceptable effects occurring to that community value. The water quality guideline values describe the concentrations of sediment, nutrients and pesticides that are needed for the protection and maintenance of marine species and the Reef's ecosystem health.
Inshore	The enclosed coastal and open coastal water bodies combined. These terms are defined and mapped under schedules in the *Environmental Protection (Water) Policy.*
MMP	Marine Monitoring Program
Marine Park	Great Barrier Reef Marine Park

NO_x	Nitrogen oxides (the sum of nitrate and nitrite)
NRM	Natural resource management
PN	Particulate nitrogen
PO_4	Phosphate (dissolved inorganic phosphorus)
PP	Particulate phosphorus
Pollutants	This synthesis report refers to suspended (fine) sediments, nutrients (nitrogen, phosphorus) and pesticides as ‘pollutants’. Within this report we explicitly mean enhanced concentrations of, or exposures to, these pollutants, which are derived from human activities (directly or indirectly) in the Great Barrier Reef ecosystem or adjoining systems (e.g. river catchments).
The Reef	Great Barrier Reef
Reef 2050 WQIP	Reef 2050 Water Quality Improvement Plan
Reef 2050 Plan	Reef 2050 Long-Term Sustainability Plan
Seagrass abundance indicator	One of three indicators included in the calculation of the seagrass index, measured using the median seagrass percentage cover relative to the site or reference guideline.
Seagrass condition index	Average score of the three seagrass indicators: abundance and resilience
Seagrass resilience indicator	Seagrass resilience is calculated based on sexual reproductive output is based on the number of reproductive structures observed (inflorescence, fruit, spathe, seed)
Secchi depth	A measure of the clarity of water based on the Secchi disk.
TSS	Total suspended solids
Water quality Long-term Index	Metric based on three indicators measured *in situ*: water clarity, productivity and particulate nutrients.
Water quality Annual Index	Metric based on five indicators measured *in situ:* water clarity, Chl-*a*, NO_x, PN and PP.
Water types	Reef WT1, WT2 and WT3 refer to the classification of waterbodies with different colour characteristics and concentrations of optically active components, water quality indicators and light attenuation typically found in the Reef during the wet season.

Appendix A: Water Quality Monitoring in the Fitzroy region 2021–22

The Fitzroy region extends from Carnarvon Gorge National Park to Rockhampton and out to the mouth of the Fitzroy River. Covering 15.7 million hectares, it has the largest catchment area draining into the Reef (Lewis *et al*. 2021), equating to ~33 per cent of all suspended sediment load from the Great Barrier Reef Catchment Area (Packett *et al*. 2009).

From 2005 to 2014, water quality monitoring occurred three times per year at three sites in the Fitzroy region through the MMP. Monitoring then ceased from 2015. In 2020, a partnership between the Great Barrier Reef Foundation and AIMS began to re-establish marine water quality monitoring in the Fitzroy region. Monitoring site locations were selected along water quality gradients related to exposure to land-based runoff, with sites located with increasing distance from the Fitzroy River mouth and from the coast (Álvarez-Romero *et al*. 2013). To maintain some continuity with the existing 10-year MMP monitoring dataset (2005–2014), the three original sites (FTZ1–3) were re-instated in the current design. *In situ* water quality monitoring is conducted at six sites (Figure A1), which are sampled ten times per year during ambient conditions (seven wet season and three dry season trips).

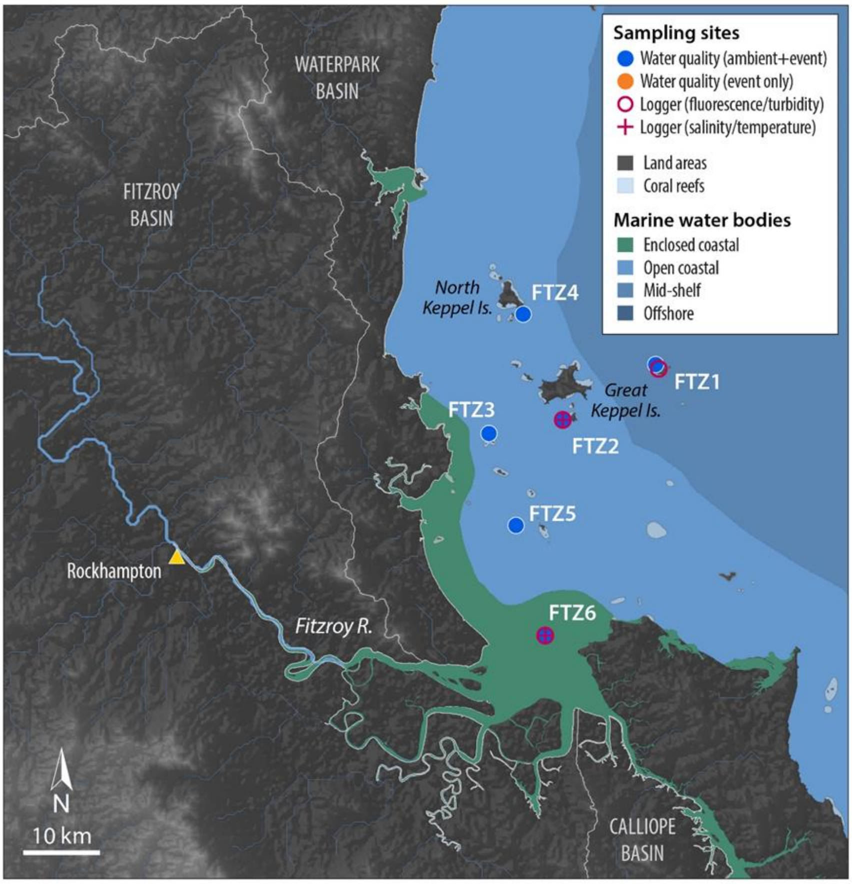

Figure A1. Map showing sampling sites in the Fitzroy region. Sites FTZ1-3 were monitored from 2005–2014 by the MMP. In 2020, monitoring resumed at FTZ1-3 and began at sites FTZ4-6.

Water quality results

The Long-term Water Quality Index showed a small (i.e. changing by a single grade) improvement in water quality over the period 2008 to 2015, which was driven by improvements in PN, PP and Chl-*a* indicators. Over the previous two years of monitoring, a trend of stability has been observed, although more data are needed to confirm this (Figure A2a).

The Annual Condition Water Quality Index score for the Fitzroy region was 'good' for the 2021–22 monitoring year (Figure A2b). Annual river discharge for the Fitzroy Basin in 2021–22 was slightly greater (approximately 1.5 times) than the long-term median. The combined discharge and loads calculated for the 2021–22 water year were around the long-term average (Moran *et al*. 2023).

Key results:

- Concentrations of NO_x and Secchi depth did not meet water quality guideline values at any monitoring sites within the Fitzroy region.
- Concentrations of PN, PP and TSS exceeded (did not meet) guideline values at most monitoring sites in the region.
- Concentrations of Chl-*a* and PO_4 were below (meeting) guideline values at most monitoring sites in the region.
- Trend analysis suggests that water clarity (TSS and turbidity) has worsened since 2015, while other variables (NO_x, PO_4, PP, PN, Secchi depth and Chl-*a*) show signs of stability. More data are needed to confirm these findings.

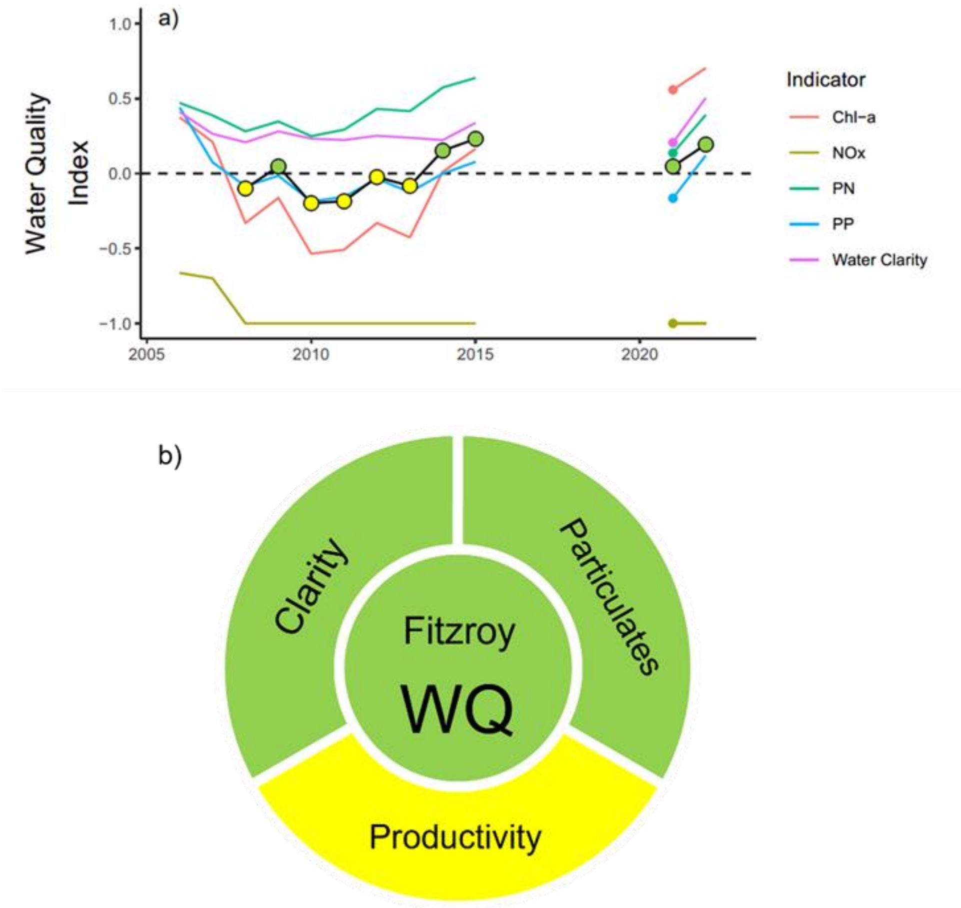

Figure A2. Water Quality Index scores for the Fitzroy region including a) the Long-term Water Quality Index, which includes monitoring data from 2005–2014 and b) the Annual Condition Water Quality Index, which scored the Fitzroy region overall as 'good' for the 2021–22 monitoring year.

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