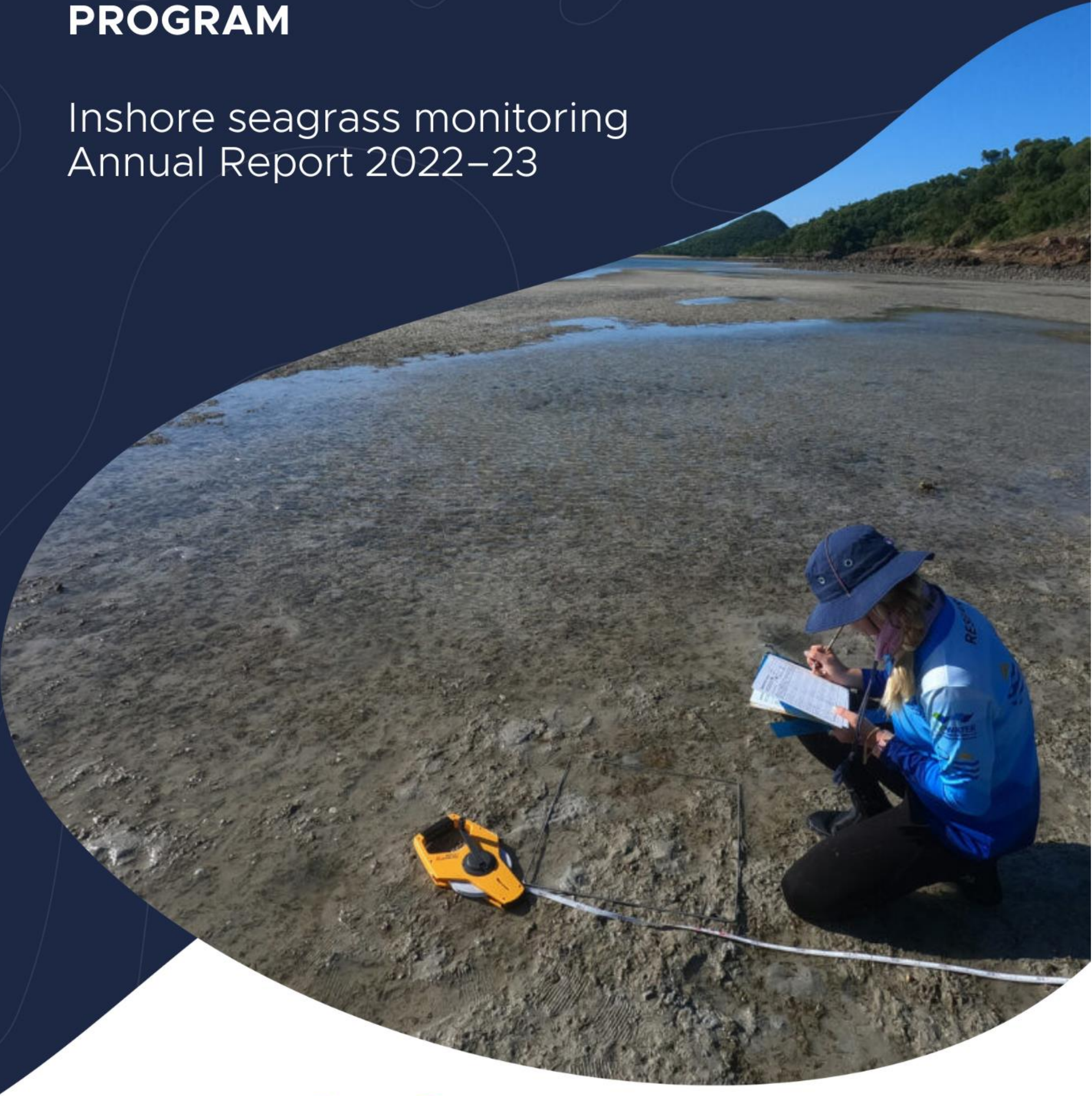
Australian Government
Great Barrier Reef Marine Park Authority

Reef Authority

GREAT BARRIER REEF MARINE MONITORING PROGRAM

Inshore seagrass monitoring Annual Report 2022–23



JAMES COOK UNIVERSITY AUSTRALIA

TropWATER

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Front cover image: Researcher sampling seagrass meadows in Lindeman Island (Mackay-Whitsunday). ©James Cook University.

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.

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

TropWATER- Centre for Tropical Water and Aquatic Ecosystem Research

James Cook University

Townsville, Qld 4811

Tropwater@jcu.edu.au

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Acronyms, abbreviations and units

Authority	Great Barrier Reef Marine Park Authority
BoM	Bureau of Meteorology
CQU	Central Queensland University
CV	coefficient of variation
DES	Department of Environment and Science, Queensland
GAM	generalised additive model
JCU	James Cook University
km	kilometre
m	metre
MMP	Great Barrier Reef Marine Monitoring Program
NRM	Natural Resource Management
Paddock to Reef program	Paddock to Reef Integrated Monitoring, Modelling and Reporting Program
PAR	Photosynthetically available radiation
QA/QC	quality assurance/quality control
QPWS	Queensland Park and Wildlife Service
Reef	Great Barrier Reef
Reef 2050 WQIP	Reef 2050 Water Quality Improvement Plan
Reef 2050 Plan	Reef 2050 Long-Term Sustainability Plan
RIMReP	Reef 2050 Integrated Monitoring and Reporting Program
RJFMP	Reef Joint Field Management Program
SE	Standard Error
Seagrass Index	seagrass condition index
SW	Seagrass-Watch
The Reef	Great Barrier Reef
TropWATER	Centre for Tropical Water & Aquatic Ecosystem Research

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The conceptual diagram symbols are courtesy of the Integration and Application Network (ian.umces.edu/symbols/), University of Maryland Center for Environmental Science. Climate data courtesy of the Australian Bureau of Meteorology, and tide data courtesy Maritime Safety Queensland, Department of Transport and Main Roads.

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We sincerely thank our reviewers, including several anonymous reviewers, for the time they spent on the careful reading of our report and their many insightful comments and suggestions which improved earlier versions of this and previous reports.

Executive summary

This document reports on the long-term health of inshore seagrass meadows in the Great Barrier Reef (the Reef). Results are presented in the context of the pressures faced by the ecosystem. Long-term health of inshore seagrass meadows is measured through seagrass abundance and resilience, which are summarised as the Seagrass Index, and supported by information on the proportion of colonising species, reproductive status, meadow extent, epiphytes on seagrass leaves and macroalgal presence.

Trends in key inshore seagrass indicators

Inshore seagrass meadows across the Reef mariginally declined in overall condition in 2022–23, with the Seagrass Index remaining **moderate** (Figure 1). Seagrass condition in the northern regions (Cape York, Wet Tropics, Burdekin and Mackay–Whitsunday) remained **moderate**, whereas condition in the two southern most regions continued to decline with Fitzroy remaining **poor** and the Burnett–Mary deteriorating to **very poor** for the first time in 16 years.

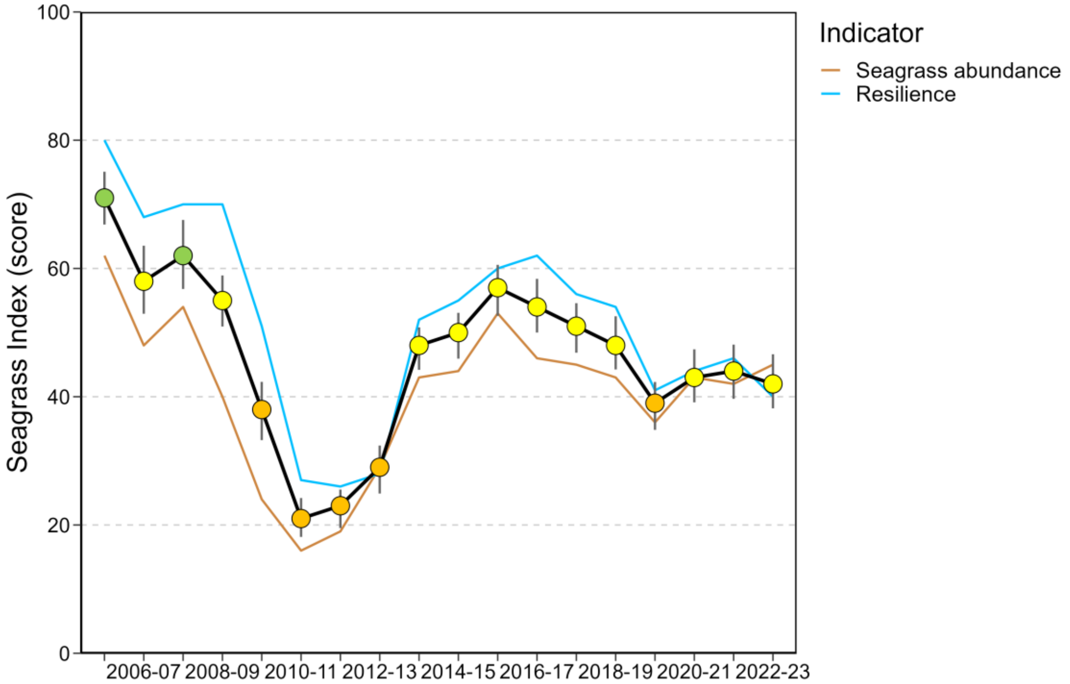


Figure 1. Overall inshore Reef Seagrass Index (±SE) with contributing indicator scores over the life of the MMP. The Index is derived from the aggregate of metric scores for indicators of seagrass condition: abundance and resilience. Index scores scaled from 0–100 and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40), ● = very poor (0–20). NB: Scores are unitless.

Reef-wide inshore seagrass abundance improved in 2022–23, after experiencing a slight stagnation in the past two years. In fact, over sixty per cent of the monitoring sites saw either improvement or stability in abundances in 2022–23. The decline in seagrass abundance between 2015 and 2019 was primarily driven by losses in the Mackay–Whitsunday and Burdekin regions, with smaller declines observed simultaneously in Cape York and the Wet Tropics. However, since 2019, the losses in the northernmost regions have subsided, with the Burdekin showing significant improvement as it recovered from the effects of heavy rainfall and above-average river discharge in early 2019. Despite these positive trends, there were still declining seagrass abundances in all three southern regions during 2020–21. Although the declines have stopped in Mackay-Whitsunday, they have persisted in the Fitzroy and Burnett-Mary regions.

Resilience declined in 2022–23 reaching its lowest point in a decade, after being on a slight improving trajectory over the previous two years. The long-term trend of the resilience indicator closely resembles that of abundance. It experienced significant declines between 2009 and 2012 due to extreme weather conditions, recovered to a good state in 2016–17, and has mostly been declining since then. The trends in the resilience score vary among regions with improvements occurring in the Wet Tropics and Mackay–Whitsundays in 2022–23, but declines in all other regions. Improvements were the result of increasing dominance of foundational seagrass species, with abundances exceeding the threshold for resistance, and the presence of sexual reproductive structures. Declines, however, were influenced by increasing prevalence of colonising species, low overall abundances, the lack of reproductive structures and declining seed banks. The largest decline and lowest resilience score was in the Burnett–Mary NRM region.

Influencing pressures

Pressures affecting inshore Reef seagrass habitats were low in 2022–23, but variable among regions and habitats. There was no cyclone activity in 2022–23. Overall, rainfall was around the long-term average but river discharge was variable among regions but above the long-term median for the Reef. The northern and central NRM regions (Cape York, Wet Tropics, Burdekin, and Mackay–Whitsunday) had rainfall that was above average in most catchments, and discharges more than 1.5 times the long-term median (except in the southern Wet Tropics). The largest anomalies were in Cape York and the largest discharge in the Normanby River (affecting Stanley Island and Bathurst Bay) was three times the long-term median. The Fitzroy and Burnett–Mary NRM regions had rainfall and discharge that were below the long-term median except in a few small catchments.

During the 2022-23 wet season, Cape York experienced turbid coloured waters that extended further offshore than the long-term average. In contrast, other regions encountered similar or less exposure than the long-term average. The greater area of seagrass exposed to the turbid waters in Cape York likely increased the risk of detrimental ecological effects.

Daily average benthic light availability during 2022-23 was slight below the long-term average (2008–2023) for inshore Reef seagrass meadows. Benthic light was lower than the long-term average (by more than 0.5 mol m^{-2} d^{-1}) at 9 of the 16 monitoring locations across all regions, and higher than the long-term average (by more than 0.5 mol m^{-2} d^{-1}) at three locations.

Within-canopy water temperatures are one of the most significant environmental pressures impacting inshore Reef seagrass meadows. Although slightly lower than the previous reporting period, temperatures in 2022–23 were the third highest since the MMP was established and nearly half a degree above the long-term average (2003–2022, 25.7°C). The southern Mackay-Whitsunday region recorded the second highest temperature in the inshore Reef since 2005. Additionally, three of the northern Reef regions experienced more days of extreme temperatures than before during the monitoring period.

Since the inception of the MMP, the inshore seagrass meadows of the Reef have faced cumulative pressures. In most years, some or all regions have been impacted by a range of factors including cyclones, floods, thermal anomalies or periods of very low light availability. Particularly severe and widespread pressures occurred in the period from 2009–10 to 2011–12, when above-average river discharge and localised cyclone damage lead to the **very poor** Seagrass Index. Other regionally-significant impacts were caused by cyclone Debbie in 2016–17 affecting the Mackay–Whitsunday region, floods in the Burdekin region in 2018–19, and floods in the Burnett–Mary region in 2021–22. Legacy effects of these past pressures have resulted in current seagrass conditions and ongoing recovery is required to achieve a higher Seagrass Index.

Conclusions

Reef-wide inshore seagrass condition was moderate in 2022–23, remaining unchanged from 2020–21 and 2021–22. Inshore seagrass condition remained a **moderate** grade in the northern and central Natural Resource Management (NRM) regions (Cape York, Wet Tropics Burdekin and Mackay–Whitsunday), while condition continued to deteriorate in the most southern regions, with the grade remaining **poor** in Fitzroy and declining to **very poor** in the Burnett–Mary.

Of concern is the inshore seagrass condition in the most southern regions; Fitzroy and Burnett–Mary. In these regions, seagrass abundance has decreased over the long-term with recent complete losses, meadow extents have been lost or remain low and highly fragmented, a considerable portion of meadows are dominated by colonising rather than foundational seagrass species (opportunistic or persistent species at the pinnacle of meadow succession), reproductive effort and seed banks are low or absent, and overall resilience is poor. These declines in seagrass condition in the most southern regions appear either a legacy of recent (4–5 years) extreme events (e.g. storms and flooding) or localised disturbances (e.g. bank destabilisation). Findings from the current monitoring period suggest seagrass ecosystems in the Fitzroy and Burnett–Mary regions may be more vulnerable to adverse or severe disturbances in the near future.

Climate change is the most significant threat to the Reef's long-term outlook, and the 2023–24 wet season is expected to include intensifying pressures, in particular an increased risk of higher temperature extremes as a consequence of an El Niño climatic phenomena. Rainfall will also be strongly influenced by local sea surface temperatures and the occurrence of cyclones. Maintaining and building seagrass resilience is now a priority to secure a future for Reef seagrass ecosystems. Water quality improvements to catchment run-off are expected to provide some relief from these impacts and improve meadow condition and resilience, but further options for building resilience and restoring degraded meadows should be encouraged.

1 Introduction

Approximately 3,464 km^2 of inshore seagrass meadows have been mapped in the Great Barrier Reef World Heritage Area (the World Heritage Area) in waters shallower than 15 m (McKenzie *et al.* 2014b; Saunders *et al.* 2015; Carter *et al.* 2016; McKenzie *et al.* 2016; Howley, Unpublished data). The remaining predominantly modelled extent (90 per cent or 32,215 km^2) of seagrass in the World Heritage Area is located in the deeper waters (>15 m) of the lagoon (McKenzie *et al.* 2022). These deepwater meadows are relatively sparse, structurally smaller, highly dynamic, composed of colonising species, and not as productive as inshore seagrass meadows for fisheries resources (McKenzie *et al.* 2010b; Derbyshire *et al.* 1995). Overall, the total estimated area of seagrass (35,679 km^2) within the World Heritage Area represents nearly half of the total recorded area of seagrass in Australia and between 13 per cent and 22 per cent globally (McKenzie *et al.* 2020), making the Reef's seagrass resources globally significant.

Tropical seagrass ecosystems of the Reef are a complex mosaic of different habitat types comprised of multiple seagrass species (Carruthers *et al.* 2002). There are 15 species of seagrass in the Reef (Waycott *et al.* 2007) and a high diversity of seagrass habitat and community types is provided by extensive bays, estuaries, rivers and the 2,300 km length of the Reef with its inshore lagoon and reef platforms. Seagrasses can be found on sand or muddy beaches, on reef platforms and in reef lagoons, and on sandy and muddy bottoms down to 70 m or more below Mean Sea Level (MSL) (Carter *et al.* 2021b).

Seagrasses in the Reef can be separated into four major habitat types: estuary/inlet, coastal, reef and deepwater (Carruthers *et al.* 2002). Environmental variables that influence seagrass species composition within these habitats include depth, tidal exposure, latitude, current speed, benthic light, proportion of mud, water type, water temperature, salinity, and wind speed (Carter *et al.* 2021a) (Figure 2). All but the outer reef habitats are significantly influenced by seasonal and episodic pulses of sediment-laden, nutrient-rich river flows, resulting from high volume summer rainfall. Cyclones, severe storms, wind and waves as well as macro grazers (e.g. fish, dugongs, and turtles) influence all habitats in this region to varying degrees. The result is a series of dynamic, spatially, and temporally variable seagrass meadows.

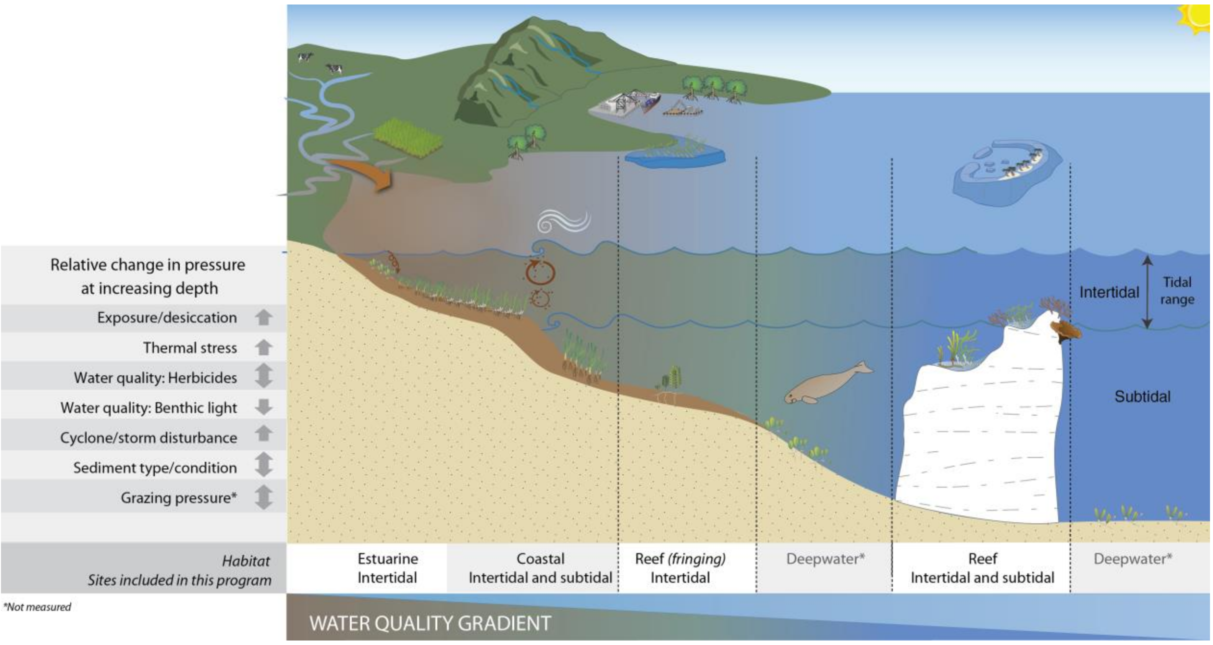


Figure 2. General conceptual model of seagrass habitats in north east Australia and the water quality impacts affecting the habitat (adapted from Carruthers *et al.* 2002, and Collier *et al.* 2014). Grey arrows indicate increase, decease or variable response with increasing depth.

The seagrass ecosystems of the Reef, on a global scale, would be for the most part categorised as being dominated by disturbance-favouring colonising and opportunistic species (e.g. *Halophila* and *Halodule* spp.), which typically have low standing biomass and high turnover rates (Carruthers *et al.* 2002, Waycott *et al.* 2007). In more sheltered areas, including reef–top or inshore areas in bays, more stable and persistent species are found, although these are still relatively responsive to disturbances (Carruthers *et al.* 2002; Waycott *et al.* 2007; Collier and Waycott 2009).

1.1 Seagrass monitoring in the Marine Monitoring Program

The strategic priority for the Great Barrier Reef Marine Park Authority (the Authority) is to sustain the Reef's outstanding universal value, build resilience and improve ecosystem health over each successive decade (GBRMPA 2014). Improving water quality is a key objective, because good water quality aids the resilience of coastal and inshore ecosystems of the Reef (GBRMPA, 2014a, b).

In response to concerns about the impact of land-based run-off on water quality, coral and seagrass ecosystems, the Reef 2050 Water Quality Improvement Plan (Reef 2050 WQIP) (Australian Government and Queensland Government 2018b) was prepared by the Australian and Queensland governments, and integrated as a major component of Reef 2050 Long-Term Sustainability Plan (Reef 2050 Plan) (Australian Government and Queensland Government 2018a), which provides a framework for integrated management of the World Heritage Area.

A key deliverable of the Reef 2050 WQIP is the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Paddock to Reef program), which is used to evaluate the efficiency and effectiveness of Reef 2050 WQIP implementation, and report on progress towards goals and targets (Australian Government and Queensland Government 2018b). The Great Barrier Reef Marine Monitoring Program (MMP) forms an integral part of the Paddock to Reef program. The MMP has three components: inshore water quality, coral and seagrass.

The overarching objective of the inshore seagrass monitoring program is to quantify the extent, frequency and intensity of acute and chronic impacts on the condition and trend of seagrass meadows and their subsequent recovery.

The inshore water quality monitoring program has been delivered by James Cook University (JCU) and the Authority since 2005. The seagrass sub-program is also supported by contributions from the Seagrass-Watch program (Burdekin and Mackay–Whitsunday) and Queensland Parks and Wildlife Service (QPWS) through the Reef Joint Field Management Program (RJFMP).

Further information on the program objectives, and details on each sub-program are available on-line (GBRMPA 2022; https://bit.ly/3Ym7a42).

1.2 Conceptual basis for indicator selection

As seagrasses are well recognised as indicators of integrated environmental pressures, monitoring their condition and trend can provide insight into the condition of the surrounding environment (e.g. Dennison *et al.* 1997). There are a number of measures of seagrass condition that can be used to assess how they respond to environmental pressures, and these measures are referred to herein as indicators (**Error! Reference source not found.**).

These indicators respond at different temporal scales, with sub-lethal indicators able to respond from seconds to months, while the meadow-scale effects usually take many months to be detectable. A robust monitoring program benefits from having a suite of indicators that can indicate sub-lethal stress that forewarns of imminent loss, as well as indicators of meadow-scale changes, which are necessary for interpreting broad ecological changes. Indicators included in the MMP span this range of scales, in particular for indicators that respond from weeks (e.g. abundance, reproductive effort), to months and even years (e.g.

composition and meadow extent). Furthermore, indicators are conceptually linked to each other and to environmental drivers of concern, in particular, water quality.

Table 1. Climate, environmental, seagrass condition and seagrass resilience indicators reported as part of inshore seagrass monitoring (see Table 2 for details on data source). Indicators that are used to calculate the Seagrass Index and Water Quality Index (indicating potential water quality pressures on Reef habitats) for the Reef Report Card are also indicated. All indicators are shown against their response time. Indicators colour grouped by category.

Report Card category	Indicator category	Minutes-Days	Weeks	Months	Years	Seagrass report	Report card
Water quality	**Climate**	Cyclones				Y	
		Rainfall & river discharge^				Y	
		Wind (resuspension of sediments, scouring of sediments, currents)				Y	
		Extreme water temperature (hours/days > threshold)				Y	
			Chronic temperature rise (weekly anomalies)			Y	
	Water quality		Total suspended solids, turbidity, Secchi depth^				Y
			Chlorophyll a^				Y
			Nutrients (dissolved and particle forms of N, P & C)^				
			Temperature and salinity^				
			Water colour (weekly colour classes)^			Y	
			Benthic light (at seagrass canopy)			Y	
Seagrass	**Habitat features**			Sediment composition		Y	
			Epiphytes and macroalgae			Y	
	Seagrass condition		Abundance (per cent cover)			Y	Y
				Spatial extent		Y	
	Seagrass resilience		Reproductive structures			Y	
			Species composition			Y	Y
			Abundance threshold			Y	
			Seed bank			Y	

^Water quality monitoring program (TropWATER James Cook University, Australian Institute of Marine Science, Howley consulting)

*Coral monitoring program (Australian Institute of Marine Science)

Measures of Environmental stressors

Climate and environment stressors are aspects of the environment, either physio-chemical or biological, that affect seagrass meadow condition. Some environmental stressors change rapidly (minutes/days/weeks/months) but can also undergo chronic shifts (years) (**Error! Reference source not found.**).

Stressors include:

- climate (e.g. cyclones, seasonal temperatures)
- local and short-term weather (e.g. wind and tides)
- water quality (e.g. river discharge, plume exposure, nutrient concentrations, suspended sediments, herbicides)
- biological (e.g. epiphytes and macroalgae)
- substrate (e.g. grain size composition).

Indicators that respond more quickly (e.g. light) provide important early-warning of potentially more advanced ecological changes (as described below). However, a measured change in a fast-responding environmental indicator is not enough in isolation to predict whether there will be further ecological impacts, because the change could be short-term. These indicators provide critical supporting information to support interpretation of slower responding seagrass condition and resilience indicators. Epiphytes and macroalgae are an environmental indicator because they can compete with and/or block light reaching seagrass leaves, therefore compounding environmental stress.

These environmental indicators are interpreted according to the following general principles:

- Cyclones cause physical disturbance from elevated swell and waves resulting in meadow fragmentation and loss of seagrass plants (McKenzie *et al.* 2012). Seagrass loss also results from smothering by sediments and light limitation due to increased turbidity from suspended sediments. The heavy rainfall associated with cyclones results in flooding, which exacerbates light limitation and transports pollutants (nutrients and pesticides), resulting in further seagrass loss (Preen *et al.* 1995).

- Daily light levels below 10 mol m^{-2} d^{-1} are unlikely to support long-term growth of seagrass, and periods below 6 mol m^{-2} d^{-1} for more than four weeks can cause loss (Collier *et al.* 2016b). However, it is unclear how these relate to intertidal habitats because very high light exposure during low tide can affect light. Therefore, it may be more informative to look at change relative to the sites.
- Elevated water temperature can impact seagrasses through chronic effects in which elevated respiration at high temperatures can cause carbon loss and reduce growth (Collier *et al.* 2017), while acute stress results in inhibition of photosynthesis and leaf death (Campbell *et al.* 2006; Collier and Waycott 2014).
- Daytime tidal exposure can provide critical windows of light for positive net photosynthesis for seagrass in chronically turbid waters (Rasheed and Unsworth 2011). However, during tidal exposure, plants are susceptible to extreme irradiance doses, desiccation, thermal stress and potentially high UV-A and UV-B leading to physiological damage, resulting in short-term declines in density and spatial coverage (Unsworth *et al.* 2012).
- Sediment grain size affects seagrass growth, germination, survival, and distribution (McKenzie 2007). Coarse, sand dominated sediments limit plant growth due to increased mobility and lower nutrients. However, as finer-textured sediments increase (dominated by mud (grain size <63μm)), porewater exchange with the overlaying water column decreases resulting in increased nutrient concentrations and phytotoxins such as sulphide, which can ultimately lead to seagrass loss (Koch 2001).

Measures of seagrass condition

Condition indicators such as meadow abundance and extent indicate the state of the plants/population and reflect the cumulative effects of past environmental conditions (**Error! Reference source not found.**). Abundance can respond to change on time-scales ranging from weeks to months (depending on species) in the Reef, while meadow extent tends to adjust over longer time-scales (months to years). Seagrass extent and abundance are integrators of past conditions, and are vital indicators of meadow condition; however, these indicators can also be affected by external factors such as grazing by mega herbivores, such as dugongs and turtles. Therefore, extent and abundance are not suitable as stand-alone indicators of environmental change and indicators that can be linked more directly to specific pressures are needed. These condition indicators also do not demonstrate capacity to resist or recover from additional impacts (Unsworth *et al.* 2015).

Seagrasses expand and produce new shoots through clonal growth, but seagrasses are also angiosperms (flowering plants). Sexual reproductive structures (flowers, fruits, and seeds) are an important feature of a healthy seagrass meadow (Kenworthy 2000; Jarvis and Moore 2010; Rasheed *et al.* 2014). Sexual reproduction is necessary to form seed banks, which facilitate meadow recovery following periods of decline, and seed germination increases clonal diversity of the meadow (richness). The level of reproductive effort (reproductive structures per unit area) by a meadow in each season provides the basis of new propagules for recruitment in the following year (Lawrence and Gladish 2018; McKenzie *et al.* 2021a).

Seagrasses possess the ability to resist disturbances through physiological processes and modifications to morphology (i.e. growth form), and recover following loss by regeneration from seed and through clonal growth (sexual and asexual reproduction, respectively). Seagrass species vary in their dependence on resistance and recovery strategies. Broadly, we categorise species as having either persistent or colonising traits based on their ability to resist or recover, and species with a mixture of those traits are categorised as opportunistic (Kilminster *et al.* 2015) (Figure 3). The contributions of species, with different life history strategies, differs between seagrass habitats, and varies through time based on pressures acting on the habitats. Meadows dominated by colonising species have lower ability to resist pressures, but higher capacity to recover from disturbances. Therefore, changes in the species composition of a meadow can indicate meadow state and infer disturbance levels. For example, coastal seagrasses are prone to small scale disturbances that cause local losses (Collier and Waycott 2009), and therefore disturbance-specialist species (i.e. colonisers) tend to dominate throughout the Reef. Community structure (species composition) is also an important feature conferring resilience, as some species are more resistant to stress than others, and some species may rapidly recover and pave the way for meadow development (Figure 3).

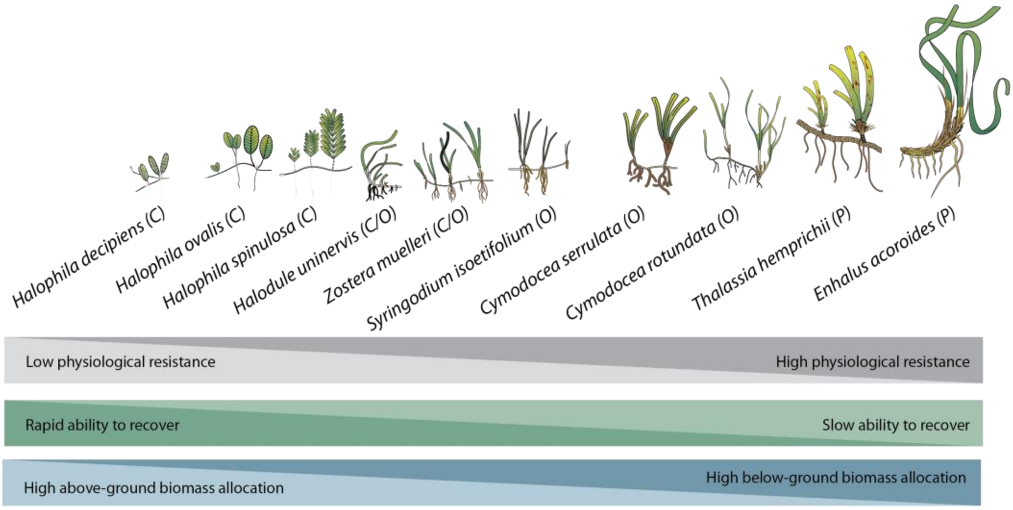


Figure 3. Dominant traits among the Reef seagrass species, with emphasis on their ability to either resist disturbances, or to recover following loss: colonising (C), opportunistic (O), or persistent (P). Adapted from Collier *et al*. (2021b) and Kilminster *et al*. (2015).

1.3 Structure of the Report

This report presents data from the fifteenth period of monitoring inshore seagrass ecosystems of the Reef under the MMP (undertaken from June 2022 to May 2023; hereafter called 2022–23). The inshore seagrass monitoring sub-program of the MMP reports on:

- abundance and species composition of seagrass (including seascape mapping) in the late dry season (September to November) of 2022 and the late wet season (March to May) of 2023 at inshore intertidal and subtidal locations
- resilience, including reproductive status of the seagrass species present at inshore intertidal and subtidal locations
- spatial and temporal patterns in light, turbidity, and temperature at sites where autonomous loggers are deployed
- trends in seagrass condition, measured as abundance (per cent cover) and resilience
- seagrass species composition in relation to environment condition and trends
- seagrass report card metrics for use in the annual Reef Report Card produced by the Paddock to Reef program.

The next section presents a summary of the program's methods. Section 3 describes the drivers and pressures on the Reef during 2022–23, in the Driver-Pressure-State-Impact-Response (DPSIR) framework, followed by Section 4, which describes the condition and trend of inshore seagrass in the context of environmental factors.

In keeping with the overarching objective of the MMP to *"Assess trends in ecosystem health and resilience indicators for the Great Barrier Reef in relation to water quality and its linkages to end-of-catchment loads",* key water quality results reported by Gruber *et al*. (2024) are replicated to support the interpretation of the inshore seagrass results.

2 Methods summary

In the following, an overview is given of the data collection, preparation and analyses methods. Detailed documentation of the methods used in the MMP, including quality assurance and quality control procedures, is available in McKenzie *et al.* (2021b).

2.1 Climate and environmental pressures

Climate and environmental pressures affect seagrass condition and resilience (Figure 2). The pressures of greatest concern are:

- physical disturbance (cyclones and benthic sheer stress)
- water quality (turbidity/light)
- water temperature
- low tide exposure
- sediment grain size/type.

The measures are either climate variables, which are generally not collected at a site-specific level, and within-canopy measure recorded at each site. The data source and sampling frequency is summarised in Table 3.

2.1.1. Climate

Cyclone tracks and total daily rainfall were accessed from the Australian Bureau of Meteorology from meteorological stations which were proximal to monitoring locations and provided by the MMP water quality sub-program (Gruber *et al.* 2024).

The presence of inshore seagrass meadows along the Reef places them at high risk of exposure to waters from adjacent water basins and exposure to flood plumes is likely to be a significant factor in structuring inshore seagrass communities (Collier *et al.* 2014; Petus *et al.* 2016). Hence we used river discharge volumes as well as frequency of exposure to inshore flood plumes as indicators of flood plume impacts to seagrasses.

Information on exposure to different optical water types is generated by the MMP water quality sub-program (Gruber *et al.* 2024). The inshore water quality sub-program includes a remote sensing component, which describes water quality characteristics for 22 weeks of the wet season (December–April). Water quality is described as water types of turbid, brown primary water, green secondary water, and tertiary waters. Colours are based on the Florel-Ule scale and are derived from daily Sentinel-3 OLCI Level 2 colour satellite images (Petus *et al.* 2019). Methods are detailed in Gruber *et al*. (Gruber *et al.* 2024). Water colour has been confirmed as a predictor of changes in seagrass abundance (Petus *et al.* 2016). Primary and secondary water types (WT1 and WT2) have the greatest effect on seagrass habitats because light is attenuated by the high levels of suspended particulate matter, phytoplankton (chlorophyll-*a*) and dissolved matter. Exposure maps are therefore based on frequency of exposure to primary and secondary water types, while tertiary water (WT3) exposure is also presented in summary tables for each site. It is important to note that Reef water types, do not always correspond to direct catchment discharge influence, and can be due to marine processes (especially the Reef WT3) and to resuspension in shallow areas (especially the Reef WT1).

Table 2 Reef optical water types used to assess exposure of seagrass to water quality pressures (from Gruber *et al.* 2024).

Reef water type	Description	Colour of water to the eye
WT1 (Primary)	Waters with high phytoplankton levels and increasing sediment and dissolved organic matter	Brownish-green
WT2 (Secondary)	Waters with colour still dominated by algae, but increased dissolved organic matter and some sediment may be present	Greenish water
WT3 (Tertiary)	Slightly below ambient water quality, but with high light penetration	Greenish-blue
WT4 (Marine)	Ambient marine water with high light penetration	Blue

Tidal height observations were used to determine if the tidal exposure regime may be increasing stress on seagrass and hence drive seagrass decline. Tidal observations were accessed from Maritime Safety Queensland and duration of annual air-exposure (hours) was determined for each meadow (i.e. monitoring site), based on the meadows height relative to the lowest astronomical tide (Appendix 2, Table 21).

2.1.2. Environment within or at the seagrass canopy

Autonomous iBTag™ or HOBO® submersible temperature loggers (iBCod™22L and HOBO® MX2201) were deployed at all sites identified in Appendix 2, Table 20. The iBCod™22L loggers recorded temperature (resolution 0.0625°C, accuracy ±0.5°C) within the seagrass canopy every 30–90 minutes and the HOBO® MX2201 loggers recorded temperature (resolution 0.04°C, accuracy ±0.5°C) every 15 minutes (Table 3). Temperature loggers were attached to the permanent marker at each site above the sediment-water interface.

Submersible Odyssey™ photosynthetic irradiance autonomous loggers were attached to permanent station markers at 23 intertidal seagrass locations from the Cape York region to the Burnett–Mary region (i.e. the light loggers are deployed at one site within the locations, Appendix 2, Table 20). The light sensor is positioned upright at the seagrass canopy. Detailed methodology for the light monitoring can be found in McKenzie *et al.* (2021b). Automatic wiper brushes clean the optical surface of the sensor every 15 minutes to prevent marine organisms fouling. Measurements were recorded by the logger every 15 minutes and are reported as total daily light (mol m^{-2} d^{-1}), hereinafter daily light. Light data presented for NRM and GBR-wide plots uses only site data where there is more than 50% of annual data available.

Sediment type affects seagrass community composition and vice versa (McKenzie et al 2007, Collier *et al.* 2020). Changes in sediment composition can be an indicator of broader environmental changes (such as sediment and organic matter loads and risk of anoxia), and be an early-warning indicator of changing species composition. Sediment type was recorded at the 33 quadrats at each site in conjunction with seagrass abundance measures (see 2.2.2) using a visual/tactile estimation of sediment grain size composition (0–2 cm below the sediment/water interface) as per standard protocols described in McKenzie *et al.* (2003). Qualitative field descriptions of sediment composition were differentiated according to the Udden-Wentworth grade scale as this approach has previously been shown to provide an equivalent measure to sieve-derived datasets (Hamilton, 1999; McKenzie 2007).

Table 3. Summary of climate and environment data included in this report, showing historical data range, measurement technique, measurement frequency, and data source. *=variable duration of data availability depending on site

	Data range	Method	Measurement frequency	Reporting units	Data source
Climate					
Cyclones	1968–2023	remote sensing and observations at nearest weather station	yearly	No. yr^{-1}	Bureau of Meteorology
Rainfall	1889–2023*	rain gauges at nearest weather station	daily	mm mo^{-1} mm yr^{-1}	Bureau of Meteorology
Riverine discharge	1970–2023	water gauging stations at river mouth		L d^{-1} L yr^{-1}	DES#, compiled by (from Gruber *et al.* 2024)
Plume exposure	2006–2023 wet season (Nov–Apr)	remote sensing and field validation	weekly	frequency of water type (1–6) at the site	MMP inshore water quality program (from Gruber *et al.* 2024)
Tidal exposure	1999–2023	wave height buoys at station nearest to monitoring site	3–10 min	hours exposed during daylight	Maritime Safety Queensland, calculated exposure by MMP Inshore Seagrass monitoring
Environment within seagrass canopy					
Water temperature	2002–2023	iBTag or HOBO® MX2201	15–90 min	°C, temperature anomalies, exceedance of thresholds	MMP Inshore Seagrass monitoring
Light	2008–2023	Odyssey 2Pi PAR light loggers with wiper unit	15 min	daily light (mol m^{-2} $d^{-}1$) frequency of threshold exceedance (per cent of days)	MMP Inshore Seagrass monitoring
Sediment grain size	1999–2023	visual / tactile description of sediment grain size composition	biannual	proportion mud	MMP Inshore Seagrass monitoring

Department of Environment and Science

2.2 Inshore seagrass and habitat condition

2.2.1 Sampling design & site selection

Monitoring of inshore seagrass meadows occurred in the six natural resource management (NRM) regions with catchments draining into the Reef: Cape York, Wet Tropics, Burdekin, Mackay–Whitsunday, Fitzroy and Burnett–Mary (Table 4, Figure 4). Seventy–four sites across 35 locations were assessed during the 2022–23 monitoring period (Table 4, Appendix 2, Table 20). This covered four estuarine, eighteen coastal, and thirteen reef locations.

Sampling is designed to detect changes in inshore seagrass meadows in response to changes in water quality associated with specific catchments or groups of catchments (region) and to disturbance events. The selection of locations/meadows was based upon a number of competing factors:

- meadows were representative of inshore seagrass habitats and seagrass communities across each region (based on Lee Long *et al.* 1993, Lee Long *et al.* 1997, Lee Long *et al.* 1998; McKenzie *et al.* 2000; Rasheed *et al.* 2003; Campbell *et al.* 2002; Goldsworthy 1994)
- meadows that span a range in exposure to riverine discharge with those in estuarine and coastal habitats generally having the highest degree of exposure, and reef meadows
- where possible include legacy sites (e.g. Seagrass-Watch) or former seagrass research sites (e.g. Dennison *et al.* 1995; Inglis 1999; Thorogood and Boggon 1999; Udy *et al.* 1999; Haynes *et al.* 2000; Campbell and McKenzie 2001; Mellors 2003; Campbell and McKenzie 2004; Limpus *et al.* 2005; McMahon *et al.* 2005; Mellors *et al.* 2005; Lobb 2006)
- meadows that are not extremely variable in per cent cover throughout the survey area i.e. a Minimum Detectable Difference (MDD) below 20 per cent (at the 5 per cent level of significance with 80 per cent power) (Bros and Cowell 1987).

Sentinel monitoring sites were selected using mapping surveys across the regions prior to site establishment. Ideally mapping was conducted immediately prior to site positioning, however in most cases (60 per cent) it was based on historic (>5 yr) information.

Representative meadows were those which (1) covered the greater extent within the inshore region, (2) were generally the dominant seagrass community type and (3) those meadows within Reef baseline abundances (based on Coles *et al.* 2001a; Coles *et al.* 2001c, 2001b, 2001d). To account for spatial heterogeneity of meadows within habitats, at least two sites were selected at each location. If meadow overall extent was larger than ~15 hectares (0.15 km^2), replicate sites were often located within the same meadow (a greater number of sites was desirable with increasing meadow size, however not possible due to funding constraints).

From the onset, inshore seagrass monitoring for the MMP was focused primarily on intertidal/lower littoral seagrass meadows due to:

- accessibility and cost effectiveness (limiting use of vessels and divers)
- occupational Health and Safety issues with dangerous marine animals (e.g. crocodiles, box jellyfish and irukandji)
- occurrence of meadows in estuarine, coastal and reef habitats across the entire Reef
- where possible, providing an opportunity for citizen involvement, ensuring broad acceptance and ownership of Reef 2050 Plan by the Queensland and Australian community.

Table 4. Inshore seagrass monitoring locations and annual sampling. SW= Seagrass-Watch, RJFMP = Reef Joint Field Management Program, ● indicates late dry (September to December) and late wet (March to May), ◐ indicates late dry only , and ◑ indicates late wet only. Shading indicates location not established. Blank cells indicate location not assessed. * indicates MMP assessments ceased in 2018.

NRM Region	Location	Program	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22	2022–23
Cape York	Shelburne Bay	MMP								●	●	◐	◐		◐	◐	◐	◐	◐	◐
	Margaret Bay	RJFMP																	◐	◐
	Piper Reef	MMP								●	●	◐	◐	◐	◐	◐	◐	◐	◐	◐
	Flinders Group	MMP, RJFMP								●	●	●	●	◐	◐	◐	◐	◐	◐	◐
	Bathurst Bay	MMP, RJFMP								●	●	◐	●	◐	◐	◐	◐	◐	◐	◐
	Weymouth Bay	SW							◑	◑		◐								
	Lloyd Bay	RJFMP											◐	◐	◐		◐	◐	◐	◐
	Archer Point	MMP*, SW	●	●	●	●	●	●	●	●	●	◐	◐	◐	◐					
Wet Tropics	Low Isles	MMP				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Yule Point	MMP	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Green Island	MMP	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Mission Beach	MMP	●	●	●	●	●	●	●	●	●	●	●	●	●	●	◐	●	●	●
	Dunk Island	MMP			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Rockingham Bay	SW				◐	◐	◐	◐	◐			◐	◐						
	Missionary Bay	RJFMP											◐	◐	◐	◐	◐	◐	◐	◐
Burdekin	Magnetic Island	MMP	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Townsville	MMP, SW	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Bowling Green Bay	MMP								●	●	●	●	●	●	●	●	●	◐	◐
	Bowen	SW		◑	●	●	●	◑									●	●	●	●
Mackay–Whitsunday	Shoal Bay	SW	●	●	●	●	●	●	●	◐	◐	◐	◐	●	●	●	●	●	●	●
	Pioneer Bay	MMP, SW	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Cid Harbour	RJFMP																	◐	◐
	Tongue Bay	RJFMP											◐	◐	◐	◐	◐	◐	◐	◐
	Whitehaven Beach	RJFMP																	◐	◐
	Hamilton Island	MMP			●	●	●	●	●	●	●	●	●	●	●	●	◐	●	●	●
	Lindeman Island	MMP													●	●	◐	●	●	●
	Repulse Bay	MMP	●	●	◑	◑	◑	◑	●	●	●	●	●	●	●	●	●	●	●	●
	St Helens Bay	SW													◐	◐	◐	◐	●	●
	Newry Islands	RJFMP											◐	◐	◐	◐	◐	◐	◐	◐
	Sarina Inlet	MMP	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Llewellyn Bay	SW																	◑	●
	Clairview	SW													◐	◐	◐	◐	●	●
Fitzroy	Shoalwater Bay	MMP	●	●	●	●	●	●	●	●	●	◐	◐	◐	●	◐	●	◐	◐	◐
	Keppel Islands	MMP			●	●	●	●	●	●	●	◐	◐	◐	●	●	●	●	◐	◐
	Gladstone Harbour	MMP	●	●	●	●	●	●	●	●	●	◐	◐	●	●	●	●	●	◐	◐
Burnett–Mary	Rodds Bay	MMP			●	●	●	●	●	●	●	●	◐	●	●	●	●	●	◐	◐
	Burrum Heads	MMP, SW	●	●	◐	●	◐	●	●	●	●	◐	●	●	●	●	●	●	●	●
	Hervey Bay	MMP	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Figure 4. Inshore seagrass survey locations that exist as of 2022-23. However, not all locations were surveyed in 2022-23 (see Table 2).

Some of the restrictions for working in hazardous waters are overcome by using drop cameras and grab samplers.

The long-term median annual daylight exposure (the time intertidal meadows are exposed to air during daylight hours) was 1.6 per cent (all meadows pooled) (Table 21). This limited the time monitoring could be conducted to the very low spring tides within small tidal windows (mostly 1–4 hrs per day for 3–6 days per month for 6–9 months of the year).

Depth range monitoring in subtropical/tropical seagrass meadows has had limited success due to logistic/technical issues and non-conformism with traditional ecosystem models because of the complexity (Carruthers *et al.* 2002), including:

- a variety of habitat types (estuarine, coastal, reef and deepwater)
- a large variety of seagrass species with differing life history traits and strategies
- tidal amplitudes spanning 3.42m (Cairns) to 10.4m (Broad Sound) (www.msq.qld.gov.au; Maxwell 1968)
- a variety of sediment substrates, from terrigenous with high organic content, to oligotrophic calcium carbonate
- turbid nearshore to clearer offshore waters
- grazing dugongs and sea turtles influencing meadow community structure and landscapes
- near-absence of shallow subtidal meadows south of Mackay–Whitsunday due to the large tides which scour the seabed.

Deepwater (>15 m depth) meadows across the Reef are comprised of only *Halophila* species and are highly variable in abundance and distribution (Lee Long *et al.* 1999; York *et al.* 2015; Chartrand *et al.* 2018). Due to this high variability they do not meet the current criteria for monitoring, as the MDD is very poor at the 5 per cent level of significance with 80 per cent power (McKenzie *et al.* 1998).

The meadows chosen for monitoring were in fact lower littoral (rarely exposed to air), although classified intertidal within the MMP. Predominantly stable lower littoral and shallow (>1.5 m below lowest astronomical tide) subtidal meadows of foundation species (e.g. *Nanozostera, Halodule*) are best for determining significant change/impact (McKenzie *et al.* 1998). Where possible, shallow subtidal and lower littoral monitoring sites were paired when dominated by similar species, such as reef locations in Cape York, Wet Tropics, Burdekin and Mackay–Whitsunday (Table 5).

Due to the high diversity of seagrass species, it was decided to direct monitoring toward the foundation seagrass species across the seagrass habitats. A foundation species is the dominant primary producer in an ecosystem both in terms of abundance and influence, playing central roles in sustaining ecosystem services (Angelini *et al.* 2011). The activities of foundation species physically modify the environment, and produce and maintain habitats that benefit other organisms that use those habitats (Ellison 2019).

Foundation species are the species types that are at the pinnacle of meadow succession. A highly disturbed meadow (due to wave/wind exposure, or low light regime) might only ever have opportunistic species as the foundational species, while a less disturbed meadow can have persistent species form the foundation. Also, whether *Nanozostera muelleri* is a foundation species is influenced by whether it grows in the tropics or in the sub-tropics, as it is more likely to form a foundation species in the sub-tropics even if it is disturbed.

For the seagrass habitats assessed in the MMP, the foundation seagrass species were those species that typified the habitats both in abundance and structure when the meadow was considered in its steady state (opportunistic or persistent) (Kilminster *et al.* 2015). The foundation species were all di-meristematic leaf-replacing forms from the following genera:

Cymodocea, Enhalus, Halodule, Nanozostera, Oceana, Syringodium and *Thalassia* (Table 5).

As the major period of runoff from catchments and agricultural lands is the tropical wet season/monsoon (December to April), monitoring is focussed on the late dry season (growing, September-November) and late wet season (March-May) to capture the condition of seagrass pre– and post–wet. Changes in indicators at sites sampled in the late dry only (e.g. Cape York) are most likely to be in response to wet season conditions in the previous reporting period.

Apart from the 47 MMP long-term monitoring sites, data included 14 sites from Seagrass-Watch and 18 sites from QPWS to improve the spatial resolution and representation of subtidal habitats (Table 6).

A description of all data collected during the sampling period has been collated by region, site, parameter, and the number of samples collected per sampling period (Table 20). The seagrass species (including foundation) present at each monitoring site is listed in Table 5 and Table 6.

2.2.2 Seagrass abundance, composition and extent

Seagrass abundance, species composition, and meadow spatial extent were assessed from samples collected in the late dry 2022 and late wet 2023 at locations identified in Table 5. Field survey methodology followed globally standardised protocols (detailed in McKenzie *et al.* 2003).

At each location, with the exception of subtidal sites, sampling included two sites nested within 500 m of each other. Subtidal sites were not always replicated within locations. Sites were defined as a 5.5 hectare area intertidally and 3.1 hectares subtidally, within a relatively homogenous section of a representative seagrass community/meadow (McKenzie *et al.* 2003).

Monitoring at sites in the late dry (September-November 2022) and late wet (March-May 2023) of each year was conducted by a qualified scientist who was trained in the monitoring protocols. In the centre of each site, during each survey, observers recorded the percentage seagrass cover within 33 quadrats (50 cm × 50 cm, placed every 5 m along three 50 m transects, located 25 m apart). Transects are placed in the same position (±3 m) each assessment.

The sampling strategy for subtidal sites was modified in 2021–22, as a result of the discontinuation of SCUBA diving; driven by budgetary constraints, logistic and occupational health and safety issues relating to diving in poor visibility coastal waters. At each site, a GoPro® drop–camera assembly (incl. frame with 0.25 m^2 quadrat in field of view), was used to visually assess the seabed and the photoquadrat footage captured for post-field analysis. Along three 50 m transects within a 50 m radius of a central point, between 10 and 33 photoquadrats were assessed for seagrass percentage cover, species composition and macroalgae abundance. Subtidal assessments were conducted using a real time drop-camera slaved to a surface tablet, to ensure photoquadrats were sufficiently spaced apart and the vision captured was suitable for post-field analysis. A Van Veen grab was used to validate seagrass species observed on the tablet screen and to assess sediment composition.

Seagrass species were identified as per Waycott *et al.* (2004). Species were further categorised according to their life history traits and strategies and classified into colonising, opportunistic or persistent as broadly defined by Kilminister *et al.* (2015) (for detailed methods, see McKenzie *et al.* 2021b).

Table 5. Inshore sentinel seagrass long-term monitoring site details including presence of foundation (■) and other (□) seagrass species in the current or previous reporting periods. ^ =subtidal. CR = *Cymodocea rotundata*, CS = *Oceana serrulata*, EA = *Enhalus acoroides*, HD = *Halophila decipiens*, HO = *Halophila ovalis*, HS = *Halophila spinulosa*, HU = *Halodule uninervis*, SI = *Syringodium isoetifolium*, TH = *Thalassia hemprichii*, ZC = *Nanozostera muelleri.*

Region	NRM region (*Board*)	Basin	Monitoring location	Site		Longitude	Latitude	CR	CS	EA	HD	HO	HS	HU	SI	TH	ZC
Far Northern	Cape York *(Cape York Natural Resource Management)*	Jacky / Olive-Pascoe	Shelburne Bay *coastal*	SR1	Shelburne Bay	142.914	-11.887			■		□		■		■	
				SR2	Shelburne Bay	142.916	-11.888										
			Piper Reef *reef*	FR1	Farmer Is.	143.234	-12.256	■				□				■	
				FR2	Farmer Is.	143.236	-12.257										
		Normanby / Jeannie	Flinders Group *reef*	ST1	Stanley Island	144.245	-14.143	■		■		□		■	■	■	
				ST2	Stanley Island	144.243	-14.142										
			Bathurst Bay *coastal*	BY1	Bathurst Bay	144.233	-14.268	■				□		■	■	■	■
				BY2	Bathurst Bay	144.232	-14.268										
Northern	Wet Tropics (*Terrain NRM*)	Daintree	Low Isles *reef*	LI1	Low Isles	145.565	-16.385					□		■		■	
				LI2^	Low Isles	145.564	-16.383					□		■			
		Mossman / Barron / Mulgrave-Russell / Johnstone	Yule Point *coastal*	YP1	Yule Point	145.512	-16.569					□		■			■
				YP2	Yule Point	145.509	-16.564										
			Green Island *reef*	GI1	Green Island	145.973	-16.762	■	■			□		■		■	
				GI2	Green Island	145.976	-16.761										
				GI3^	Green Island	145.973	-16.755	■	■			□		■	■	■	
		Tully / Murray / Herbert	Mission Beach *coastal*	LB1	Lugger Bay	146.093	-17.961					□		■			
				LB2	Lugger Bay	146.094	-17.961										
			Dunk Island *reef*	DI1	Pallon Beach	146.141	-17.944	■	■			□		■		■	
				DI2	Pallon Beach	146.141	-17.946										
				DI3^	Brammo Bay	146.140	-17.932		■		□	□		■			
Central	Burdekin (*NQ Dry Tropics*)	Ross / Burdekin	Magnetic island *reef*	MI1	Picnic Bay	146.841	-19.179					□		■			■
				MI2	Cockle Bay	146.829	-19.177	■	■			□		■	■	■	
				MI3^	Picnic Bay	146.841	-19.179		■		□	□	□	■			
			Townsville *coastal*	SB1	Shelley Beach	146.771	-19.186		■			□		■			■
				BB1	Bushland Beach	146.683	-19.184										
			Bowling Green Bay *coastal*	JR1	Jerona (Barratta CK)	147.241	-19.423					□		■			■
				JR2	Jerona (Barratta CK)	147.240	-19.421										
	Mackay–Whitsunday (*Reef Catchments*)	Proserpine / O'Connell	Lindeman Island *reef*	LN1^	Lindeman Is.	149.028	-20.438					□		■			
				LN3	Lindeman Is.	149.033	-20.438					□		■			
			Repulse Bay *coastal*	MP2	Midge Point	148.702	-20.635					□		■			■
				MP3	Midge Point	148.705	-20.635										
			Hamilton Island *reef*	HM1	Catseye Bay - west	148.957	-20.344					□		■	■		■
				HM2	Catseye Bay - east	148.971	-20.347										
		Plane	Sarina Inlet *estuarine*	SI1	Point Salisbury	149.304	-21.396					□		■			■
				SI2	Point Salisbury	149.305	-21.395										
Southern	Fitzroy (*Fitzroy Basin Association*)	Shoalwater / Fitzroy	Shoalwater Bay *coastal*	RC1	Ross Creek	150.213	-22.382					□		■			■
				WH1	Wheelans Hut	150.275	-22.397										
			Keppel Islands *reef*	GK1	Great Keppel Is.	150.939	-23.196					□	□	■			■
				GK2	Great Keppel Is.	150.940	-23.194										
		Calliope / Boyne	Gladstone Harbour *estuarine*	GH1	Pelican Banks	151.301	-23.767					□		■			■
				GH2	Pelican Banks	151.304	-23.765										
	Burnett–Mary (*Burnett–Mary Regional Group*)	Baffle	Rodds Bay *estuarine*	RD1	Cay Bank	151.655	-24.058					□		■			■
				RD3	Turkey Beach	151.589	-24.038										
		Burrum	Burrum Heads *coastal*	BH1	Burrum Heads	152.626	-25.188					□		■			■
				BH3	Burrum Heads	152.639	-25.210										
		Mary	Hervey Bay *estuarine*	UG1	Urangan	152.907	-25.301					□		■			■
				UG2	Urangan	152.906	-25.303										

Table 6. Additional inshore sentinel seagrass long-term monitoring sites integrated from the Seagrass-Watch (intertidal sites) and RJFMP drop-camera (subtidal sites)^ programs, including presence of foundation (■) and other (□) seagrass species in the current or previous reporting periods. NRM region from www.nrm.gov.au. ^ =subtidal, ~ =not assessed in 2022–23.

Region	NRM region (*Board*)	Basin	Monitoring location	Site		Longitude	Latitude	CR	CS	EA	HD	HO	HS	HU	SI	TH	ZC
Far Northern	Cape York (*Cape York Nat Res Manage)*	Jacky	Margaret Bay *coastal*	MA1^	Margaret Bay	143.19358	-11.9574					□	□	■			
				MA2^	Margaret Bay	143.20338	-11.9559										
		Lockhart	Weymouth Bay *reef*	YY1~	Yum Beach	143.36059	-12.571	■	■	■		□		■		■	
			Lloyd Bay *coastal*	LR1^	Lloyd Bay	143.485	-12.797					□	□	■			
				LR2^	Lloyd Bay	143.475	-12.825										
		Normanby / Jeannie	Flinders Group *reef*	FG1^	Flinders Island	144.225	-14.182					□	□	■			
				FG2^	Flinders Island	144.225	-14.182										
			Bathurst Bay *coastal*	BY3^	Bathurst Bay	144.285	-14.276					□		■			
				BY4^	Bathurst Bay	144.300	-14.275										
		Endeavour	Archer Point *reef*	AP1~	Archer Point	145.31894	-15.60832	■	■	■		□		■		■	□
				AP2~	Archer Point	145.31847	-15.60875										
Northern	Wet Tropics	Tully / Murray / Herbert	Rockingham Bay *reef*	GO1~	Goold Island	146.15327	-18.17395	■	■			□		■			
			Missionary Bay *coastal*	MS1^	Cape Richards	146.213	-18.216					□		■			
				MS2^	Macushla	146.217	-18.205										
Central	Burdekin (*NQ Dry Tropics*)	Ross / Burdekin	Townsville *coastal*	SB2	Shelley Beach	146.763	-19.182		■			□		■			■
		Don	Bowen *coastal*	BW1	Port Dennison	148.250	-20.017					□		■			■
				BW2	Port Dennison	148.252	-20.017										
	Mackay–Whitsunday (*Reef Catchments*)	Proserpine	Shoal Bay *reef*	HB1	Hydeaway Bay	148.482	-20.075	■				□		■		■	
				HB2	Hydeaway Bay	148.481	-20.072										
			Pioneer Bay *coastal*	PI2	Pigeon Island	148.693	-20.269					□	□	■			■
				PI3	Pigeon Island	148.698	-20.271										
		Proserpine / O'Connell	Cid Harbour *reef*	CH4^	Cid Harbour	148.9506	-20.213		■		□	□	□	■	■		
				CH5^	Cid Harbour	148.9451	-20.222										
			Tongue Bay *reef*	TO1^	Tongue Bay	149.016	-20.240					□		■		■	
				TO2^	Tongue Bay	149.012	-20.242										
			Whitehaven Beach *reef*	WB1^	Whitehaven Bch	149.0386	-20.2808		■			□	□	■	■		
				WB2^	Whitehaven Bch	149.0475	-20.2903										
		O'Connell / Pioneer	St Helens Bay *coastal*	SH1	St Helens Bch	148.835	-20.822					□		■			■
			Newry Islands *coastal*	NB1^	Newry Bay	148.926	-20.868		■			□	□	■	■		
				NB2^	Newry Bay	148.924	-20.872										
		Plane	Llewellyn Bay *coastal*	LL1	Deception Inlet	149.318	-21.424					□					■
			Clairview *coastal*	CV1	Clairview	149.533	-22.104					□		■			■
				CV2	Clairview	149.535	-22.108										

Mapping of the meadow extent and meadow–scape (i.e. patches and scars) within each site was also conducted as part of the monitoring in both the late dry and late wet periods. Mapping followed standard methodologies (McKenzie *et al.* 2001) using a handheld GPS on foot at intertidal sites and drop-camera at subtidal sites. Seagrass meadow–scape that tended to grade from dense continuous cover to no cover (i.e. over a continuum that included small patches and shoots of decreasing density) had the meadow edge delineated where there was a non-vegetated space with the distance of more than 3 metres (i.e. accuracy of the GPS). Each entire site (5.5 ha intertidal and 3.1 ha subtidal) was mapped (seagrass and no seagrass). It should be noted that within a site, areas that are not suitable for seagrass can occur, e.g. consolidated sediments, coral reef or dry sandy beach. The relative spatial extent was calculated by dividing the mapped seagrass area by the total habitable area for seagrass within the entire site.

2.2.3 Seagrass reproductive status

Seagrass reproductive state was assessed from samples collected in the late dry 2022 and late wet 2023 at locations identified in Table 5. Samples were processed according to standard methodologies (McKenzie *et al.* 2021b).

In the field, 15 haphazardly placed cores (100 mm diameter x 100 mm depth) of seagrass were collected within each site from an area adjacent (of similar cover and species composition) to the monitoring transects. In the laboratory, reproductive structures (spathes, fruits, female and male flowers) of plants from each core were identified and counted for each sample and species. Reproductive effort was calculated as number of reproductive structures (fruits, flowers, spathes; species pooled) per core for analysis.

Seeds banks and abundance of germinated seeds were sampled according to standard methods (McKenzie *et al.* 2021b) by sieving (2 mm mesh) 30 cores (50 mm diameter, 100 mm depth) of sediment collected across each site and counting the seeds retained in each. For *Nanozostera muelleri*, where the seed are <1 mm diameter, intact cores (18) were collected and returned to the laboratory where they were washed through a 710 µm sieve and seeds identified using a hand lens/microscope. Seeds are no longer collected at reef subtidal sites as sampling on SCUBA was discontinued as a result of budgetary constraints, logistic and occupational health and safety issues.

2.2.4 Epiphytes and macroalgae

Epiphyte and macroalgae cover were measured in the late dry and late wet seasons according to standard methods (McKenzie *et al.* 2003). The total percentage of leaf surface area (both sides, all species pooled) covered by epiphytes and percentage of quadrat area covered by macroalgae were measured each monitoring event. Values were compared against the Reef long-term average (1999–2010) calculated for each habitat type.

2.3 Calculating Report Card scores

2.3.1 Seagrass abundance

Seagrass abundance state in the MMP is measured using the median seagrass per cent cover relative to the site or reference guideline (habitat type within each NRM region). Abundance guidelines (threshold levels) were determined using the long-term (>4 years) baseline where the percentile variance plateaued (generally 15-20 sampling events), thereby providing an estimate of the true percentile value (McKenzie 2009). Guidelines for individual sites were only applied if the conditions of the site aligned with reference conditions and the site had been subject to minimal/limited disturbance for 3–5 years (see Appendix 1, Table 19).

Abundance at each site for each monitoring event was allocated a grade:

- *very good*, median per cent cover at or above 75th percentile
- *good*, median per cent cover at or above 50th percentile
- *moderate*, median per cent cover below 50th percentile and at or above low guideline
- *poor*, median per cent cover below low guideline
- *very poor*, median per cent cover below low guideline and declined by >20 per cent since previous sampling event).

The choice of whether the 20th or 10th percentile was used for the low guideline depended on the within-site variability; generally, the 20th percentile is used, unless within-site variability was low (e.g. CV<0.6), whereby the 10th percentile was more appropriate as the variance would primarily be the result of natural seasonal fluctuations (i.e. nearly every seasonal low would fall below the 20th percentile). Details on the per cent cover guidelines can be found in Appendix 1.

A grade score from 0 to 100 (Table 7) was then assigned to enable integration with other seagrass indicators and other components of the Reef report card (Department of the Premier and Cabinet 2014). Annual seagrass abundance scores were calculated using the average grade score for each site (including all sampling events per year), each habitat and each NRM.

Table 7. Scoring threshold table to determine seagrass abundance grade. low = 10th or 20th percentile guideline. NB: scores are unitless.

Grade	Percentile category	Score
very good	75–100	100
good	50–75	75
moderate	low–50	50
poor	<low	25
very poor	<low by >20 per cent	0

2.3.2 Seagrass resilience

Resilience can be described as the capacity of an ecosystem to cope with disturbance (Connolly *et al.* 2018), and to adapt to change without switching to an alternative state (Holling 1973; Unsworth *et al.* 2015). For monitoring and reporting, '*a set of measurable biological characteristics that exemplify seagrass meadows' resistance to pressures and essential mechanisms for recovery*' are required to assess resilience (Udy *et al.* 2018). The resilience indicator takes a subset of measurable characteristics for which long-term data is available to develop a score.

The seagrass resilience indicator is based on the premise that resilience includes a resistance and recovery element. Seagrass species vary in their dependence on these traits. 'Colonising' species generally have low levels of resistance traits and 'persistent' species have high levels of these traits. Resistance is incorporated into the metric through meadow condition, and whether abundance and species composition exceed critical thresholds (<20th percentile or >50 per cent, respectively). It is also influenced by the proportion of persistent species. Sites that are dominated by colonising species therefore have low levels of resistance, making them highly vulnerable to events such as periods of elevated turbidity caused by flood plumes. Sites that are in impacted state and have low abundance relative to the average for that site are also vulnerable.

Reproductive effort indicates potential for recovery from seeds and likelihood of high clonal diversity. By contrast, traits that enable the species to recover following an impact are the highest in 'colonising' species and lowest in 'persistent' species. These traits include forming a seed bank from flowers and rapid growth rates. 'Opportunistic' species have traits of both resistance and recovery.

The resilience score is calculated using a decision tree. It includes resistance potential and likelihood of recovery based on reproductive effort (as a proxy for seed/propagules) graded according to the species in the habitat.

Sites are scored from 0 to 100 in each year using a decision tree (Collier *et al.* 2021a). The three main categories within the tree are:

- low resistance sites
- high resistance sites but non-reproductive (low recovery potential)
- high resistance and reproductive (increased recovery potential).

The conceptual basis for the resilience indicator and the statistical analysis supporting the decisions in the tree are detailed in Appendix 1, Figure 89.

The resilience scores are graded as: very poor (<20), poor (20≤40), moderate (40≤60), good (60≤80), very good (80≤100).

Table 8. Scoring thresholds and decisions for the resilience metric. *Foundational = opportunistic and persistent species. NB: scores are unitless.

Description	Species composition / abundance	Reproductive effort	Score calculation	Score	Category
1 Low resistance	Per cent colonising species >50 per cent AND/OR total per cent cover <20^{th} percentile of site	Reproduction not present	Proportion of colonising species	0–15	1.1
		Reproduction present (any species)	Proportion of foundational species and reproductive presence/absence	5–30	1.2
2.1 High resistance but low recovery potential	Per cent foundational species > 50 per cent AND total cover >20^{th} percentile of site	Reproduction (foundational) not present last 3 years	Proportion of persistent species present (min <10^{th} percentile, max 95^{th} percentile)	30–50	2.1.1
		Not reproductive this year, but reproductive (foundational) in last 3 years (seed bank is likely to be present)		50–70	2.1.2
2.2 High resistance and high recovery potential	Per cent foundational species >50 per cent AND total cover >20^{th} percentile of sites AND persistent species present	Reproduction (foundational) present	Reproductive structure count (min <10th percentile, max 95^{th} percentile)	70–100	2.2.1
				85–100	2.2.2

2.3.3 Seagrass Index

The seagrass condition index (Seagrass Index) is an average score (0–100) of the two seagrass condition indicators:

- seagrass abundance (per cent cover)
- seagrass resilience.

Each indicator is equally weighted, in accordance with the Paddock to Reef Integration Team's original recommendations. To calculate the overall score for seagrass of the Reef, the regional scores were weighted on the percentage of World Heritage Area seagrass (shallower than 15 m) within that region (Table 9). *Please note: Cape York omitted from the score in reporting prior to 2012 due to poor representation of inshore monitoring sites*.

Table 9. Area of seagrass shallower than 15 m depth in each region within the World Heritage Area boundaries. (from McKenzie *et al.* 2014a; McKenzie *et al.* 2014b; Carter *et al.* 2016; Waterhouse *et al.* 2016).

NRM	Area of seagrass (km^2)	Per cent of World Heritage Area
Cape York	2,078	0.60
Wet Tropics	207	0.06
Burdekin	587	0.17
Mackay–Whitsunday	215	0.06
Fitzroy	257	0.07
Burnett–Mary	120	0.03
World Heritage Area	**3,464**	**1.00**

2.4 Data analyses

All analysis was run in the software R-4.2.2 (R Core Team 2022).

2.4.1 Score propagation of error

All seagrass condition indicators had uncertainties associated with their measurements at the lowest reporting levels (e.g. percentage, count, ratio, *etc*.) which was presented as Standard Error (calculated from the site, day, or core standard deviations). To propagate the uncertainty (i.e. propagation of error) through each higher level of aggregation (e.g. habitat, NRM region and Reef), the square root of the sum of squares approach (using the SE at each subsequent level) was applied (Ku 1966). The same propagation of error approach was applied to the annual seagrass report card scores to calculate a more exact measure of uncertainty in the two seagrass indicators and overall Seagrass Index.

2.4.2 Abundance (per cent cover) generalised additive models (GAM)

Due to the high proportion of zeros and the unbalance of the per cent cover data through time (different sites monitored at each seasonal sampling period), we used a two-step approach to show the temporal trend.

1) Modelling the per cent cover average and confidence intervals for each sampling event.

The first step of the analysis was to accurately estimate the mean and 95 per cent CI for each season sampling period across various level (e.g. Reef wide, per NRM region, per habitat types). Because the data we want to analysed is a percentage with a high proportion of 0, we need to use a zero-inflated beta distribution (ZABE) (Zuur, Beginner's Guide to Zero-Inflated Models with R ,2016). The package gamlss (Rigby and Stasinopoulos 2005) was used for the analysis with the family BEZI (https://search.r-project.org/CRAN/refmans/gamlss.dist/html/BEZI.html).

The zero-inflated beta distribution is given as:

1) if (y=0) – Binomial model

   f(y) = nu

2) if y=(0,1) – Beta model

   f(y|mu,sigma)=(1-nu)*(Gamma(sigma)/Gamma(mu*sigma)*Gamma((1-mu)*sigma))*y^(mu*sigma-1)*(1-y)^(((1-mu)*sigma)-1)

   The parameters satisfy 0<mu<1, sigma>0 and 0<nu<1.

The expected values (E) and variance (VAR) are:

E(y)=(1-nu)*mu

Var(y)=(1-nu)*(mu*(1-mu))/(sigma+1) + nu*(1-nu)*mu^2

In our models Site was included as a random effect. Because some sites had very drastic changes in their abundance through time with sometimes complete seagrass loss, random effect cannot be accurately estimated over the whole time series. Therefore, per cent cover at the quadrat level for each seasonal date was analysed separately. The inclusion of random effect in the model is important to account for site-specific variance which results in more accurate estimations of confidence intervals around the mean across the various levels. The intercept model fitted was as followed:

Formula : Percent_cover ~ 1 + re (random(~1|Site)

The random effect of site was included in the three parameters estimated (mu, sigma and nu) but was dropped for sigma and nu if a parametrization error was encountered. In the extreme case of a zero-inflation superior to 95 per cent all random effects were dropped due to very limited number of quadrats with seagrass present.

We used a common bootstrapping method where a random distribution of 10000 was produced for mu and nu based on their parameter estimates and standard error outputted by the gamlss package to calculate the mean and 95 per cent CI of the resulting model. This gave 10000 expected values where the mean, 2.5 quantile and 97.5 quantile were calculated.

In the case where only a few sites were included (<5) and one of the sites only had 0 per cent cover for all quadrats, the algorithm was having difficulties estimating the zero-inflation parameter (nu) with the inclusion of site as a random effect. This resulted in the bootstrapped expected values to not be normally distributed (2 separate peaks of values centred on 0 and on the mean of the sites with seagrass present) which would not lead to an appropriate estimate of the overall mean. In these very rare scenarios, the same zero-inflated beta model was run but with site as a fixed effect which led to a distribution of bootstrapped expected values for each site. The overall mean was obtained as the arithmetic mean of the site bootstrapped mean and the 2.5 quantile and 97.5 quantile were respectively the minimum and maximum of the 2.5 quantile and 97.5 quantile of the site bootstrapped CI.

This process was repeated of each seasonal date at various scales. As part of our regular validation process the residuals of all models were checked for violations of the generalised model assumptions.

2) Trends in per cent cover

Generalised additive models (GAMs) with the beta (logit link) family were fitted to resulting mean and 95 per cent CI from the first process to identify the presence and consistency of trends through time, using the mgcv (Wood 2020) package. The GAMs were used in a multilevel approach to show trends at the Reef, NRM region, habitat, location and site levels. The details and summary outputs of all the GAMs shown in the figures can be found in the Appendix (Table 24 Table 25, Table 26). There was no significant autocorrelation observed for consecutive years of order 1 to 3. However, the GAMs were weighted based on how many sites were included in the mean calculated to ensure the seasonality and unbalanced nature of our sampling was not affecting the long-term trend.

The final results presented were:

- the prediction for the GAM fitted through the mean points
- lower CI as the predictions – 1.96*SE of the GAM fitted through the lower 95 per cent CI points
- upper CI as the predictions + 1.96*SE of the GAM fitted through the upper 95 per cent CI points

2.4.3 Abundance (per cent cover) long-term trends

Trend analysis was conducted to determine if there was a significant trend (reduction or increase) in seagrass abundance (per cent cover) at a particular site (averaged by sampling event) over all time periods. A Mann-Kendall test was performed using the "trend" package. Mann-Kendall is a common non-parametric test used to detect overall trends over time. The measure of the ranked correlation is the Kendall's tau coefficient (Kendall-τ), which is the proportion of up-movements against time vs the proportion of down-movements, looking at all possible pairwise time-differences. As the test assumes independence between observations, data was checked for autocorrelation and if present a corrected *p*-value was calculated using the "modifiedmk" package (Hamed and Rao 1998).

2.4.4 Resilience

Analysis of trends in the resilience scores was conducted using Generalised Linear Models (GLMs) with a gaussian distribution instead of GAMs, as this metric relies on samples collected once a year. Due to the low frequency of sampling the use of a smoother (GAM) is not recommended.

2.5 Reporting Approach

The data is presented in a number of ways depending on the indicator and section of the report:

- Report Card scores for seagrass condition are presented at the start of each section. These are a numerical summary of the condition within the region relative to a regional baseline (described further below)
- Climate and environmental pressures are presented as averages (daily, monthly or annual) and threshold exceedance
- Seagrass community data such as seagrass abundance, are presented as averages (sampling event, season or monitoring period with SE) and threshold exceedance data
- Seagrass ecosystem data such as sediment composition, epiphyte and macroalgae are presented as averages (sampling event, season or monitoring period) and relative to the long-term
- Trend analysis (GAM plots) are also used to explore the long-term temporal trends in biological and environmental indicators.

Within each region, estuarine and coastal habitat boundaries were delineated based on the Queensland coastal waterways geomorphic habitat mapping, Version 2 (1:100 000 scale digital data) (Heap *et al.* 2015). Reef habitat boundaries were determined using the National Mapping Division of Geosciences Australia geodata topographic basemap (1:100 000 scale digital data).

3 Drivers and pressures influencing seagrass meadows in 2022–23

The following section provides detail on the overall climate and environmental pressures during the 2022–23 monitoring period, at a relatively broad level as context for understanding trends in seagrass condition. It includes:

- climate (cyclones and rainfall), river discharge and turbid water exposure
- daily light (within-canopy)
- within-canopy temperature and threshold exceedance
- seagrass meadow sediment characteristics.

Supporting data is detailed within Appendix 2 and Appendix 3:

3.1 Summary

Long-term trends in the Water Quality Index indicate improvements in water quality across all regions examined in 2022–23, particularly in the Burdekin region which was ‘good’ for the second year in a row (Gruber *et al.* 2024). The Wet Tropics region slightly improved again after attaining the highest long-term Water Quality Index for any region or year in 2021–22 and was also ‘good’. The long-term Water Quality Index also improved in the Mackay–Whitsunday region but remained moderate (Gruber et al 2024). The Cape York Annual Water Quality Index remained stable and was good.

Environmental stressors in 2022–23 were around the long-term average for most measures for the Reef on average except for elevated discharge (Table 10), but variable among regions. The northern NRM regions (Cape York, Wet Tropics, Burdekin and Mackay–Whitsunday) had river discharges that exceeded the long-term median, except for a few catchments in each region (Gruber et al 2024). Rainfall and river discharge were below the long-term median in the Fitzroy and Burnett–Mary NRM regions except for a few small catchments (Gruber et al 2024).

Table 10. Summary of environmental conditions at monitoring sites across the Reef in 2022–23 compared to previous monitoring period and the long-term average (range indicated for each data set). *intertidal only.

Environmental pressure	Long-term average	2021–22	2022–23
Climate			
Cyclones, number of events (1968–2022)	4	1	0
Wet season daily rainfall, mm d^{-1} (1961–1990)	4.0	3.3	4.1
Riverine discharge, ML yr^{-1} (1986–2016)	51,812,207	71,817,742	83,283,163
Wet season turbid water exposure, per cent (2003–2018)	89	83	85
Within seagrass canopy			
Temperature, °C (±) (max) (2003–2022)*	25.7 ±0.1 (46.6)	26.2 ±0.4 (45.5)	26.1 ±0.5 (46.5)
Daily light, mol m^{-2} d^{-1} (2008–2022) annual average	13.8	14.1	14.1
(min site–max site)	(6.1–20.9)	(7.2–20.9)	(11.1–20.9)
Proportion mud, per cent			
estuarine intertidal (1999–2022)	44.5 ±2.1	36.3 ±2.1	42.2 ±2.1
coastal intertidal (1999–2022)	27.6 ±2.1	26.0 ±1.7	22.6 ±1.7
coastal subtidal (2015–2022)	54.1 ±2.5	59.8 ±2.1	55.4 ±2.1
reef intertidal (2001–2022)	4.3 ±1.2	4.2 ±1.0	3.2 ±1.0
reef subtidal (2008–2022)	15.7 ±0.9	29.5 ±1.7	16.0 ±1.7

The frequency with which the monitoring sites were exposed to water type 1 (WT1) (increased phytoplankton/sediment/ dissolved organic matter, ‘brown’) and 2 (WT2) (increased phytoplankton/dissolved organic matter and some sediment, ‘green’) during the wet season was below the long-term average across the Reef (Figure 8). Exposure to WT1 was elevated in Cape York and exposure to WT2 in the Wet Tropics. The presence of this turbid water is affected by resuspension-driven events as well as discharge and the relative attribution to these processes is discussed in further detail by Gruber *et al*. (2024). The risk of exposure of mapped seagrass to the water types are assessed in the water quality report (Gruber et al 2024). In Cape York, there was a 9% increase in exposure to the moderate risk category, and a reduced chance of exposure (5%).

Daily light levels were similar to the long-term Reef average in 2022–23. There were differences in trends among locations that did not directly correlate to river discharge or by habitat. At ten locations, daily light was below the long-term average and notably light was considerably lower than the long-term average at a reef location in the Wet Tropics (Dunk Island) and Mackay–Whitsunday NRM regions (Hamilton Island) and a coastal location in the Burnett–Mary (Burrum Heads). Daily light was higher at the remaining six locations.

Within canopy temperatures in 2022–23 were marginally cooler than the previous reporting period (2021–22), remaining slightly above the long-term average, and the equal third highest since the MMP was established (Figure 7). The number of extreme heat days (days >40°C) were the highest since monitoring was established, and occurred across Cape York, Wet Tropics, and Mackay–Whitsunday NRM regions. The second hottest seawater temperature ever recorded since the MMP was established was 46.5°C in the southern Mackay–Whitsunday region (Figure 11).

There were no active cyclones in the 2022–23 wet season to affect Reef waters. There were, however, tropical lows that brought considerable rainfall particularly in Cape York (Gruber et al 2024).

3.2 Rainfall

Rainfall across the Reef regions in the 2022–23 wet season was generally above average in the northern NRM regions (Cape York to Mackay–Whitsunday) with the largest deviations in Cape York (Figure 5, Figure 6). The exceptions to this was rainfall in the catchments in the southern Wet Tropics (Murray and Tully Rivers), the Black River in the Burdekin Region and Lockhart River in Cape York. Rainfall for the Fitzroy and Burnett–Mary NRM regions was below the long-term average of wet seasons from 1961–1990 (Figure 5) (Gruber et al 2024).

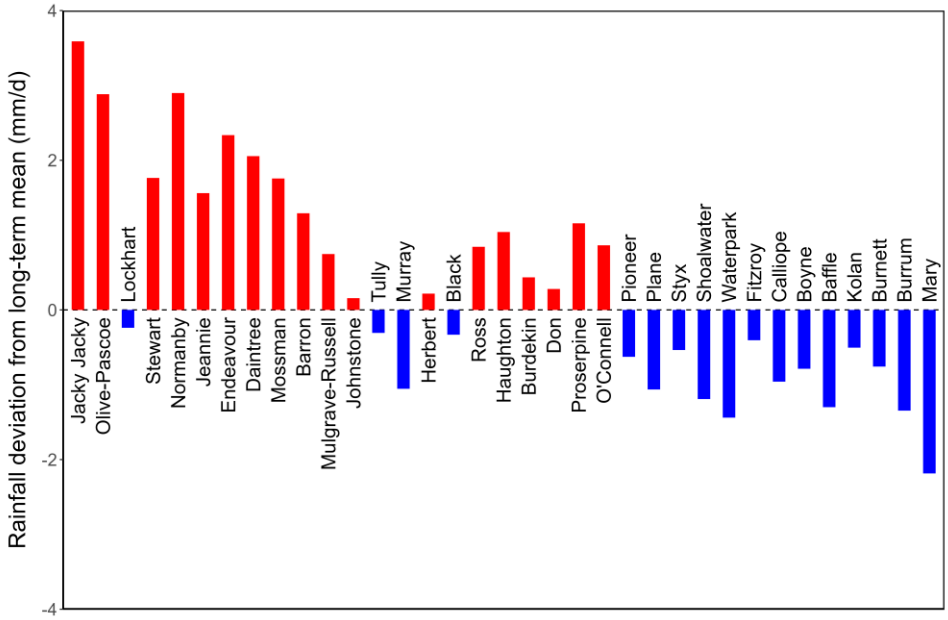


Figure 5. Per basin difference between annual average daily wet season rainfall (December 2022–April 2023) and the long-term average (1961–1990). Red and blue bars denote basins with rainfall above and below the long-term average, respectively. Note that the basins are ordered from north to south (left to right). Basins have been grouped into NRM regions as indicated by shaded panels. Compiled by Gruber *et al.* (2024).

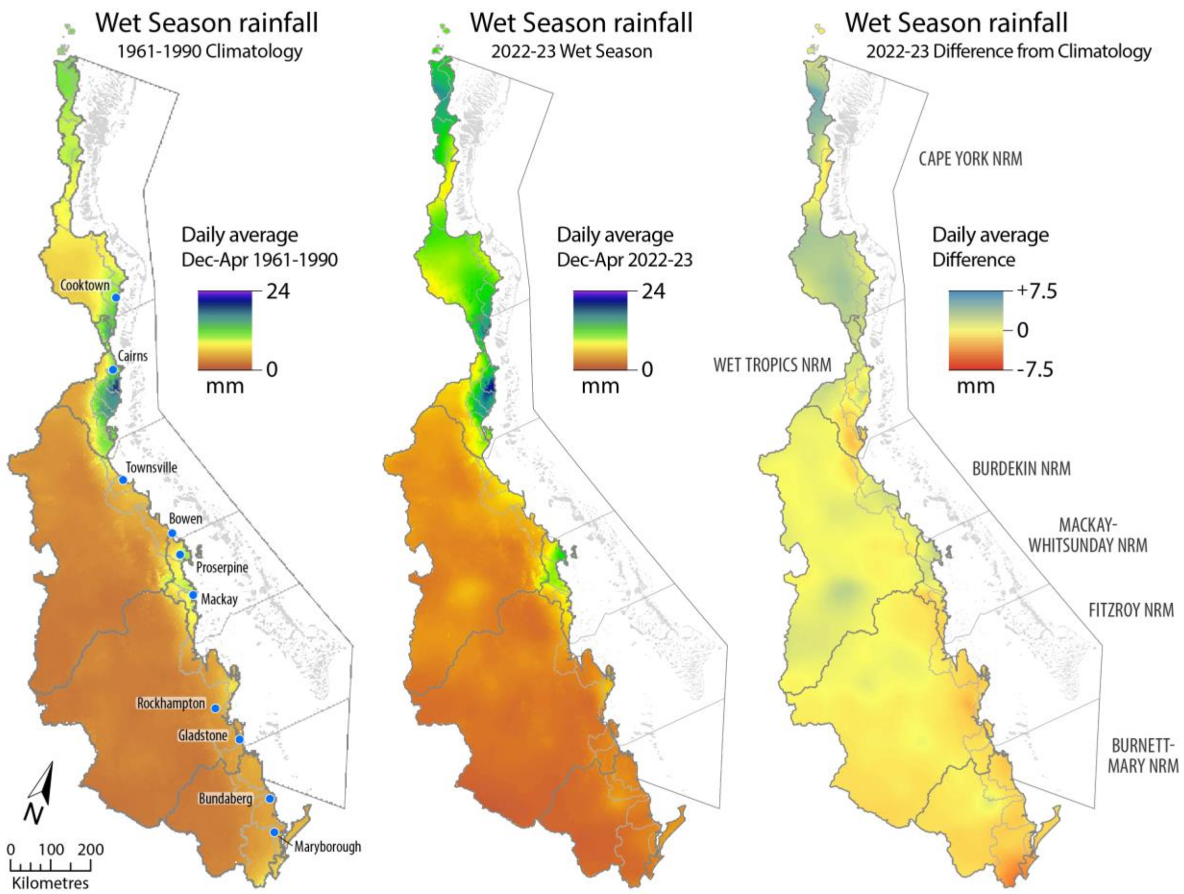


Figure 6. Average daily rainfall (mm day^{-1}) in the Reef catchment: (left) long-term annual average (1961–1990; time period produced by BOM), (centre) 2022–23 and (right) the difference between the long-term annual average and 2022–23 rainfall patterns where negative values indicate less rain. From by Moran *et al*. (2023).**River discharge**

Annual river discharge for the Reef was above the long-term median in 2022–23 following two wet years in 2020–21 and 2021–22, and a dry year in 2019–20 (Table 11). Discharges from basins entering Cape York were all above the long-term median, reaching more than three times above it in the Normanby River. River discharge was also above the long-term median (more than double) in the Daintree and Barron Rivers in the northern Wet Tropics, but not in the southern Wet Tropics. River discharge in 2022–23 was also two times the long-term median in three of the Burdekin region rivers, including the Burdekin River and in two of the Mackay–Whitsunday rivers. River discharge was below the long-term median in the Fitzroy and Burnett–Mary regions on average but were elevated in the relatively small Water Park Creek and Burrum River.

Table 11. Annual water year discharge (ML) of the main Reef rivers (1 October 2022 to 30 September 2023, inclusive) compared to the previous three wet seasons and long-term (LT) median discharge (1986–87 to 2021–22). Colours indicate levels above the long-term median: yellow = 1.5 to 2 times, orange = 2 to 3 times and red = greater than 3 times. Compiled by Moran *et al*. (2023).

Region	Basin	LT median	2019 - 2020	2020 - 2021	2021 - 2022	2022 - 2023
Cape York	Jacky Jacky Creek	2,471,267	2,320,007	3,607,722	2,365,731	4,611,721
	Olive Pascoe River	3,180,267	3,295,502	5,540,683	4,879,388	6,053,581
	Lockhart River	1,538,839	1,594,598	2,680,976	2,360,994	2,929,152
	Stewart River	758,172	564,816	1,419,942	569,738	1,366,633
	Normanby River	3,864,344	2,752,573	6,149,878	3,562,637	11,791,399
	Jeannie River	1,428,920	668,813	1,342,490	1,566,621	2,093,623
	Endeavour River	1,583,881	752,514	1,489,348	1,734,492	2,310,900
Wet Tropics	Daintree River	1,918,174	1,109,229	1,834,774	2,519,318	4,685,640
	Mossman River	604,711	399,108	654,566	800,754	815,267
	Barron River	622,447	346,727	667,265	692,908	1,217,590
	Mulgrave-Russell River	4,222,711	2,870,672	4,771,460	4,091,750	4,291,804
	Johnstone River	4,797,163	3,466,725	5,324,040	4,712,174	5,385,426
	Tully River	3,393,025	2,200,744	4,123,338	3,175,489	3,660,701
	Murray River	1,484,246	1,053,705	1,947,050	1,269,280	1,526,232
	Herbert River	3,879,683	1,606,187	6,842,168	3,283,590	4,919,143
Burdekin	Black River	293,525	144,144	429,282	273,677	353,756
	Ross River	279,376	293,165	232,975	202,811	209,681
	Haughton River	558,735	335,094	595,709	735,754	1,219,825
	Burdekin River	4,406,780	2,203,056	8,560,072	5,442,976	9,702,259
	Don River	496,485	481,577	510,906	383,927	999,723
Mackay-Whitsunday	Proserpine River	859,348	592,063	537,613	446,839	1,869,821
	O'Connell River	835,478	575,617	522,680	434,427	1,817,882
	Pioneer River	616,216	383,506	235,359	277,610	761,905
	Plane Creek	1,058,985	1,141,784	600,958	489,222	1,440,350
Fitzroy	Styx River	629,037	796,233	927,219	1,080,829	849,506
	Shoalwater Creek	727,306	920,902	1,072,570	1,250,433	982,586
	Water Park Creek	392,614	551,010	675,102	820,627	601,479
	Fitzroy River	2,875,792	2,786,994	436,730	4,505,289	3,078,896
	Calliope River	257,050	184,697	123,050	250,551	135,396
	Boyne River	179,108	99,139	31,002	171,925	44,649
Burnett-Mary	Baffle Creek	347,271	161,554	112,323	1,000,587	170,693
	Kolan River	115,841	28,792	19,211	818,716	83,734
	Burnett River	264,307	332,366	118,241	3,894,616	358,852
	Burrum River	130,835	112,113	44,691	1,612,683	270,059
	Mary River	908,873	551,344	420,909	10,139,380	673,298
	Sum of basins	59,819,075	37,677,067	64,602,302	71,817,742	83,283,163

3.4 Turbid water exposure and flood plume extent

The frequency of exposure to wet season water types, extent of the water types, and the within-canopy environmental pressures daily light and water temperature and deviations in these compared to the long-term average are summarised in Figure 7.

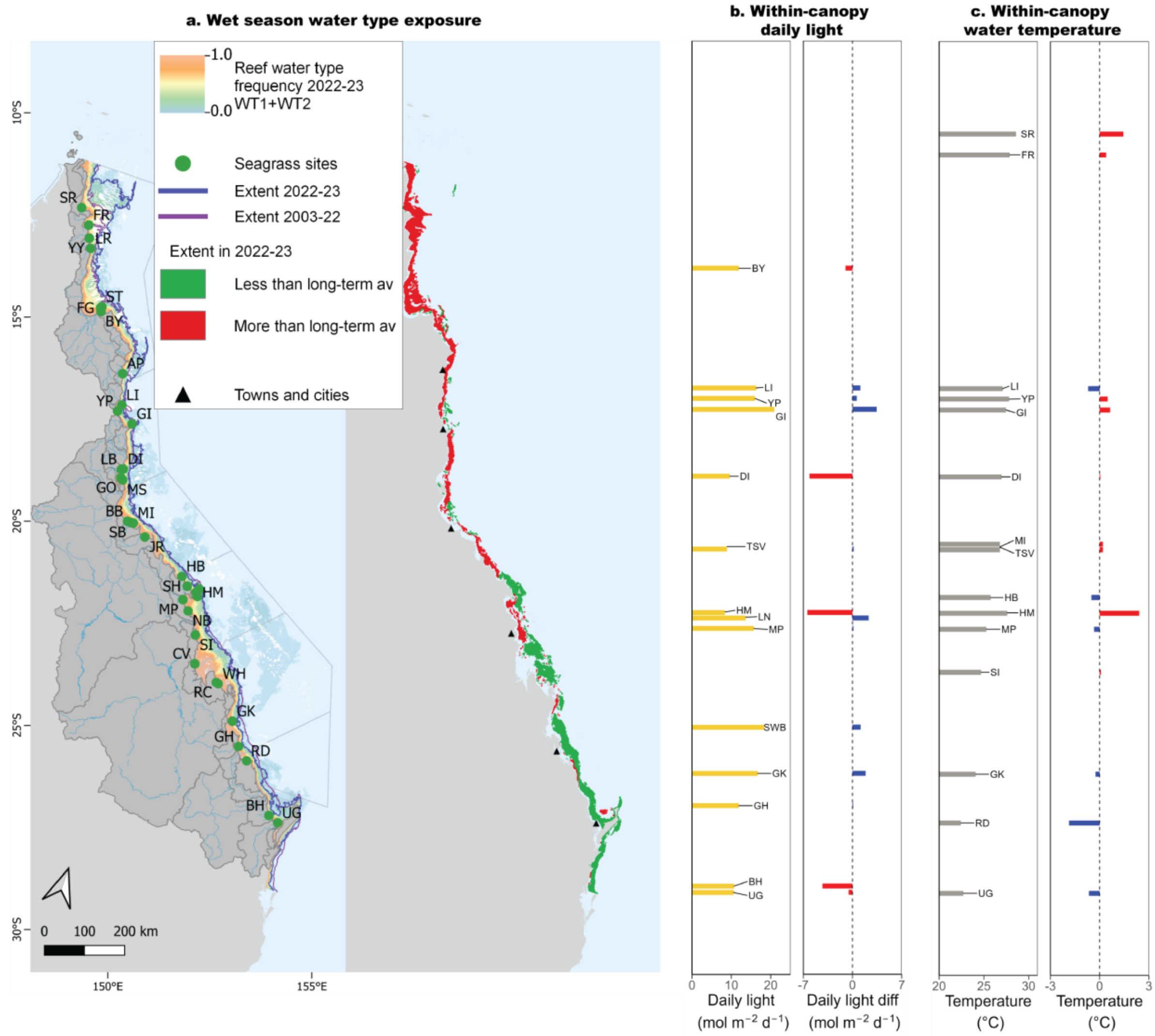


Figure 7. Environmental pressures in the Reef during 2022–23 and relative to long-term: a. Frequency of turbid water (WT1 and WT2) exposure shown in the left-hand panel in the Reef from December 2022 to April 2023 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed), and right-hand panel the distribution of WT1 and WT2 (10 per cent boundary) in 2022–23 relative to the long-term average, with red showing that that these water types extended further in 2022–23 and green showing they did not extend as far; b. within canopy daily light (shown as I_d) for all sites, and the deviation in daily light relative to the long-term average; and c. average within canopy water temperature, and deviation from the long-term average. Panels a and b from Gruber *et al*. (2024).

Turbid coloured water (WT1 and WT2) dominated the water types in the wet season (December 2022–April 2023) as is characteristic of inshore conditions over the long-term (2003–2019, Figure 7, panel 1). WT1 and WT2 extended further off shore in 2022–23 than the long-term average in Cape York, the Wet Tropics and Burdekin was similar to the long-term average in the Mackay-Whitsundays and extended less further offshore than average in the Fitzroy and Burnett–Mary NRM regions (Figure 7, panel 2).

The frequency which the seagrass sites were exposed to WT1 and WT2 combined in the wet season was above multiannual conditions in Cape York and in the Wet Tropics (Figure 8). By area, there was a 9% increase in mapped Cape York seagrass that was exposed to the moderate risk category of water types compared to the long-term average but in the Wet Tropics there was a decrease in risk of exposure to high and moderate risk (Gruber et al

2024). Exposure of seagrass sites to WT1 and WT2 were below multiannual conditions in all other regions with the largest differences occurring in the Fitzroy where there was less exposure to WT1 but more exposure to WT2 (lower turbidity, higher light) resulting in very little change in exposure to the water types combined. In the Mackay–Whitsunday NRM region there was less exposure to both WT1 and WT2. By area, there was little change in the risk categories for water quality in the Burdekin region compared to the long-term average and in the Mackay–Whitsunday NRM region there was an increase in the likelihood that mapped seagrass was not exposed to any water quality risk in the wet season (Gruber et al 2024). Area of risk is not assessed for the Fitzroy and Burnett–Mary regions in the water quality report.

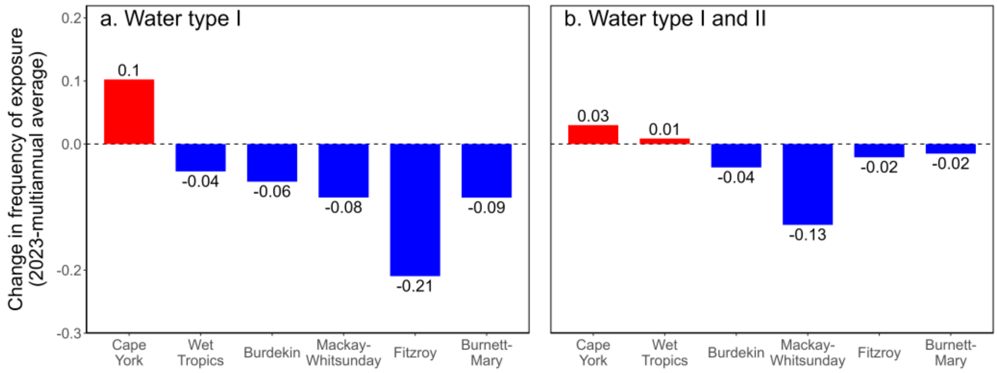


Figure 8. Difference in the frequency of exposure to primary (WT1, left) and primary and secondary optical water types (WT1 and WT2, right) at seagrass monitoring sites during the wet season (December 2022–April 2023) compared to the long-term multiannual exposure (2003–2018).

3.5 Daily light

Daily light reaching the top of the seagrass canopy in the Reef in 2022–23 was 12.4 mol m^{-2} d^{-1} when averaged for all sites (Table 10), compared to a long-term average of 13.8 mol m^{-2} d^{-1}. During this monitoring year only 16 out of 23 of the locations where light is monitored had at least 50% of usable data due to various instrument failures. Daily light was lower than the long-term average at five locations in all regions except the Burdekin and Fitzroy regions (Figure 7). There are regional, habitat and location levels differences.

Daily light in shallow habitats can be affected by water quality, depth of the site and cloud cover, which affects the frequency and duration of exposure to full sunlight at low tide (Anthony *et al.* 2004; Fabricius *et al.* 2012). Differences in daily light among seagrass meadows reported here are largely a reflection of site-specific differences in water quality, except in reef subtidal habitats where depth results in lower benthic light compared to adjacent reef intertidal habitats. Water quality is affected by river discharge and resuspension from wind and currents.

Daily light in the regions in 2022–23 from north to south were (↓ = lower than, ↑ = greater than the long-term, ↕ = similar to long-term i.e. <0.5 mol m^{-2} d^{-1} difference):

- Cape York (13.5 mol m^{-2} d^{-1}) ↓
- northern Wet Tropics (15.0 mol m^{-2} d^{-1}) ↓
- southern Wet Tropics (9.6 mol m^{-2} d^{-1}) ↓
- Burdekin (10.3 mol m^{-2} d^{-1}) ↓
- Mackay–Whitsunday (12.3 mol m^{-2} d^{-1}) ↕
- Fitzroy (15.1 mol m^{-2} d^{-1}) ↕
- Burnett–Mary (9.9 mol m^{-2} d^{-1}) ↓

Daily light in the habitats in 2022–23 from highest to lowest were (↓ = lower than, ↑ = greater than, ↕ = similar to long-term i.e. <0.5 mol m^{-2} d^{-1} difference):

- reef intertidal, n = 9 (15.6 mol m^{-2} d^{-1}) ↕
- coastal intertidal, n = 10 (13.4 mol m^{-2} d^{-1}) ↑
- estuarine, n = 3 (11.2 mol m^{-2} d^{-1}) ↕

Daily light on the Reef is generally high in intertidal habitats when averaged for the year because of the occasional exposure to very high light when low tide occurs in daylight hours. However, these periods of exposure to high light occur infrequently during the wet season, because the tides do not drop to low levels during daylight hours at that time of year. Average daily light levels follow a gradient increasing from inshore to offshore: reef intertidal sites have the highest daily light levels followed by coastal intertidal and estuarine intertidal sites. Daily light for each of the sites is presented in Figure 7. The annual daily light level was much lower than the long-term average at Dunk Island, Hamilton Island and Burrum Heads (Figure 100, Figure 101, Figure 102). These sites had lower than usual light levels in the dry season, which may reflect a combination of wind-induced resuspension and elevated turbidity (this would not show in water type exposure which is only assessed for the wet season) for the two reef sites. Burrum Heads was also likely to have legacy effects of the highly elevated discharge in the previous reporting year.

Long-term trends show a peak in within–canopy daily light that occurs from September to December, as incident solar irradiation reaches its maximum prior to wet season conditions (Figure 9). This also coincides with the peak seagrass growth period, and the predominant sampling period in this program. The peak in light at this time of year appears to have been getting progressively lower over the data set. This is in part due to increases in the number of sites over time; however, no new sites have been added since 2021 (intertidal reef habitat, Lindeman Island) and so are unlikely to be the only cause for the decline. The lowest light levels typically occur in the wet season, particularly in January to July. In 2022–23, daily light quickly decreased with the onset of the wet season and then improved towards the end of the wet season. The 28-day rolling average for light was below the long-term wet season average for most of the wet season.

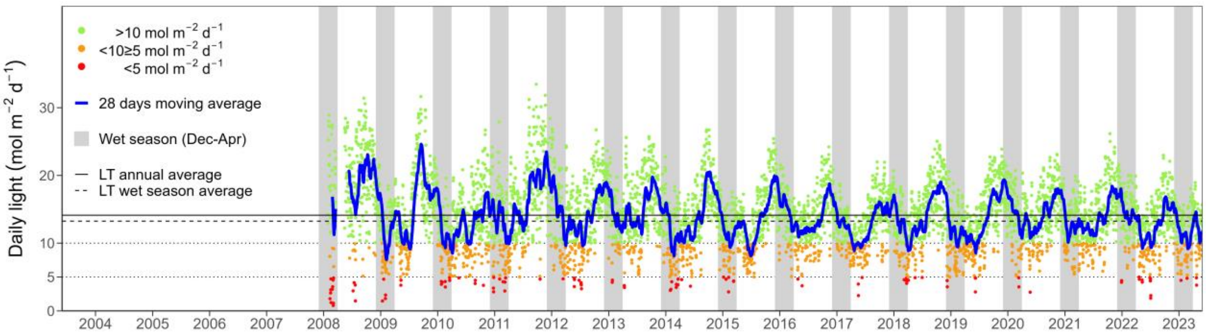


Figure 9. Daily light (coloured points) and 28-days moving average (blue, bold line) for all sites combined from 2008 to 2023. In 2008–2009, light data is from the Burdekin and Wet Tropics regions only. Other regions were included from 2009–2010, with Cape York added post 2012–2013 reporting period. Shaded vertical bars indicate the wet season months (December to April) used for analysis of wet season optical water types Moran *et al*. (2023). The solid horizontal line indicates the long-term Reef average, and the dashed line indicates the wet season long-term Reef average. Dotted lines are for visual reference and indicate an approximate short-term light threshold (5 mol m^{-2} d^{-1}, NB 6 mol m^{-2} d^{-1} may also be used as a management threshold) with red points being values below the line and long-term light threshold (10 mol m^{-2} d^{-1}) with orange points showing values below it (Collier *et al.* 2016b).

3.6 Within-canopy seawater temperature

Daily within-canopy seawater temperature across the inshore Reef in 2022–23 was slightly lower than the previous reporting period (Figure 10). Since 2013, the frequency of weekly warm water deviations appears to have increased, relative to cooler occurrences (Figure 10). The 2022–23 average temperature (26.1 ±0.5°C) was the equal third highest since the

MMP was established (2016-17 was the highest) and 0.4°C above the long-term (2003–2022, 25.7°C) (Table 10). However, there were regional and habitat differences relative to the long-term (Figure 7).

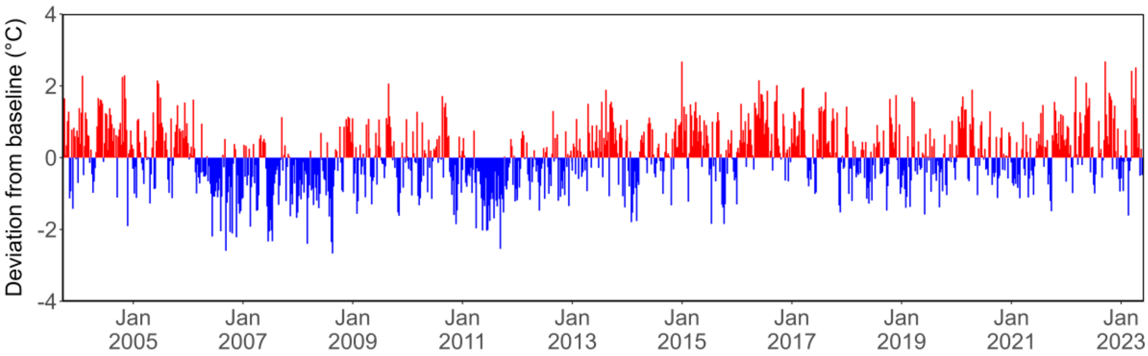


Figure 10. Inshore intertidal sea temperature deviations from baseline for Reef seagrass habitats from 2003 to 2023. Data presented are deviations from 19-year mean weekly temperature records (based on records from September 2003 to June 2022). Weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars. Blue bars represent weeks with temperatures lower than the average and are plotted as negative deviations.

Daily within-canopy seawater temperatures in the regions in 2022–23 (including number of days above 35°C and 40°C) from north to south as difference relative to the long-term average (↑ = above, ↓ = below, ↕ = similar to long-term, difference = greater than 0.3°C) were:

- Cape York (avg = 27.8°C, max = 41.5°C, days$_{>35\leq40°C}$ = 61, days$_{>40°C}$ = 1)↑
- northern Wet Tropics (avg = 27.5°C, max = 42.0°C, days$_{>35\leq40°C}$ = 77, days$_{>40°C}$ = 3)↑
- southern Wet Tropics (avg = 27.0°C, max = 34.3°C, days$_{>35°C}$ = 0)↕
- Burdekin (avg = 26.8°C, max = 39.5°C, days$_{>35\leq40°C}$ = 37) ↕
- Mackay–Whitsunday (avg = 25.5°C, max = 46.5°C, days$_{>35\leq40°C}$ = 78, days$_{>40°C}$ = 16) ↕
- Fitzroy (avg = 23.9°C, max = 39.8°C, days$_{>35\leq40°C}$ = 6)↓
- Burnett–Mary (avg = 23.3°C, max = 37.3°C, days$_{>35°C}$ = 3) ↓

Daily within-canopy seawater temperatures in each habitat in 2022–23 relative to respective long-term average (↑ = above, ↓ = below, ↕ = similar to long-term, difference = greater than 0.3°C) were:

- estuarine habitat (avg = 23.9°C, max = 46.5°C)↕
- coastal intertidal habitat (avg = 26.5°C, max = 44.7°C)↑
- reef intertidal habitat (avg = 26.6°C, max = 42.0°C)↑

The hottest seawater temperature recorded at inshore seagrass sites along the Reef during 2022–23 was 46.5°C at Sarina Inlet (29Oct22) in the southern Mackay–Whitsunday region. This was the second hottest temperature ever recorded since the MMP was established (hottest was 46.6 ºC at Shelley Beach, 3pm on 10Jan08). In 2022-23, Cape York, the Wet Tropics, and Mackay–Whitsunday NRM regions recorded more days of extreme temperatures (>40°C) since monitoring was established (Figure 11). Extreme temperature days can cause photoinhibition but when occurring at such low frequency, they were unlikely to cause burning or mortality.

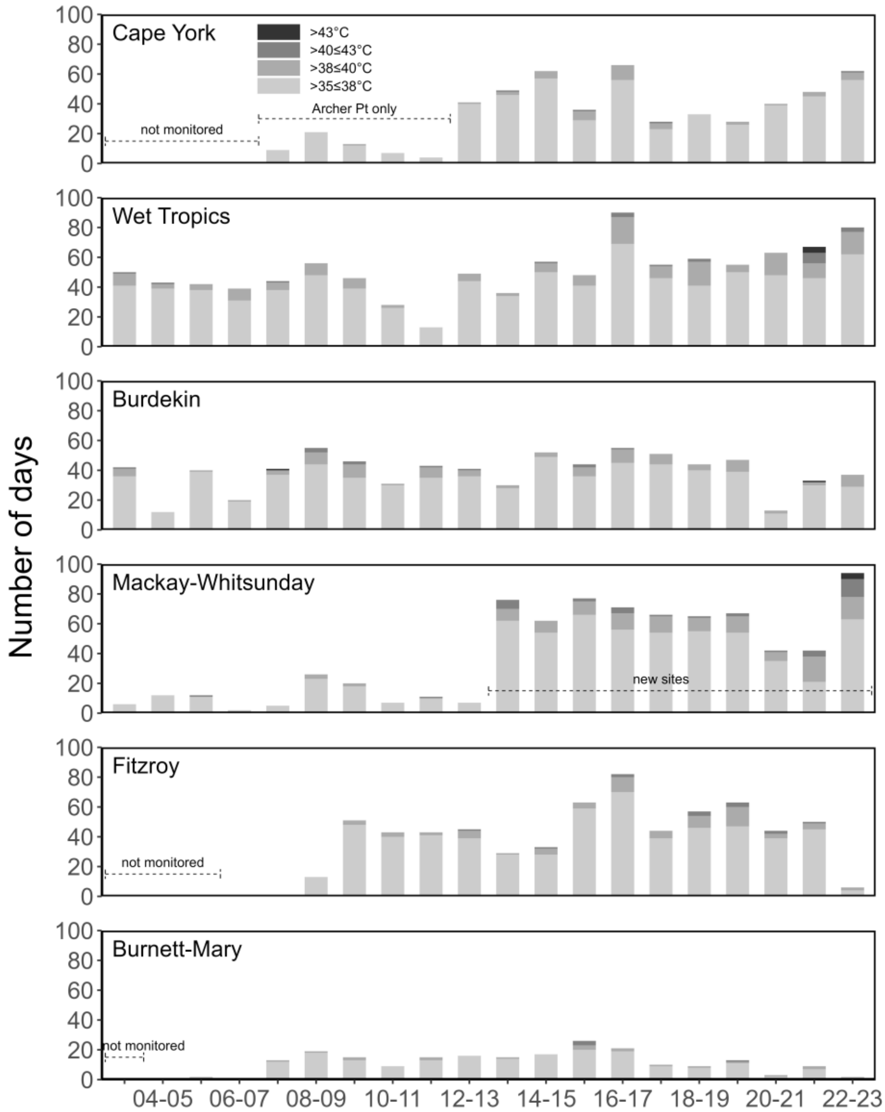


Figure 11. Number of days when inshore intertidal sea temperature exceeded 35°C, 38°C, 40°C and 43°C in each monitoring period in each NRM region.Thresholds adapted from Campbell *et al*. 2006; Collier *et al*. 2012a.

3.7 Seagrass meadow sediments

Coastal subtidal and estuarine seagrass habitats across the Reef had a greater proportion of fine sediments (i.e. mud) than other habitats (Table 12). Sediments at intertidal coastal habitats were predominately medium and fine sands, while reef habitats (intertidal and subtidal) were dominated by medium sands (Table 12).

Table 12. Long-term average (±SE) sediment composition for each seagrass habitat (pooled across regions and time) monitored within the Reef (1999–2022). *only 7 years of data.

Habitat	Mud	Fine sand	Sand	Coarse sand	Gravel
estuarine intertidal	44.5 ±2.1	23.0 ±2.1	30.4 ±1.8	0.2 ±0.5	1.8 ±0.9
coastal intertidal	27.6 ±2.1	31.7 ±2.4	36.4 ±2.5	0.4 ±0.7	3.9 ±1.2
coastal subtidal*	54.1 ±2.5	8.8 ±0.3	18.4 ±.2.3	5 ±0.9	13.7 ±1.1
reef intertidal	4.3 ±1.2	6.9 ±1.8	53.4 ±2.8	14.9 ±1.9	20.6 ±2.3
reef subtidal	15.7 ±0.9	14.2 ±1.0	57.8 ±5.3	1.1 ±0.5	11.2 ±5.3

During the 2022–23 monitoring period the contribution of mud to sediment type relative to the previous year increased at estuarine habitats (Figure 12). The contribution of mud sediments declined in all other habitats, but in subtidal habitats remained above the long-term average (Figure 12). Historically, the composition of sediments has fluctuated at all habitats, with the proportion of mud declining below the long-term average at estuarine and coastal habitats immediately following periods of physical disturbance from storms when seagrass cover greatly declines (e.g. cyclones in 2006 and 2011). Conversely, the proportion of mud increased above the long-term average at reef (intertidal and subtidal) habitats during periods of extreme climatic events (e.g. cyclones and/or flood events).

Finer-textured sediments (i.e. mud) tend to have higher nutrient concentrations and greater levels of anoxia. Although anaerobic conditions may stimulate germination in some species, the elevated sulphide levels generally inhibit leaf biomass production in more mature plants. Only seagrass species adapted for growth in anaerobic mud sediments (e.g. *Nanozostera*) are able to persist, providing sufficient light for photosynthesis is available.

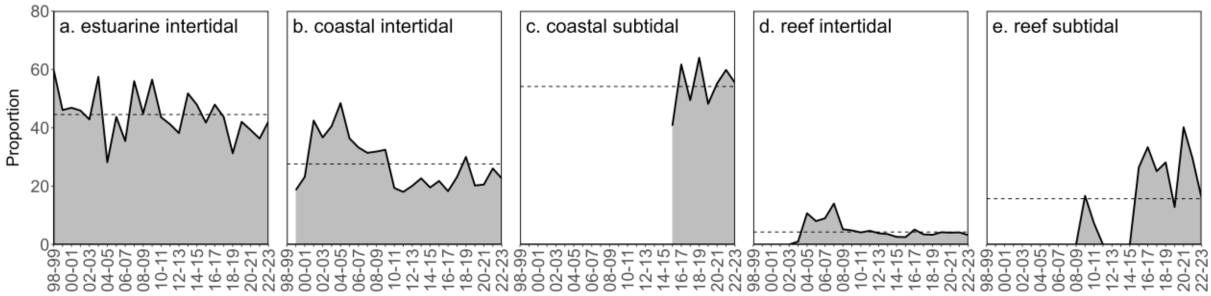


Figure 12. Proportion of sediment composed of mud (grain size <63µm) at inshore Reef seagrass monitoring habitats from 1999–2023. Dashed line illustrates the Reef long-term average for each habitat type.

4 Seagrass condition and trend

The following results section provides detail on the overall seagrass responses for the 2022–23 monitoring period, in context of longer-term trends. It is structured as an overall inshore Reef summary with condition and trend for each habitat type presented separately, including:

- a summary of the key findings from the overall section including a summary of the report card score
- seagrass abundance (per cent cover) and spatial extent
- seagrass species composition based on life history traits
- seagrass reproductive effort and seed banks
- epiphyte and macroalgae abundance
- linkage back to broad-scale environmental pressures.

Detailed results for each region are presented in the next section. Supporting data identified as important in understanding any long-term trends is detailed within Appendix 2 and 3. Detailed site specific data can be accessed at https://bit.ly/3THVNUd. Seagrass condition trends can also be accessed with water quality and coral condition results at the Reef Knowledge System MMP dashboard at https://bit.ly/4aGrG5A .

4.1 Overall inshore Reef seagrass condition and trend

Inshore seagrass meadows across the Reef remained unchanged in overall condition in 2022–23, with the condition grade remaining **moderate** (Figure 13).

In summary, the unchanged condition was due to the increase in seagrass abundance being offset by a similar decrease increase in the resilience indicator:

- After a slight stagnation in the past two years, the seagrass abundance indicator has shown an improvement in 2022–23. However, it still remains moderate. Seagrass abundance has fluctuated temporally at meadows monitored in the MMP over the life of the program, displaying periods of decline and variable recovery. The largest declines occurred from 2009 to 2012, caused by consecutive years of above-average rainfall, and resultant discharges of poor quality water, followed by extreme weather events, after which abundance increased (Figure 13, Figure 15b). Following 2012, seagrass recovery proceeded for five years until stalling in 2016-17 as a result of regional climatic events, after which abundances subsequently declined. From late 2020, seagrass abundances improved, although recovery appears somewhat muted with a slight decline relative to the previous reporting period. Based on the average score against the seagrass guidelines (determined at the site level), the abundance of inshore seagrass across the Reef over the 2022–23 were in a moderate condition (Figure 13).

- The resilience indicator declined in 2022–23 (Figure 13) after being on a slight improving trajectory over the previous two years and reached the lowest value in 10 years. The long-term trend in the resilience indicator is similar to the abundance indicator with large declines from 2009 to 2012 due to extreme weather events recovering to good in 2016–17 then starting to decline again in 2017–18 from which the Indicator has not substantially recovered.

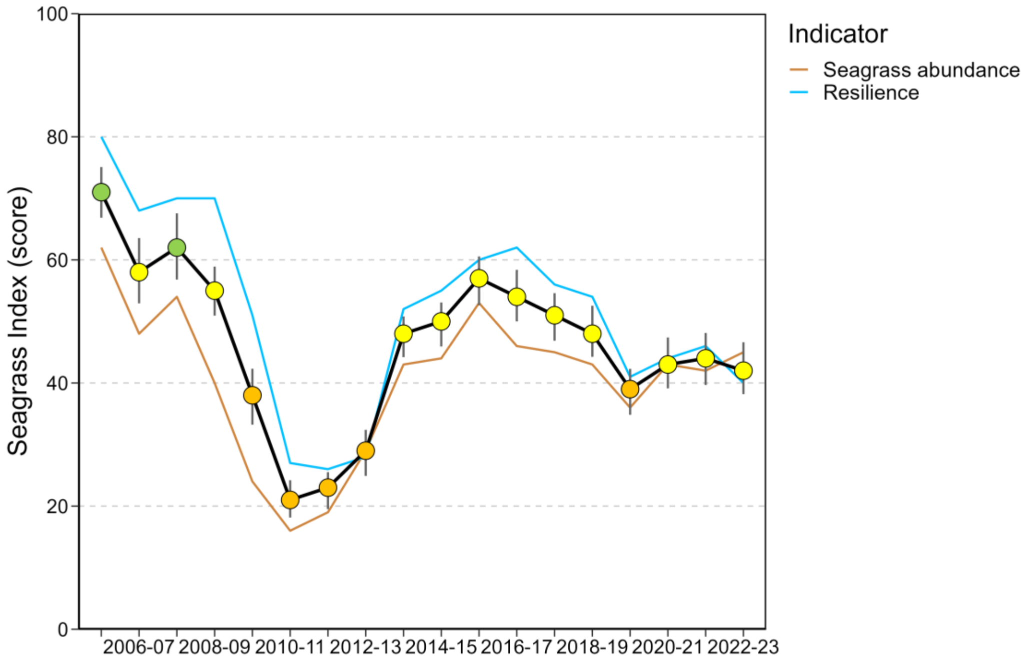


Figure 13. Overall inshore Reef Seagrass Index (± SE) with contributing indicator scores over the life of the MMP. The Index is derived from the aggregate of metric scores for indicators of seagrass condition: abundance and resilience. Index scores scaled from 0–100 and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40), ● = very poor (0–20). NB: Scores are unitless.

4.2 Trends in seagrass condition indicators between regions

The overall inshore Reef score for seagrass is derived from the average of seagrass indicator scores in each of the six NRM regions, weighted by inshore seagrass area. In 2022–23 the score improved in two NRM regions (Cape York, Mackay–Whitsunday) remained stable in one (Wet Tropics) and deteriorated in the remaining, in particular the most southern (Fitzroy and Burnett-Mary) (Figure 14). Over the long term, the indicators tend to diverge during periods of elevated disturbance and loss, but converge and follow a similar trend during periods of low disturbance. These patterns and trends in the indicators are more apparent at the regional scale, with the variation among the six regions:

- Seagrass abundance was graded as moderate across all NRM regions from Mackay–Whitsunday to the north, while the Fitzroy and Burnett–Mary regions were rated as poor and very poor, respectively (Figure 14). The abundance score in 2022–23 increased from the previous year 2021–22 in the Cape York, Mackay–Whitsunday and Fitzroy regions and declined in all other regions, with the exception of the Burnett–Mary which remained unchanged. The largest change to the abundance score was in the Mackay–Whitsunday region, which greatly improved compared to 2021–22 resulting in an increase to moderate from poor in the previous year. It is the first time the score has been moderate in the Mackay–Whitsunday region in seven years. The Fitzroy region also recovered to poor in 2022–23 after dipping to very poor in the previous year.

- The seagrass resilience score was moderate in the Wet Tropics, Burdekin and Mackay–Whitsunday NRM regions, but poor in the Cape York, Fitzroy and Burnett–Mary NRM regions (Figure 14). The trends in the resilience score vary among regions with improvements occurring in 2022–23 in the Wet Tropics and Mackay–Whitsundays but declines in all other regions. The largest decline and lowest score was in the Burnett–Mary NRM region.

Inshore seagrass condition scores across the regions reflect a system that is being impacted by heatwaves, cyclones, and elevated discharge from rivers. Regional differences in condition and indicator scores appear due to the legacy of significant environmental conditions in 2016–17 (e.g. cyclone Debbie in Mackay–Whitsunday, above-average riverine discharge throughout the southern and central Reef and in 2018–19 in the Burdekin region and a marine heatwave in the northern and central Reef). There are also local-scale changes influencing regional scores, particularly in the Fitzroy region.

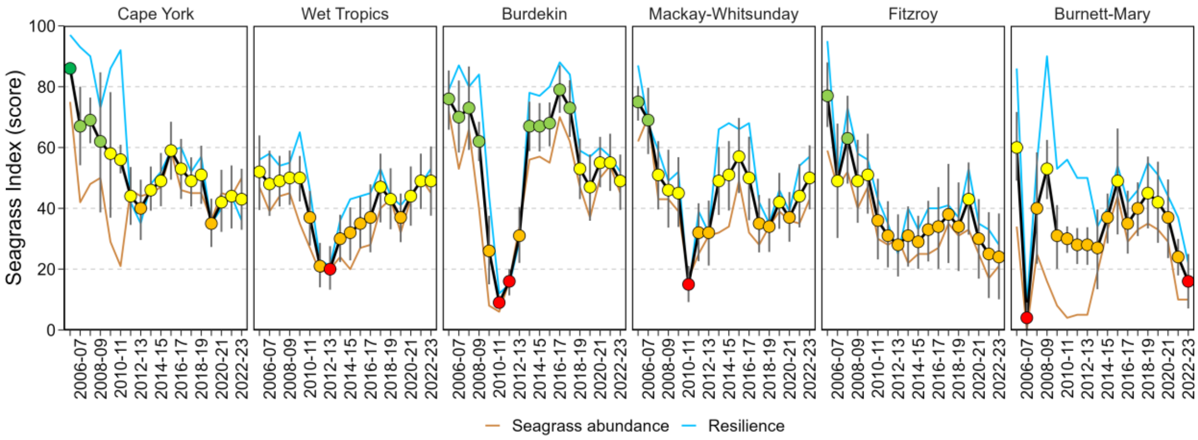


Figure 14. Seagrass Index (± SE) with contributing indicator scores for each NRM region over the life of the MMP. The Index is derived from the aggregate of metric scores for indicators of seagrass condition: abundance and resilience. Values are indexed scores scaled from 0–100 and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40), ● = very poor (0–20). NB: Scores are unitless.

The long-term trends for each of the contributing indicators used to calculated the Seagrass Index are shown in Figure 15. Results from the generalised additive models are presented for per cent cover to show long-term trends. Seagrass abundance has varied over decadal time-scales, declining in the 2009–10 through 2011–12 monitoring periods, then recovering to some extent depending on region, and subsequently declining over recent years. The overall trend has been relatively stable since 2018–19. The resilience indicator score has similarly declined to its lowest levels in the 2010–11 through 2012–13 monitoring periods. The resilience score has varied little over the past four years but slightly declined in 2022–23 after small increases in the previous two years.

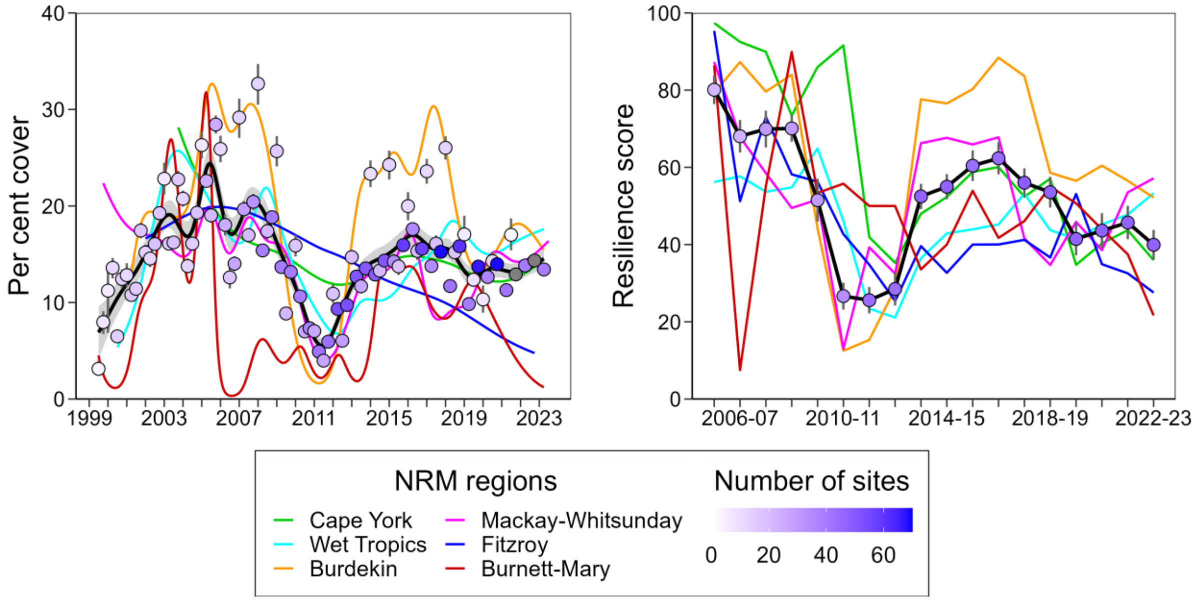


Figure 15. Trends in the seagrass indicators used to calculate the Seagrass Index including trends in Reef seagrass abundance (per cent cover, ± SE) represented by a GAM plot (black line with shaded areas defining 95 per cent confidence interval), and coloured lines representing NRM trends (left), and trends in Reef resilience score (black line and circles, ± SE) and coloured lines represent trends in NRM resilience scores (right). Circle colour relates to number of sites assessed. Please note: Reef resilience scores are weighted.

4.3 Trends in seagrass condition indicators by habitat type

4.3.1 Seagrass abundance, composition and extent

Seagrass abundance has fluctuated since monitoring was established. An examination of long-term abundances at inshore Reef sites indicates no significant trend overall, with:

- no significant trends at 80 per cent of long-term monitoring sites assessed, although 10 per cent of sites significantly increased in abundance and 18 per cent decreased (Appendix 3, Table 22)
- the rate of change in abundance was similar at sites increasing (0.5 ±0.2 per cent, sampling event^{-1}) and decreasing (-0.6 ±0.2 per cent sampling event^{-1}) (Appendix 3, Table 22)
- the most variable seagrass habitat in abundance (since 2005) was estuarine intertidal (CV=112.6%), followed by reef habitats (intertidal CV=56.2% and subtidal CV=48.4%), and lastly, coastal habitats (intertidal CV=39.3% and subtidal CV=29.5%).

Since 1999, the median percentage cover values for the Reef were mostly below 25 per cent cover, and depending on habitat, the 75th percentile occasionally extended beyond 50 per cent cover (Figure 16). These long-term percentage cover values were similar to the Reef historical baselines, where surveys from Cape York to Hervey Bay (between November 1984 and November 1988) reported around three-quarters of the per cent cover values fell below 50 per cent (Lee Long *et al.* 1993). The findings highlight the need to use locally-relevant reference sites and score thresholds.

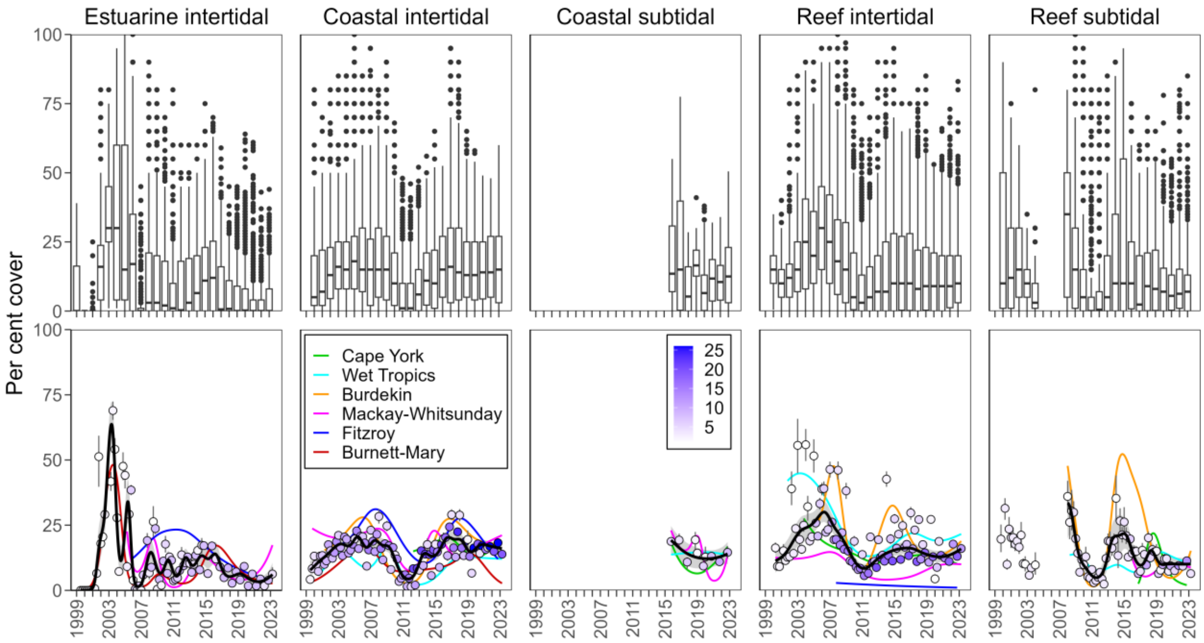


Figure 16. Seagrass per cent cover measures per quadrat from habitats monitored from June 1999 to May 2023 (sites pooled). In the whisker plots (top), the box represents the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the dots represent outlying points. GAM plots (bottom), showing trends for each NRM (coloured lines) and combined as dark lines with shaded areas defining 95th confidence intervals of those trends. Colour of circles represents the number of sites assessed to calculate the average, and vertical error bars represent standard error.

In 2022–23, coastal habitats continued to have the highest average abundance of all habitat types, and estuarine the lowest (Figure 16). Over the past decade, the patterns of seagrass abundance in each habitat have been similar between intertidal sites in coastal and reef habitats; gradually increasing after the extreme weather events of early 2011 (e.g., cyclone Yasi), followed by declines from 2017 to 2019 (a consequence of cyclone Debbie), before improving from 2020 (Figure 16).

Estuarine habitats, which are monitored only in the southern NRM regions (Mackay–Whitsunday, Fitzroy and Burnett–Mary), reached record per cent cover level prior to the establishment of the MMP, but have remained low since 2005–06. Over the last decade, estuarine abundances have fluctuated at a location level, most often at smaller localised scales where there has been some acute event related changes, e.g. sediment deposition and/or reduced light availability due to discharge events, or sediment movement due to climatic pressures. Following 2016, seagrass abundances have progressively declined, reaching their lowest levels during the previous year before the onset of recovery in 2022–23 (Figure 16).

In 2022–23, the overall inshore Reef relative meadow spatial extent continued to increase relative to the previous year, however late dry season extents remain lower than the baseline (2005), 2014–15 and 2015–16 (Figure 17). The overall trend is seagrass meadow extent since the MMP was established in 2005, shows a gradual decline from 2008–09 to early 2011, recovering within 3–4 years, subsequently declining from late 2016 to early 2019 before once again starting to recover (Figure 17). Similar to seagrass abundance, these periods of decline in relative extent are a consequence of extreme weather and associated flooding or location specific climate (e.g. frequency of strong wind days).

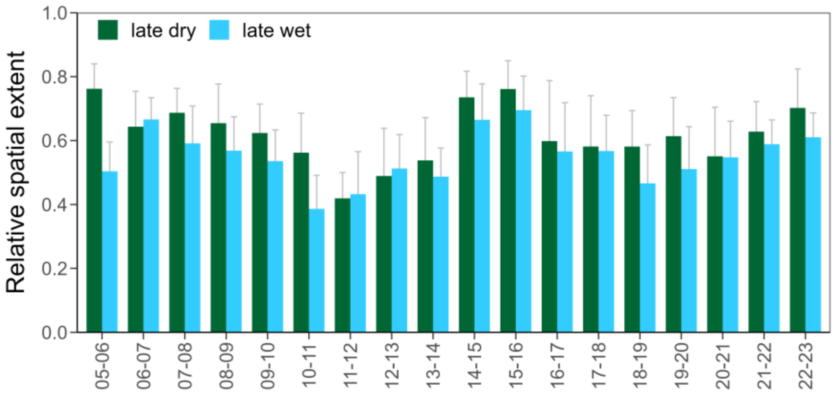


Figure 17. Average relative spatial extent of seagrass distribution at monitoring sites across inshore Reef (locations, habitats and NRM regions pooled, + SE). Green bars represent late dry and Blue bars late wet.

After a series of consecutive above-average wet seasons from 2009, capped with the extreme weather events in 2011 that caused widespread declines in seagrass extent (Figure 17) and abundance, there was increasing proliferation of species displaying colonising traits (*sensu* Kilminster *et al.* 2015), such as *H. ovalis,* at coastal and reef sites (Figure 18). From 2012–13 to 2015–16, the proportion of species displaying colonising traits gradually declined, until 2016–17 when they once again proliferated. Since then, the proportion has fluctuated within habitats. Over the 2022–23 monitoring period, with the exception of coastal intertidal habitats, the proportion of species displaying colonising traits increased above the inshore Reef average for each respective habitat type. This may indicate an increase in environmental pressures affecting seagrass growth requirements.

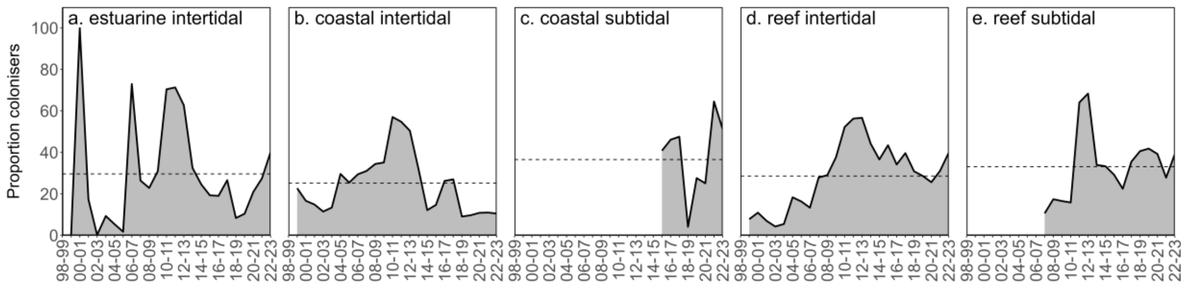


Figure 18. Proportion of total seagrass abundance composed of species displaying colonising traits (e.g. *Halophila ovalis*) in: a) estuarine intertidal, b) coastal intertidal, c) coastal subtidal, d) reef intertidal and e) reef subtidal habitats (sites pooled) of the Reef (regions pooled) for each monitoring period. Dashed line illustrates Reef average proportion of colonising species in each habitat type.

4.3.2 Seagrass reproductive status

Seagrass reproductive structures (flowers, fruits, spathes) increased in 2022–23 in the late dry on average in intertidal habitats across the inshore Reef to the highest level since 2019–20, but declined to very low levels in the wet and late wet seasons. Since the implementation of the MMP, the maximum reproductive effort and the inter-annual variability in reproductive effort has differed between habitats, and varied both within and between years. Reproductive effort across the inshore Reef meadows are typically higher in the late dry season, while seed density fluctuates less seasonally (Figure 19, Figure 20). The number of reproductive structures also tends to decline in meadows with distance from the coast, with the highest abundances on average in estuarine and coastal habitats and the lowest at reef habitats, particularly those furthest from shore.

Reproductive effort in estuarine habitats was the highest since 2016–17 (Figure 19) and seeds were the highest since 2013–14 (Figure 20). This trend was driven by increases in reproductive effort in the Mackay–Whitsunday and Fitzroy NRM regions, and they were predominantly for foundation species This trend was not observed in the Burnett–Mary where there was only one reproductive structure observed at one site in Rodds Bay. Despite this, there was an increase in seed density in the Burnett–Mary to the highest level recorded indicating that flowering had occurred but not at the time of sampling (Figure 20). Seeds were absent in the Mackay–Whitsunday NRM region but slightly increased in the Fitzroy.

In coastal habitats, reproductive effort and seed density was highly variable inter-annually - more than in other habitats. The historically high reproductive effort in coastal habitats (2017 to 2019) was due to a record number of reproductive structures in the northern Wet Tropics (Yule Point) and Burdekin (Bushland Beach and Jerona). Since 2019, reproductive effort across inshore Reef coastal habitats has remained low and in 2022–23 was similar to the previous reporting period (Figure 19). The only region to increase reproductive effort was the Mackay–Whitsunday NRM region, with others remaining similar to previous years and low. Seed bank densities also improved in coastal habitats throughout 2022–23 (Figure 20). This was driven primarily by improvements in the northern Wet Tropics, with high seed densities returning after a decline in the previous reporting year.

Reef habitats typically have the lowest reproductive effort and seed bank densities of all habitats (Figure 19, Figure 20). This is partly because of the predominance of persistent seagrass species which do not produce a seed bank in the majority of reef habitats, however, other foundational species such as *Halodule uninervis,Cymodocea rotundata* and *Oceana serrulata* have low rates of reproduction at reef sites. In 2022–23, reproductive effort remained low across reef intertidal habitats, with increases occurring in the southern Wet Tropics and small increases in the Burdekin. Seed densities remained low on average at reef intertidal sites with a small increase occurring in the Burdekin NRM region. At reef subtidal sites, reproductive effort increased on average to the second highest on record, which was due to large increases into the northern Wet Tropics, but low levels remaining at other sites. Seeds are no longer measured at reef subtidal sites as sampling on SCUBA was discontinued (see 2.2.3).

Overall, reproductive structures were absent at nearly half of the sites assessed in 2022–23. The greatest losses occurred in Cape York, while the largest improvement was in the Mackay–Whitsunday region (Figure 19). Seed densities in seed banks decreased or remained absent at over two third of sites in 2022–23, relative to the previous reporting period, with the greatest declines in the Burdekin region. Reductions in seed density are likely the result of reduced reproductive structures and success (failure to form seeds) or loss of seed bank (germination or grazing). This indicates vulnerability of these habitats to future disturbances, as recovery may be hampered although the density of seeds needed to initiate or optimise recovery is unknown.

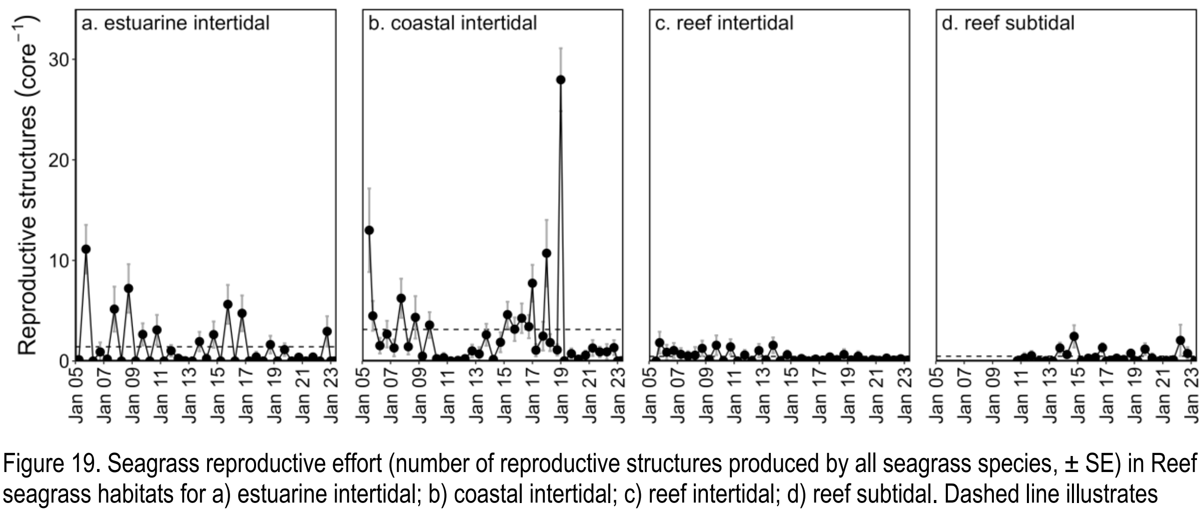


Figure 19. Seagrass reproductive effort (number of reproductive structures produced by all seagrass species, ± SE) in Reef seagrass habitats for a) estuarine intertidal; b) coastal intertidal; c) reef intertidal; d) reef subtidal. Dashed line illustrates Reef long-term average reproductive effort in each habitat type.

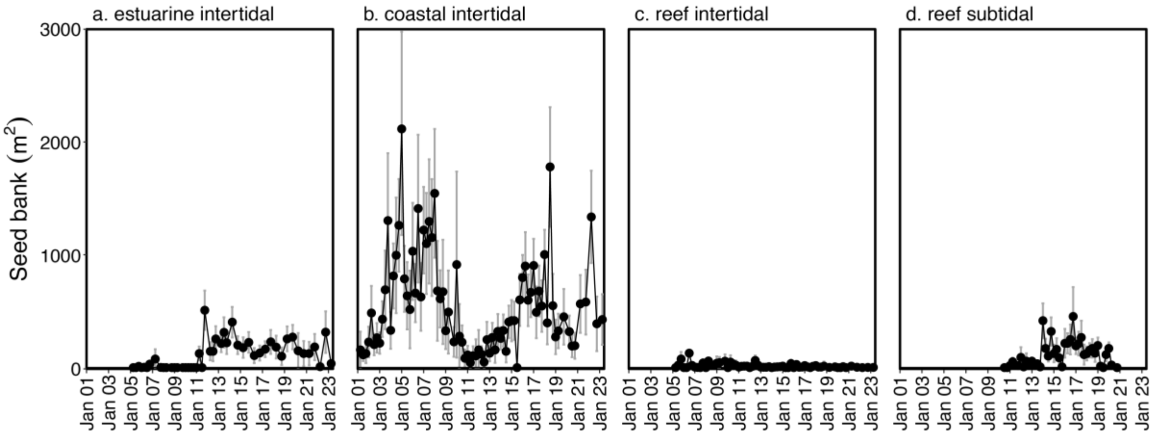


Figure 20. Average seeds banks (seeds per square metre of sediment surface, all sites and species pooled, ± SE) in Reef seagrass habitats: a) estuarine intertidal; b) coastal intertidal; c) reef intertidal; d) reef subtidal.

4.3.2.1 *Resilience*

The resilience score was poor in reef intertidal habitats and was moderate in estuarine, coastal and reef subtidal habitats. Resilience only slightly changed in all habitat types on average (Figure 21, Table 23) and there were declines and improvements at locations for all habitat types depending on the NRM region. Resilience improved in 2022–23 in estuarine sites. There was a lot of variability in the trends within region in estuarine habitats with large declines at the two estuarine locations of the Burnett–Mary but improvements in Fitzroy and Mackay–Whitsunday locations. Resilience declined in coastal habitats (Figure 21, Table 23) driven predominantly by declines in Cape York and the Burdekin NRM regions. Resilience also declined slightly at reef intertidal habitats with the largest declines at Lindeman Island in the Mackay–Whitsundays and Great Keppel Island in the Fitzroy. Resilience was slightly improved at reef subtidal habitats (Figure 21, Table 23), with the most notable change being a large increase at Green Island to a score of 100, but it was relatively stable at other locations.

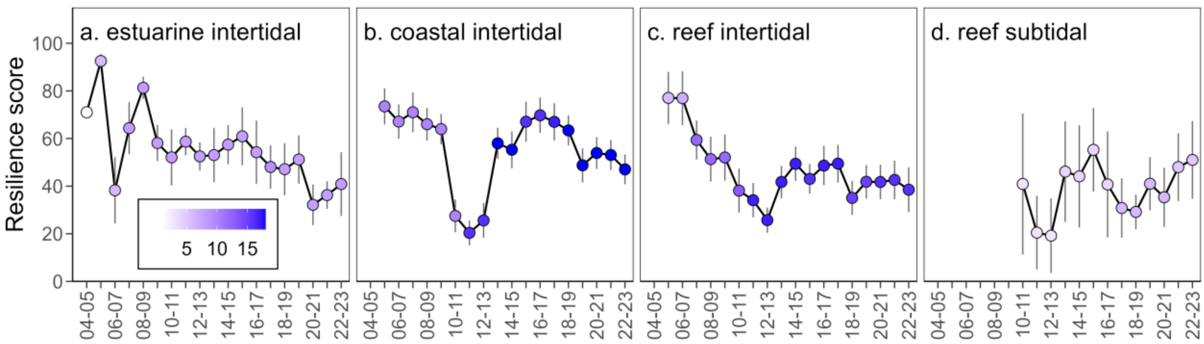


Figure 21. Trends in resilience score summarised for each habitat type of the Reef. Blue shading of points indicates the number of sites contributing to the score. Vertical error bars represent standard error.

Resilience in 2022–23 improved and was the highest and rated moderate in the Mackay–Whitsunday and Wet Tropics NRM regions, followed by the Burdekin NRM region. The resilience score declined, was rated poor and was the lowest in the Burnett–Mary followed by the Fitzroy and Cape York NRM regions.

4.3.3 Epiphytes and macroalgae

Epiphyte cover on seagrass leaves has fluctuated over the previous 10 years in estuarine and coastal seagrass habitats, often varying seasonally. For example, in 2022–23, epiphytes in estuarine and reef intertidal habitats declined in the late dry 2022, from above the long-term average in the previous year, and increased above the long-term average in the late wet season. Conversely, epiphyte cover in coastal intertidal habitats generally increases in the late dry and declines in the late wet (Figure 22). Epiphyte cover at reef subtidal sites remained above the long-term average for the duration of 2022–23, after periodically dipping below the long-term average in the late wet season of 2022 (Figure 22).

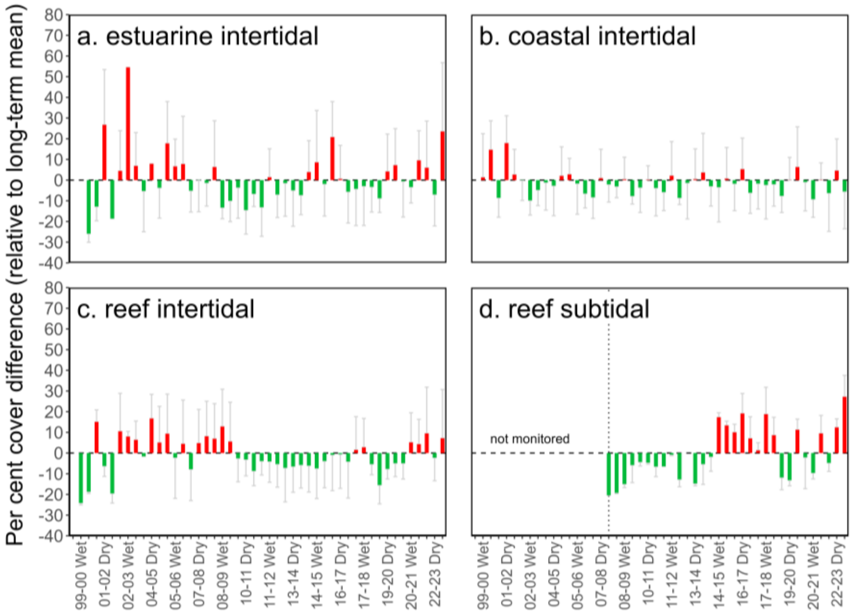


Figure 22. Epiphyte abundance (per cent cover) relative to the long-term average (the zero axis) for each Reef seagrass habitat (sites pooled, ± SE). Reef long-term average (2005 to 2022); estuarine = 25.6 ±5.1 per cent, coastal intertidal = 17.4 ±4.2 per cent, reef intertidal = 22.4 ±4.7 per cent, reef subtidal = 20.3 ±4.5 per cent.

Macroalgae abundance in 2022–23 followed the general trends of the previous 10 years in intertidal estuarine and coastal habitats, remaining below the overall inshore Reef long-term average for each of the habitats (Figure 23). Macroalgae abundance at reef intertidal and subtidal habitats similarly remained below the Reef long-term average for the third consecutive year. Overall, macroalgae abundances remained low across all seagrass habitats.

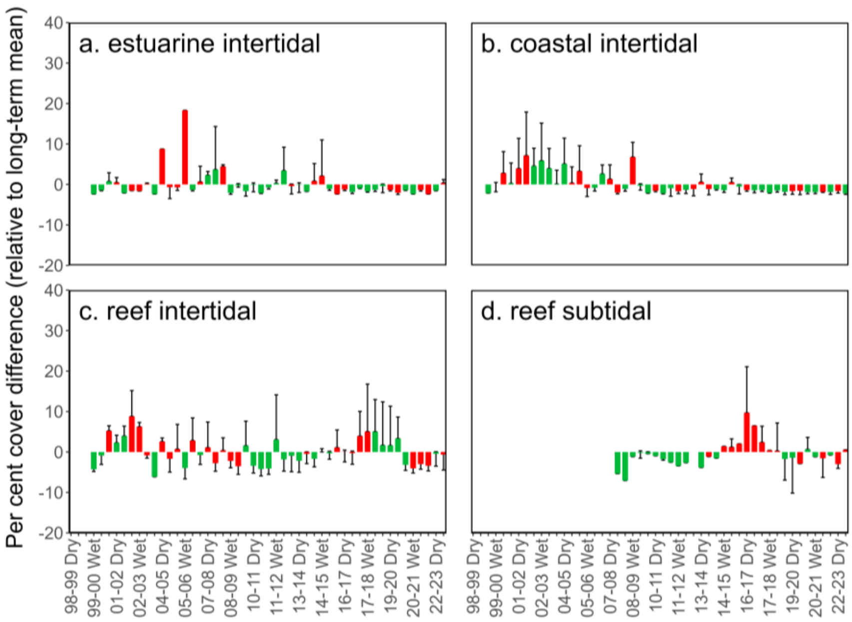


Figure 23. Macroalgae abundance (per cent cover) relative to the long-term average for each inshore Reef seagrass habitat. (sites pooled, ± SE). Reef long-term average; estuarine = 2.0 ±1.4 per cent, coastal intertidal = 2.2 ±1.5 per cent, reef intertidal = 6.9 ±2.6 per cent, reef subtidal = 6.8 ±2.6 per cent.

5 Regional Reports

This section presents detailed results on the condition and trend of indicators within regions, and relates the results to local environmental factors including:

- annual daytime tidal exposure at each monitoring site
- daily light at each monitoring location
- sediment grain size composition at each monitoring site
- tables detailing statistical analysis.

5.1 Cape York

5.1.1 2022–23 Summary

Wet season rainfall and annual river discharge were above the long-term average for the region and exposure of the seagrass sites to turbid water types 1 and 2 was slightly elevated. Within-canopy water temperatures were above average for the third consecutive year in the last decade and were 0.3ºC above the decadal long-term average.

Seagrass condition was assessed only in the late dry in Cape York, which precedes the summer when the highest temperatures occurred. Seagrass meadow condition across the Cape York NRM region in 2022–23 was marginally lower than 2021–22 and remained **moderate**. The decrease was due to resilience deteriorating to a lower grade and although the abundance indicator improved, it was not sufficient to offset the decline in resilience. For the indicators:

- abundance score was moderate
- resilience score was poor.

Seagrass abundance (per cent cover) in 2022–23 increased from the previous period overall. The improvement in seagrass abundance was driven by increases at coastal intertidal and subtidal sites, as gains in reef intertidal sites in the north were offset by continued declines in the south. Similarly, reef subtidal sites have continued to decline over the last three years.

Overall, the resilience score deteriorated from moderate to poor. Coastal sites experienced a significant decline, particularly after a substantial increase in the previous year. In the north, low scores were due to low reproductive structures or colonising species' dominance, while both coastal and reef locations in the south lacked reproductive structures. Reproductive structures continue to be rarely observed in Cape York in 2022–23 for the third consecutive year, which may hinder replenishment of the declining seed banks and weaken capacity to recover from seeds in the near future.

The number of sites, date established and duration of monitoring at individual sites affects the long-term trends for the region. Prior to 2011–12, there was only one location monitored while trends after this time include a number of sites and habitat types. Elevated discharge in 2010–11 and 2018–19 led to declines in seagrass condition. The coastal and reef subtidal habitats have highly variable seagrass abundances and succumbed to elevated discharge after 2018–19. Post flood surveys were conducted in the growing season of the following year when the score dropped to poor again. The resilience of coastal habitats was also affected by the extreme weather and seagrass habitats across the region were recovering until resilience declined in 2022–23, a legacy of impacts during the previous wet season.

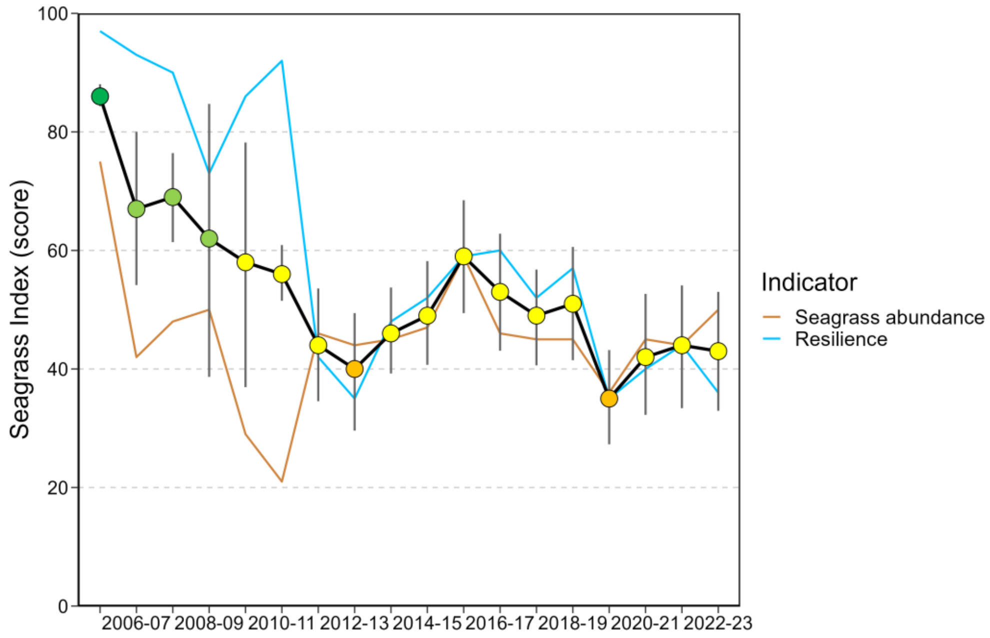


Figure 24. Temporal trend in the Seagrass Index (± SE) with contributing indicator scores for the Cape York NRM region (averaged across habitats and sites). Index scores scaled from 0–100 and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40), ● = very poor (0–20). NB: Scores are unitless.

5.1.2 Climate and environmental pressures

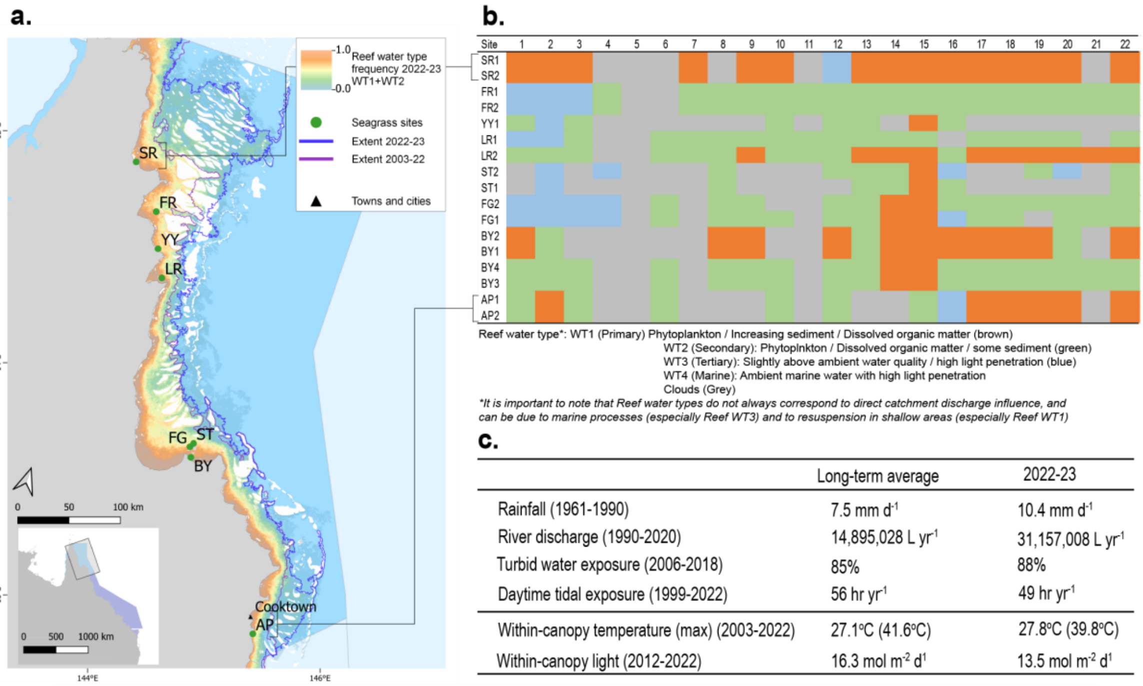
One tropical low (07U, Hale) formed in Cape York on the 6–7th January 2023, which later formed into a cyclone after it had moved offshore and out of Reef waters. Cyclone Kevin began as a tropical low near Cooktown on the 27th of February 2023, and similarly moved offshore and formed into a cyclone when it was well beyond Reef waters.

Wet season rainfall across the basins of Cape York was above the long-term average for the region based on elevated rainfall in all catchments except for Lockhart River (Figure 25 Table 11). Annual discharge from rivers in the Cape York region were more than double the long-term average and the fourth highest since 2003–04.

Exposure to water types 1 (WT1) and 2 (WT2) was slightly greater than the long-term average in Cape York (Figure 25 Figure 7 and Figure 8). The inshore waters of Cape York had predominantly WT2 over the wet season in December-April (Figure 25b) but the increase in exposure was due predominantly to an increase in WT1. Shelburne Bay sites (SR1 and SR2), followed by Bathurst Bay sites (BY1 and BY2), had the highest exposure to turbid WT1 water. Reef habitats at Piper Reef (FR) and Stanley Island (ST) had the lowest level of exposure to WT1 and WT2 amongst the inshore seagrass monitoring sites. There was also a lot of cloud, and the water type exposure could not be determined (grey colours).

The risk of exposure of mapped seagrass to the water types are assessed in the water quality report (Gruber et al 2024). In Cape York, there was a 9% increase in exposure to the moderate risk category in 2022–23 compared to the long-term average.

Daily light (mol m^{-2} d^{-1}) reaching the top of the seagrass canopy is generally very high at all Cape York sites (long-term average = 16.4 mol m^{-2} d^{-1}). In 2022–23, daily light (13.5 mol m^{-2} d^{-1}) was lower than the long-term average (Figure 25d). This was because the loggers only recorded for a short time at Piper reef and Stanley Island (Figure 98). Therefore, daily light at Bathurst Bay was the only contributor to the regional average through the wet season, and it has the lowest daily light of all Cape York sites on average. Cape York sites are surveyed only once per year, and the instruments are not usually able to function for a full year due to battery life and inevitable fouling.



c.

	Long-term average	2022-23
Rainfall (1961-1990)	7.5 mm d[1]	10.4 mm d[1]
River discharge (1990-2020)	14,895,028 L yr[1]	31,157,008 L yr[1]
Turbid water exposure (2006-2018)	85%	88%
Daytime tidal exposure (1999-2022)	56 hr yr[1]	49 hr yr[1]
Within-canopy temperature (max) (2003-2022)	27.1ºC (41.6ºC)	27.8ºC (39.8ºC)
Within-canopy light (2012-2022)	16.3 mol m[-2] d[1]	13.5 mol m[-2] d[1]

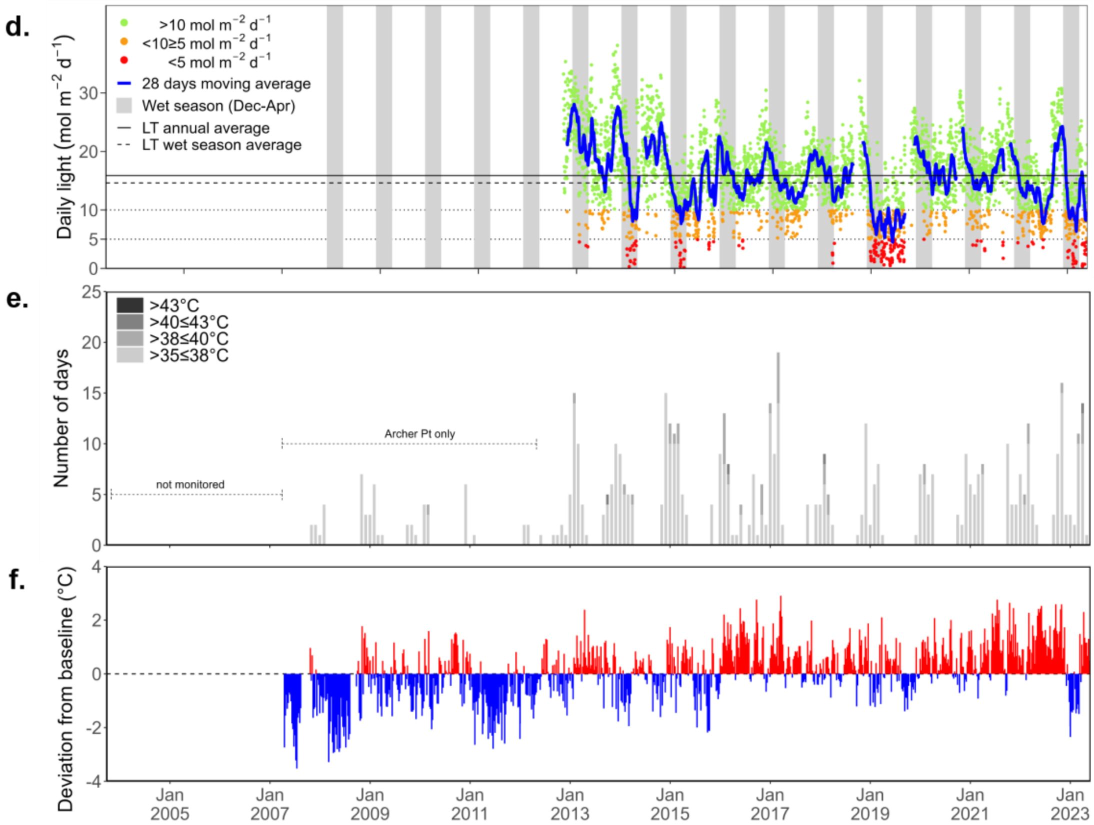


Figure 25. Environmental pressures in the Cape York region including: a. frequency of exposure to primary (WT1) and secondary (WT2) water from December 2022 to April 2023 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the long-term average (2003–2018) exposure boundary (purple line), and the first (blue line) and third quartile (white line) of the long-term average (from Gruber *et al.* 2024), b. wet season water type at each site; c. average conditions and max temperature over the long-term and in 2022–23; d. daily light and the 28-day rolling mean of daily light for all sites; e. number of day temperature exceeded 35°C, 38°C, 40°C and 43°C, and; f. deviations from 13-year mean weekly temperature records at intertidal sites.

2022–23 was the third warmest year of intertidal within-canopy temperatures since monitoring was established in the region (Figure 25c). Maximum within-canopy temperatures exceeded 35°C for a total of 62 days (in total among all sites where temperature is monitored) during 2022–23 (Figure 25e), with the highest temperature recorded at 37.3°C (Piper Reef, 31Jan23). Daytime tidal exposure (hours water has drained from the intertidal meadow) was at the Cape York long-term median, having increased over the last few years from its shortest duration in 2020–21 (Figure 25c, Figure 90), which may have provided some respite from the elevated temperatures.

In the Cape York NRM region, there was little change in reef habitat sediments, which remained dominated by sands and coarser sediments (Appendix 2, Figure 105). However, coastal habitats which were dominated by fine sand, had a greater proportion of mud in 2022–23, particularly at both sites located within Shelburne Bay (Appendix 2, Figure 106).

5.1.3 Inshore seagrass and habitat condition

There are 19 seagrass monitoring sites in Cape York from 10 locations (Table 13). Four seagrass habitat types were assessed across the Cape York region in 2022–23, with data from 14 of the 19 long-term monitoring sites (Table 13, Table 20).

Table 13. List of data sources of seagrass and environmental condition indicators for each seagrass habitat type in the Cape York NRM region. For site details see Table 5 and Table 6. Open square indicates not measured in 2022–23, blank cells indicate data not usually collected/measured at site. ▪ drop camera sampling (RJFMP), *Seagrass-Watch.

Habitat	Site		abundance	composition	extent	reproductive effort	seed banks	meadow sediments	epiphytes	macroalgae
coastal intertidal	BY1	Bathurst Bay	■	■	■	■	■	■	■	■
	BY2	Bathurst Bay	■	■	■	■	■	■	■	■
	SR1	Shelburne Bay	■	■	■	■	■	■	■	■
	SR2	Shelburne Bay	■	■	■	■	■	■	■	■
coastal subtidal	BY3▪	Bathurst Bay	□	□					□	□
	BY4▪	Bathurst Bay	■	■					■	■
	LR1▪	Lloyd Bay	■	■					■	■
	LR2▪	Lloyd Bay	□	□					□	□
	MA1▪	Margaret Bay	■	■					■	■
	MA2▪	Margaret Bay	■	■					■	■
reef intertidal	AP1	Archer Point	□	□			□	□	□	□
	AP2	Archer Point	□	□			□	□	□	□
	FR1	Farmer Is. (Piper Reef)	■	■	■	■	■	■	■	■
	FR2	Farmer Is. (Piper Reef)	■	■	■	■	■	■	■	■
	ST1	Stanley Island (Flinders Group)	■	■	■	■	■	■	■	■
	ST2	Stanley Island (Flinders Group)	■	■	■	■	■	■	■	■
	YY1*	Yum Beach (Weymouth Bay)	□	□			□	□	□	□
Reef subtidal	FG1▪	Flinders Island (Flinders Group)	■	■					■	■
	FG2▪	Flinders Island (Flinders Group)	■	■					■	■

5.1.3.1 Seagrass Index and indicator scores

During the 2022–23 reporting period, the Seagrass Index score for the Cape York region marginally declined since the previous reporting period, with the overall grade remaining **moderate** (Figure 26).

The abundance indicator has continued to improve since 2020–21 (Figure 26), although there was a short dip during the previous period. Despite the overall improvement, losses continued at subtidal habitats in the south of the region (Flinders Group and Bathurst Bay), and at the intertidal reef habitat in the north (Piper Reef). The improvement in abundance was mostly offset by deterioration in the resilience indicator. The resilience score declined across intertidal coastal and reef locations, with the exception of Piper Reef which was unchanged. Losses appear a consequence of reduced reproductive effort and seed banks, particularly in the coastal habitats of Shelburne and Bathurst Bays (Figure 26).

The abundance indicator in 2022–23 remained above long-term averages in a moderate state. However, the resilience indicator remained below the long-term average for the fourth consecutive year, declining a grade to poor for the first time since 2019–20. Overall, the Cape York Seagrass Index remains well below the 2005–06 baseline and in 2022–23 was the fourth lowest over the last decade.

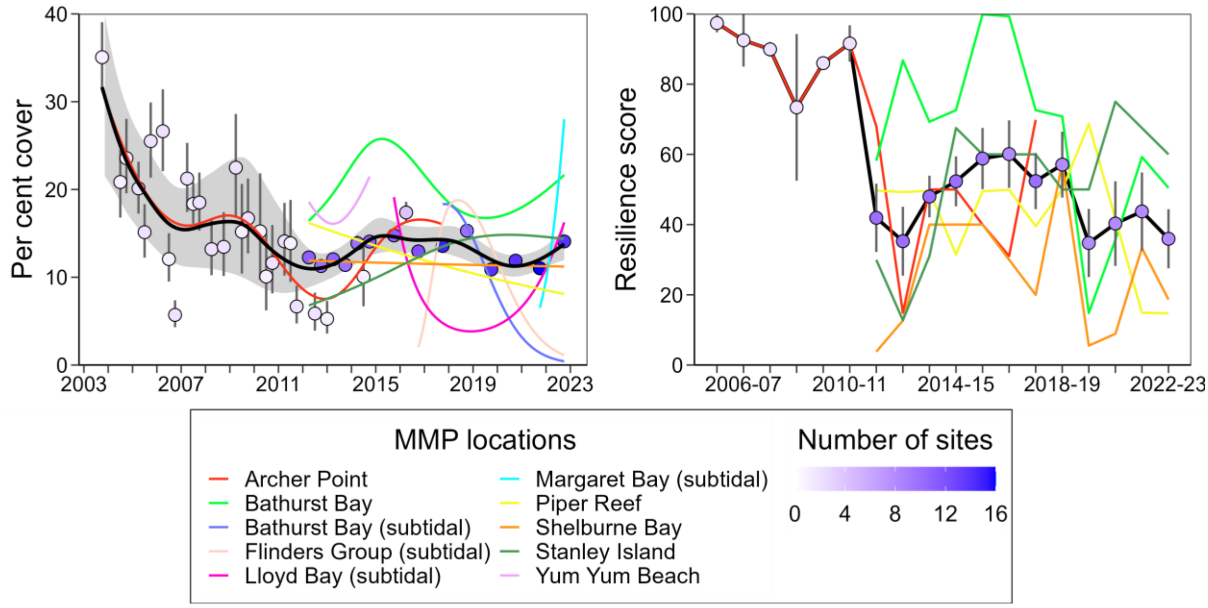


Figure 26. Temporal trends in the Cape York seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area defining 95 per cent confidence intervals); b. average annual resilience score (±SE) and trends for each location (coloured lines). Colour of circles represents the number of sites assessed to calculate the average.

An examination of the long-term trends in abundance across the Cape York NRM region needs to be interpreted carefully as new sites were included in 2012–13, which are associated with consistently lower abundance compared to the highest levels recorded for the region (Figure 26). Archer Point, which was the only location monitored prior to 2012–13, has also not been included in the resilience score since October 2017, when monitoring continued only as part of Seagrass-Watch due to logistical difficulties.

5.1.3.2 Seagrass abundance, composition and extent

The improvement in seagrass abundance in 2022–23 is a consequence of increasing per cent cover at coastal intertidal and subtidal habitats. For the fourth year in a row, coastal intertidal abundances have increased at all sites, reaching their highest levels since 2019–20. However, subtidal abundances have not improved consistently across the region, as replicate sites in Bathurst Bay in the south were devoid of seagrass in 2022–23 (Figure 27). Over the last year, seagrass abundance at reef intertidal and subtidal habitats has remained largely unchanged. While there was some improvement in abundance at reef intertidal sites in the north (Piper Reef) after losses in the previous year, these gains were offset by continued decline at Stanley Island (Flinders Group, in the south) for the fourth year. Reef subtidal habitats at the Flinders Group have remained low and have continued to decline since 2018-19.

Bathurst Bay and the Flinders Group are located adjacent to the Normanby-Kennedy river basin, which discharges substantial volumes of sediment-laden water during high rainfall and flow events that can significantly impact seagrass growth within the discharge vicinity. As the seagrass was assessed before the 2022-23 wet season, the declines in subtidal and reef intertidal abundances are likely the legacy of a flooding event (from TC Tiffany) in the previous year (early February 2022). These losses could worsen at these sites in 2023–24 due to above-average rainfall and discharges more than three times above the long-term median in the 2022-23 wet season.

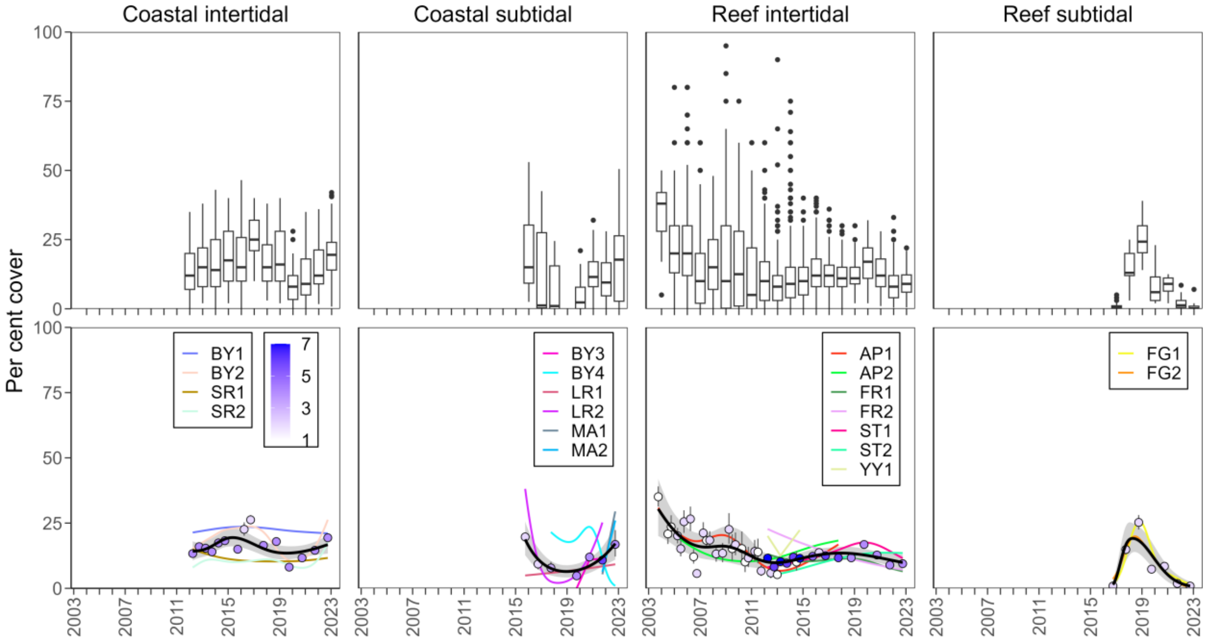


Figure 27. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends for each habitat monitored in the Cape York region from June 2005 to May 2023. Whisker plots (top) show the box representing the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the dots represent outlying points. GAM plots (bottom), show trends for each habitat and coloured lines represent individual site trends.

An examination of the long-term trend in seagrass abundance shows seagrass per cent cover progressively decreased at reef intertidal habitats across Cape York from 2003 to 2012, after which there was a slight improvement, particularly at Stanley Island, but abundances at the reef intertidal sites remain low (Figure 27, Table 22). Coastal intertidal and subtidal habitats which have only been monitored since 2012 and 2015 respectively, and over the last decade, show no long-term trend (Figure 27, Table 22).

In 2022–23, the proportion of species displaying colonising species traits (*Halophila ovalis*) were higher than the previous reporting year in all Cape York habitats, except coastal intertidal which declined. With the exception of intertidal reef habitats, the proportions of colonising species remained above the Reef long-term averages for all other habitats (Figure 28).

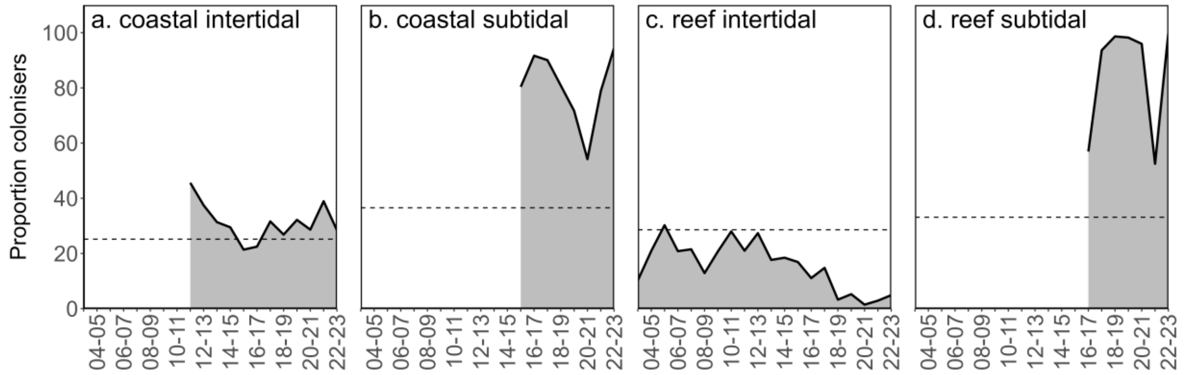


Figure 28. Proportion of seagrass abundance composed of colonising species at inshore intertidal habitats in the Cape York region, 2004 to 2023. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

Seagrass spatial extent mapping was conducted within meadows to determine if changes in abundance were a consequence of the meadow landscape changing and to indicate if plants were allocating resources to colonisation (asexual reproduction). Only intertidal meadows are mapped across the Cape York region and prior to 2012, mapping only occurred at the reef intertidal meadows of Archer Point (Figure 29). Over the last decade, additional reef and coastal meadows in the Cape York region were included. Generally, there has been some variation in the relative meadow extent at coastal intertidal habitats over the years (Figure 29). These fluctuations are primarily due to modifications in drainage channels. Meanwhile, at reef habitats, the relative meadow extent seems to have slightly increased in the past ten years.

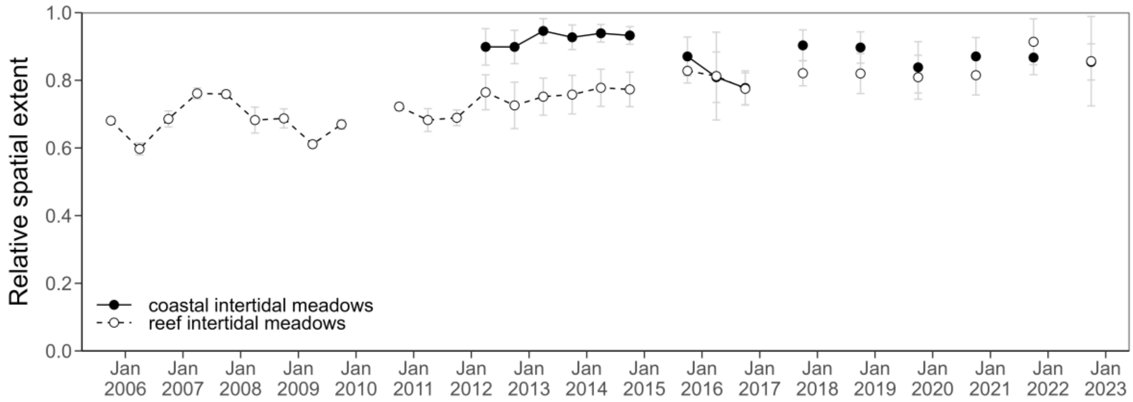


Figure 29. Change in relative spatial extent (± SE) of seagrass meadows within monitoring sites for each intertidal coastal and reef habitat and monitoring period across the eastern Cape York NRM region, 2005–2023.

5.1.3.3 *Seagrass reproductive status*

Total reproductive effort is only monitored at intertidal meadows in Cape York. Reproductive effort remained low at coastal habitats in 2022–23 after reaching its peak in late 2016 (Figure 30). Historically, from 2006 to 2012, reproductive effort in reef intertidal habitats was recorded only at Archer Point, which has not been assessed since 2017. Reproductive effort is now based on sites introduced in 2012, which have consistently low numbers of reproductive structures. In 2022–23 reproductive effort at reef intertidal meadows remained very low. The low reproductive effort will hinder replenishment of the seed banks, rendering most meadows vulnerable to further disturbances because of their limited capacity to recover from seed (i.e. low resilience). No sexually reproductive structures were observed at reef habitats in 2022–23.

Seed banks are also only measured at intertidal sites, which are dominated by *H. uninervis* at most of the sites in Cape York. A seed bank has persisted in the coastal meadows of Bathurst Bay for the last decade, but seed densities in 2022–23 were the lowest recorded for coastal habitats because they were not assessed at Bathurst Bay for logistical reasons (Figure 30). Seed are typically low in density or absent in reef intertidal habitats, and in 2022–23 none were recorded (Table 5).

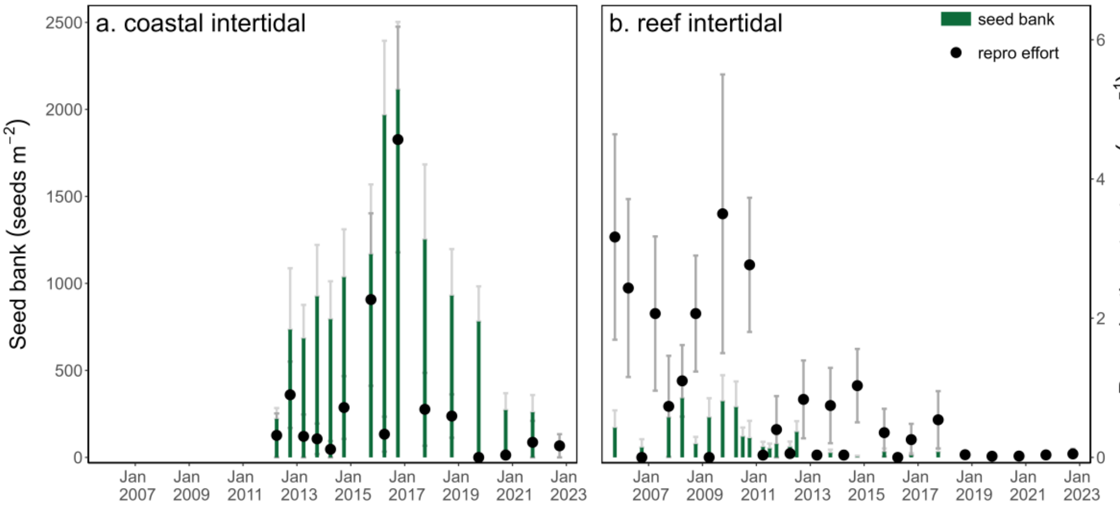


Figure 30. Seed banks and reproductive effort at inshore intertidal coastal (a) and reef (b) habitats in the Cape York region, for late dry season, 2005–23(species and sites pooled). Seed banks (green bars, ± SE) presented as the total number of seeds per m^2 sediment surface. Reproductive effort (dots, ± SE) presented as the average number of reproductive structures per core. NB. Reproductive effort was also assessed in the late wet season from 2008 to 2016.

5.1.3.4 Resilience

The resilience score is calculated for locations where reproductive effort is assessed. In Cape York, this is at intertidal coastal and reef habitats. In 2022–23, the resilience score was low overall and the third lowest on record.

At coastal sites, the score declined in 2022–23 following a considerable increase into the previous year. At Bathurst Bay, abundance increased but there were no reproductive structures present and at BY2 there had been none for more than three years. In Shelburne Bay, at site SR1, colonising species were less than the colonising species threshold (at 46%) but the composition of reproductive structures present were of colonising species. By contrast at SR2, colonising species dominated and there were no reproductive structures in 2022–23.

Resilience declined slightly at reef intertidal sites due to declines in the score at Stanley Island (ST1). Cover and composition were above the thresholds at both Stanley island sites and there were persistent species present. But there were no reproductive structures present, though there had been in the previous year at ST1. At Piper reef, percent cover was below the low cover threshold at both sites placing them in the low resistance category. There were reproductive structure of colonising species present at FR2.

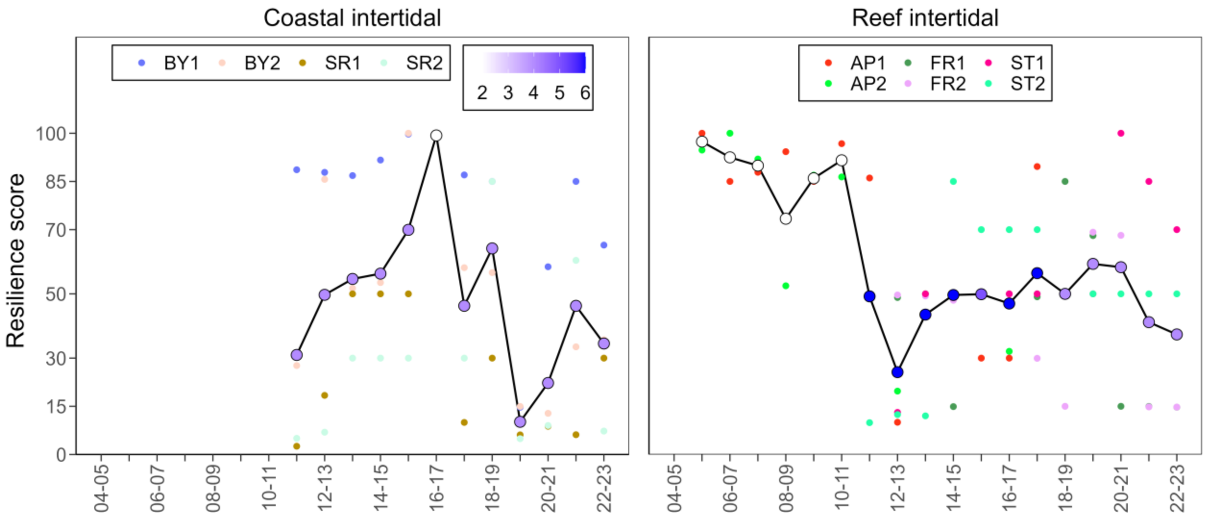


Figure 31. Temporal trend in the resilience score for each habitat monitored in the Cape York NRM region from 2005–2023. Coloured small points represent different sites. Shades of blue for the larger points indicate the number of sites that contribute to the score.

5.1.3.5 Epiphytes and macroalgae

In 2022–23 there has been an increase in epiphyte cover on seagrass leaf blades in intertidal coastal habitats for the second year in a row, exceeding the long-term average. Meanwhile, epiphyte cover in intertidal reef habitats remains below the long-term average for the fifth consecutive year (Figure 32). Subtidally, epiphyte cover at coastal habitats saw an increase above the long-term average for the first time, but in reef habitats, it remained above the long-term average but decreased (Figure 32). Nonetheless, low epiphyte cover overall is unlikely to have a significant impact on seagrass growth.

Per cent cover of macroalgae continues to vary between habitats. Macroalgae cover at intertidal habitats continued below the long-term average at coastal sites for the sixth consecutive year (Figure 32b), whereas it has remained above at reef sites for the second year in a row (Figure 32). At intertidal reef habitats, macroalgae are growing attached to coral rubble in the meadow, and not considered to be at levels sufficient to impact seagrass. Macroalgae is variable at coastal subtidal habitats, decreasing from its highest level in the previous year, but remaining above long-term average in 2022–23. Macroalgae at reef subtidal sites continued to remain below the overall inshore Reef long-term average.

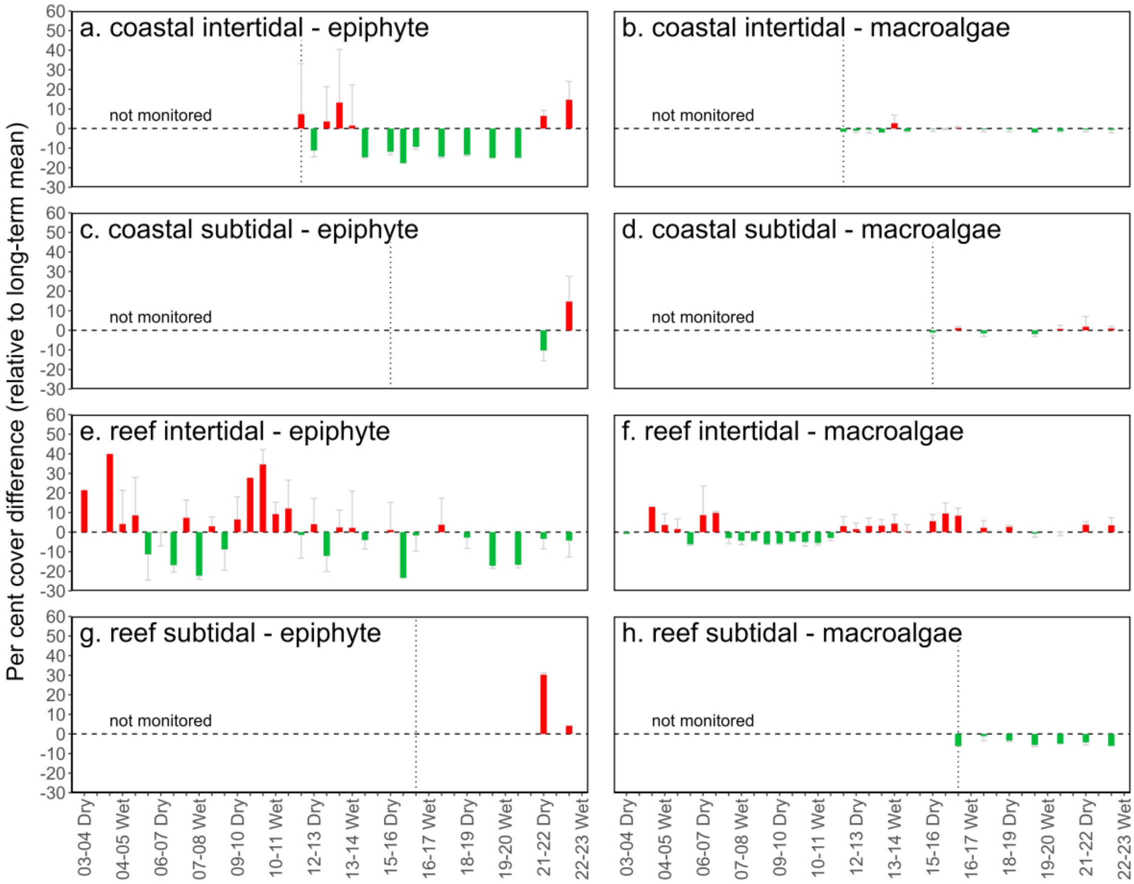


Figure 32. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Cape York, 2001–2023 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

5.2 Wet Tropics

5.2.1 2022–23 Summary

Rainfall, river discharge and turbid water exposure in 2022–23 in the northern Wet Tropics were slightly above average and light levels were below average. In the southern Wet Tropics, rainfall and river discharge were around the long-term average, but light levels were very low. Within-canopy water temperatures in the northern Wet Tropics were similar to the previous year and 0.5ºC above average for the third consecutive year. In the southern sub-region, temperatures were similar to the long-term average.

Seagrass meadows within the Wet Tropics showed no change overall in the Seagrass Index in 2022–23. Seagrass condition in the northern Wet Tropics NRM region increased and was good (Figure 33). Seagrass condition deteriorated and remained poor in the southern Wet Tropics, after reaching its highest score for the sub-region in the previous year (Figure 33). The combined regional condition was **moderate** (Figure 33).

Contributing indicators in the north were:

- abundance was good
- resilience was moderate.

Contributing indicators in the south were:

- abundance was poor
- resilience was moderate.

In the northern Wet Tropics sites, seagrass abundance deteriorated across the sub-region in 2022–23 relative to the previous period largely because of declines some reef intertidal and subtidal sites, and slightly less favourable climatic conditions across the sub-region. However, resilience increased in the north due to improvements in both coastal and reef intertidal habitats.

Compared to the northern sub-region, the southern Wet Tropics showed a lower overall abundance and has been on a declining trend for the second consecutive year, after reaching its peak in 2020-21. This can be attributed to the decrease in abundance in the reef and coastal subtidal habitats. The low abundances across the sub-region appear 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 has been challenged, particularly in the south, by unstable substrates, chronic poor water quality compared to the north (high turbidity, light limitation) and limited recruitment capacity.

Resilience increased overall in the northern Wet Tropics due to improvements across all habitats, although differences were apparent between locations. Although both intertidal coastal and reef meadows improved, the largest contributing factor to higher scores was the reef subtidal meadows at Green Island, where the meadow condition was above critical thresholds for abundance and composition, and numerous reproductive structures for foundation species. Seed banks declined in coastal habitats in the north in 2022–23 and remained low at reef intertidal or subtidal habitats. In the south, resilience slightly declined but was the second highest level recorded. This was due to slight decreases in the resilience score at coastal intertidal sites where the meadow was below critical per cent cover thresholds and comprised of only opportunistic species which were not observed to be flowering. Additionally, there was no recent history of flowering.

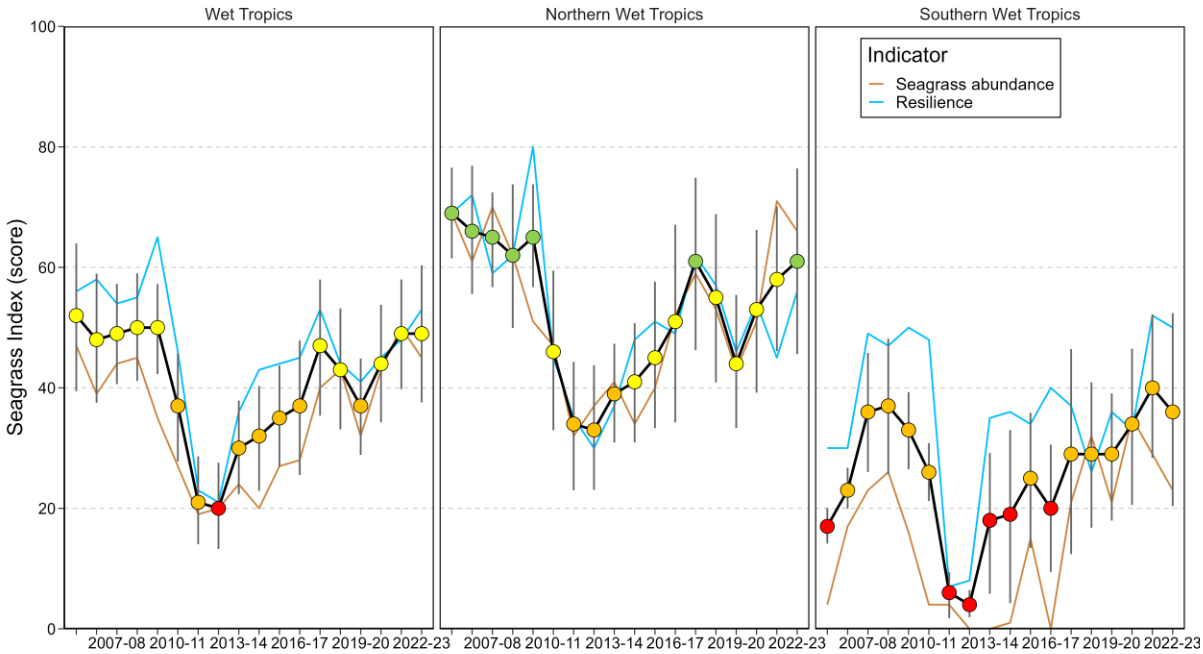


Figure 33. Temporal trend in the Seagrass Index (± SE) with contributing indicator scores for the Wet Tropics NRM region and sub-regions (average across habitats and sites). Values are indexed scores scaled 0–100 (± SE) and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40), ● = very poor (0–20). NB: Scores are unitless.

5.2.2 Climate and environmental pressures

Unlike the previous year, no tropical cyclones impacted the Wet Tropics region in 2022–23. Annual rainfall was slightly higher than the long-term average in the northern Wet Tropics, however, river discharge across the region was above the long-term average in 2022–23.

Exposure to primary (WT1) or secondary (WT2) turbid water was also slightly higher than the long-term average across the northern Wet Tropics during 2022–23 (Figure 34a, b). Sites were primarily exposed to WT2 except at Yule Point where there was more exposure to WT1 (Gruber *et al.* 2024). Daily light levels at the intertidal sites (15.0 mol m^{-2} d^{-1} in 2022–23) were lower than the long-term average in the northern Wet Tropics (Figure 34c, d). This appears to be due to low light during the wet season at Yule Point and lower light in the dry season than typically occurs at Green Island (Figure 99).

The risk of exposure of mapped seagrass to the water types are assessed in the water quality report (Gruber et al 2024). In the Wet Tropics (north and south combined), there was a 29% increase in exposure to the low risk category in 2022–23 compared to the long-term average and decrease in exposure to the moderate (-15%) or high risk categories (-14%).

Intertidal within-canopy temperatures in the northern Wet Tropics were above the long-term average in intertidal habitats for the third consecutive year in 2022–23 (Figure 34e). Maximum intertidal within-canopy temperatures exceeded 35.0°C for a total of 80 days during 2022–23, the second highest number of days in a period since monitoring commenced. Maximum temperatures also exceeded 40.0°C for three days and the highest temperature was 42.0°C at Low Isles (LI1) on the 07 April 2023.

Daytime tidal exposure in the north was below the long-term median (Figure 34c, Figure 91, Figure 92), which could affect water temperature, especially extremes (potentially increasing temperature in shallow water) and light levels.

In 2022-23, seagrass habitats in the northern Wet Tropics experienced several significant pressures. These included above-average rainfall, river discharge, and exposures to turbid waters and elevated temperatures, as well as below-average daily light and tidal exposure.

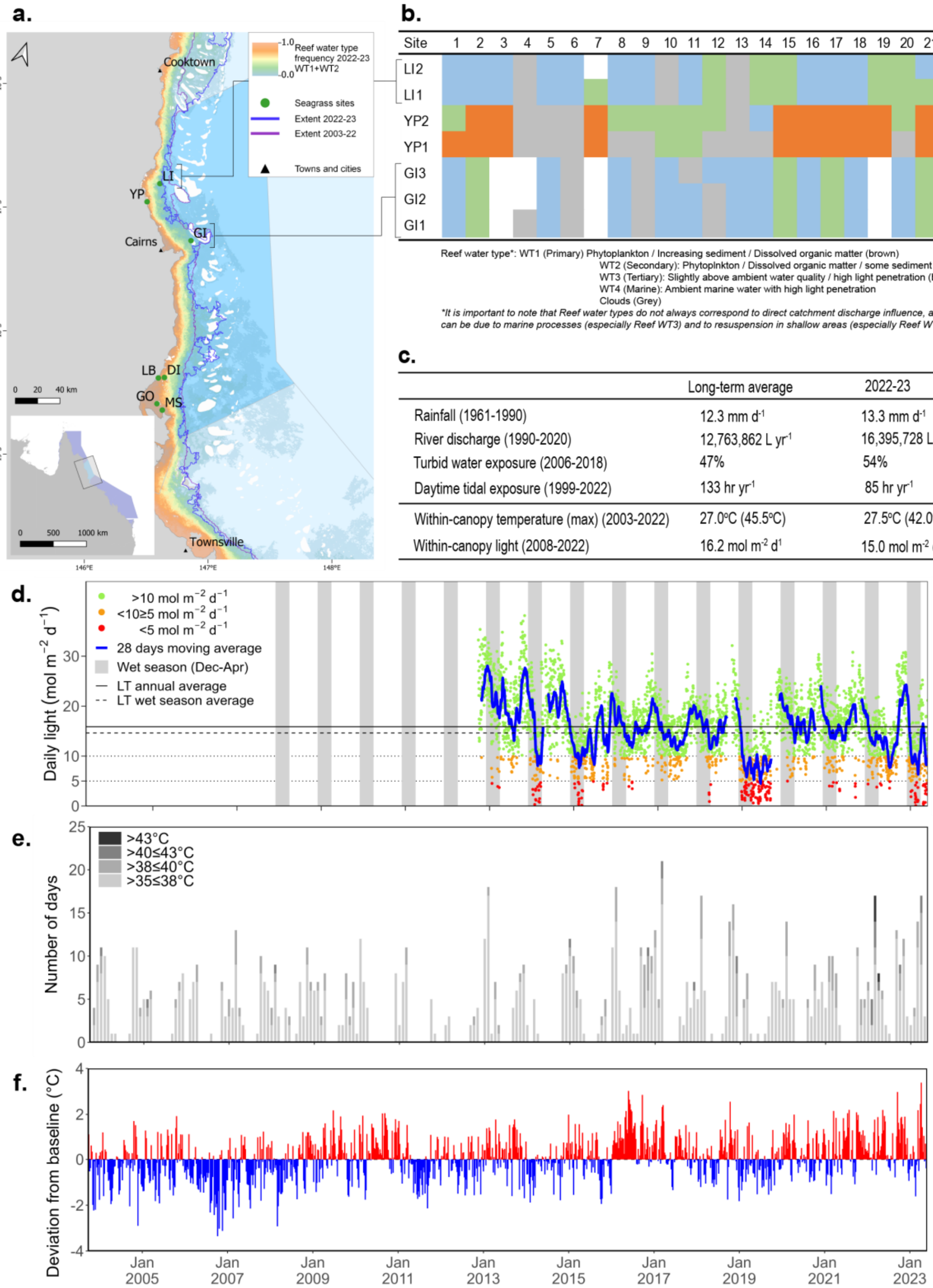


Figure 34. Environmental pressures in the northern Wet Tropics region including: a. frequency of exposure to primary (WT1) and secondary water (WT2) from December 2022 to April 2023 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the long-term average (2003–2018) exposure boundary (purple line), and the first (blue line) and third quartile (white line) of the long-term average (from Gruber *et al.* 2024); b. wet season water type at each site; c. average conditions and max temperature over the long-term and in 2022–23; d. daily light and the 28-day rolling mean of daily light for all sites; e. number of days temperature exceeded 35°C, 38°C, 40°C and 43°C; and f. deviations from 13-year mean weekly temperature records at intertidal sites.

In the southern Wet Tropics, annual rainfall was around the long-term average, but discharge was slightly elevated during the 2022–23 wet season (Figure 5). Exposure to secondary turbid water occurred on 95 per cent of weeks during the wet season, which was a lower level of exposure than average (99 per cent) (Figure 35a, c). There was limited exposure to WT1 and more exposure to WT2 at coastal sites, including Lugger Bay (LB1 and LB2) and Missionary Bay (MS1 and MS2) (Figure 35b).

Overall, conditions in the southern Wet Tropics were relatively benign in 2022–23, but despite this, light levels (with an annual average of 9.6 mol m^{-2} d^{-1}) was considerably lower than the long-term average of 16.2 mol m^{-2} d^{-1} (Figure 35d, Figure 100). This decrease was due to very low dry season light levels as well as low light levels during the wet season (Figure 35d). It is important to note that light measurements were only recorded at Dunk Island in the southern Wet Tropics.

Dunk Island is the only location where within-canopy temperatures are measured in the southern Wet Tropics. In 2022-2023, temperatures were similar to the long-term average (Figure 35b). However, the maximum intertidal within-canopy temperatures did not exceed 35°C, unlike the previous year. The highest temperature recorded during this period was 34.3°C on 16 April 2023 (Figure 35e, f). It is worth noting that daytime tidal exposure has been well below average for three consecutive years (Figure 35b, Figure 91, Figure 92), which could be a contributing factor to the lower temperatures.

Across the Wet Tropics region, coastal sediments were composed primarily of fine sand, while reef habitats were composed of sand and coarser sediments (Figure 107, Figure 108). In 2022–23, sediments at the intertidal monitoring sites appeared unchanged and similar to the long-term average. The proportion of fine sediments (i.e. mud) was well below the inshore Reef long-term average (Figure 107, Figure 108). However, subtidal sites did experience a slight increase in finer sediments in the north and coarser sediments in the south (Figure 109).

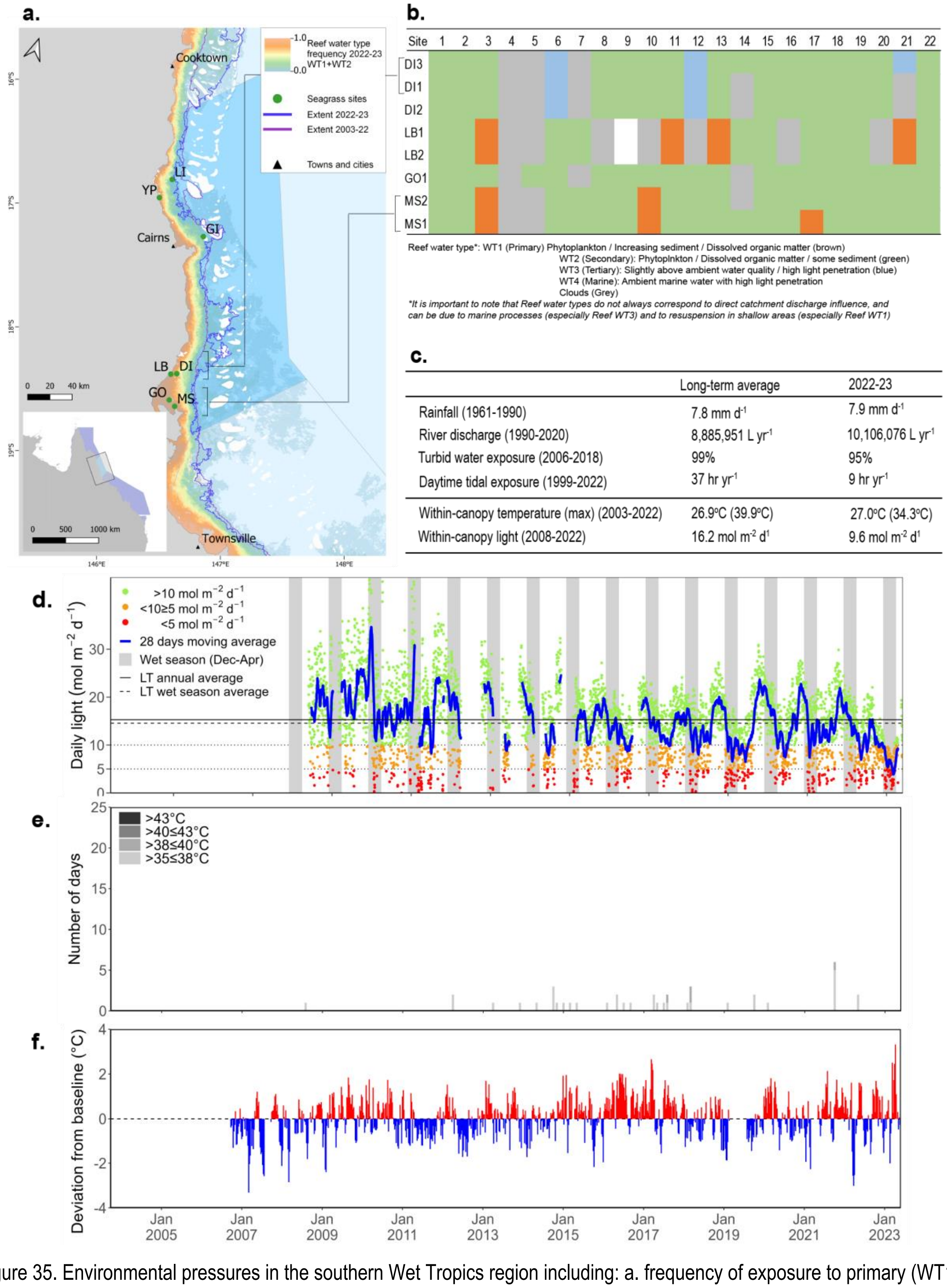


Figure 35. Environmental pressures in the southern Wet Tropics region including: a. frequency of exposure to primary (WT1) and secondary (WT2) water from December 2022 to April 2023 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the long-term average (2003–2018) exposure boundary (purple line), and the first (blue line) and third quartile (white line) of the long-term average (from Gruber *et al.* 2024); b. average conditions and max temperature over the long-term and in 2022–23; c. wet season water type at each site; d. daily light and the 28-day rolling mean of daily light for all sites; e. number of days temperature exceeded 35°C, 38°C, 40°C and 43°C; and f. deviations from 13-year mean weekly temperature records at intertidal sites.

5.2.3 Inshore seagrass and habitat condition

Four seagrass habitat types were assessed across the Wet Tropics region with data from 14 of the 15 long-term monitoring sites in 2022–23 (Table 14).

Table 14. List of data sources of seagrass and environmental condition indicators for each seagrass habitat type in the Wet Tropics NRM region. Open square indicates not measured in 2022–23, blank cell indicates data not usually collected/measured at site. ▪ drop camera sampling (RJFMP), *Seagrass-Watch. For site details see Table 5 and Table 6.

Sub region	Habitat	Site		abundance	composition	extent	reproductive effort	seed banks	meadow sediments	epiphytes	macroalgae
north	coastal intertidal	YP1	Yule Point	■	■	■	■	■	■	■	■
		YP2	Yule Point	■	■	■	■	■	■	■	■
	reef intertidal	LI1	Low Isles	■	■	■	■	■	■	■	■
		GI1	Green Island	■	■	■	■	■	■	■	■
		GI2	Green Island	■	■	■	■	■	■	■	■
	reef subtidal	LI2	Low Isles	■	■	■	■		■	■	■
		GI3	Green Island	■	■	■	■		■	■	■
south	coastal intertidal	LB1	Lugger Bay	■	■	■	■	■	■	■	■
		LB2	Lugger Bay	■	■	■	■	■	■	■	■
	coastal subtidal	MS1▪	Missionary Bay	■	■					■	■
		MS2▪	Missionary Bay	■	■					■	■
	reef intertidal	DI1	Dunk Island	■	■	■	■	■	■	■	■
		DI2	Dunk Island	■	■	■	■	■	■	■	■
		GO1*	Goold Island	□	□			□	□	□	□
	reef subtidal	DI3	Dunk Island	■	■	■	■		■	■	■

5.2.3.1 Seagrass Index and indicator scores

In the 2022–23 monitoring period, the Seagrass Index for the overall Wet Tropics region remained unchanged from the previous period and was **moderate** (Figure 33). The increase in the resilience indicator was offset by a decrease in the abundance indicator, when averaged across the Wet Tropics. There were differences in the trends of the indicators between sub-regions, with the increase in the northern Index being offset by declines in the southern.

In the northern Wet Tropics, seagrass abundance decreased slightly, but remained good overall. The only abundance score increase occurred in the reef subtidal meadow at Green Island, but the grade remained unchanged and very good. Abundance score declines at Green Island intertidal and Low Isles subtidal, however, both resulted in a grade change from very good to good and poor to very poor, respectively. Coastal intertidal meadows at Yule Point remained unchanged and very good (Figure 36). The long-term trend in seagrass per cent cover shows a period of decline starting in 2008–09 when there were Reef-wide declines associated with extreme weather. However, the Wet Tropics has had relatively stable abundance compared to other regions and has recovered to within pre-2008 levels though there were fewer sites in the earlier records.

Resilience in the northern Wet Tropics improved in 2022–23, recovering from declines in the previous period (Figure 36). This was driven by increased resilience scores at Green Island (reef intertidal and subtidal) and Yule Point (intertidal coastal) habitats. Coupled with good to very good abundance scores, this indicates that the meadows at Green Island and Yule

Point have a high ability to resist pressures and a high capacity to recover should they be severely impacted. Conversely, the meadows at Low Isles (intertidal and subtidal) with very poor to poor abundance and very poor resilience may be vulnerable to further pressures in future.

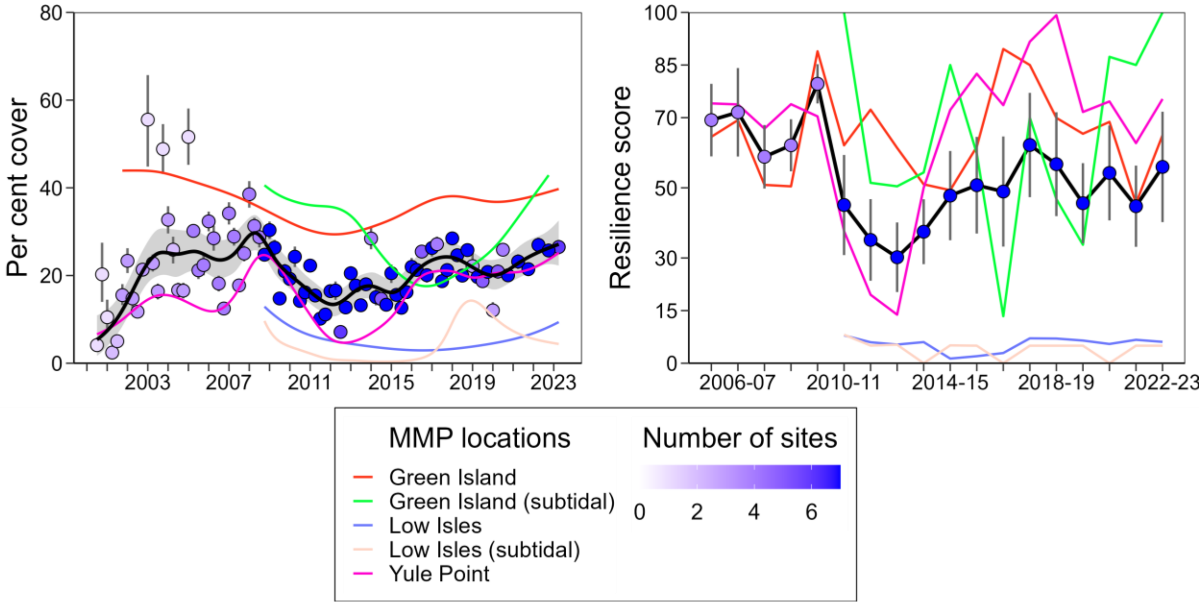


Figure 36. Temporal trends in the northern Wet Tropics seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area defining 95 per cent confidence intervals); b. average annual resilience score (±SE) and trends for each location (coloured lines). Colour of circles represents the number of sites assessed to calculate the average.

In the southern Wet Tropics, the Seagrass Index declined after reaching its highest level in the previous year (Figure 33). This was driven by deterioration in both abundance and resilience indicators. Both the abundance and resilience indicators have been highly variable since 2012–13, often with what appears as an annual lag from abundance to resilience (Figure 33). The abundance indicator, which saw a drop for the second year in a row, was driven by reduced abundance at the subtidal reef site (DI3), which fell from poor to very poor grade in 2022–23 (Figure 37). The decline in the resilience indicator was attributed to lower resilience at the coastal intertidal sites (Lugger Bay), which similarly fell from poor to very poor grade in 2022–23.

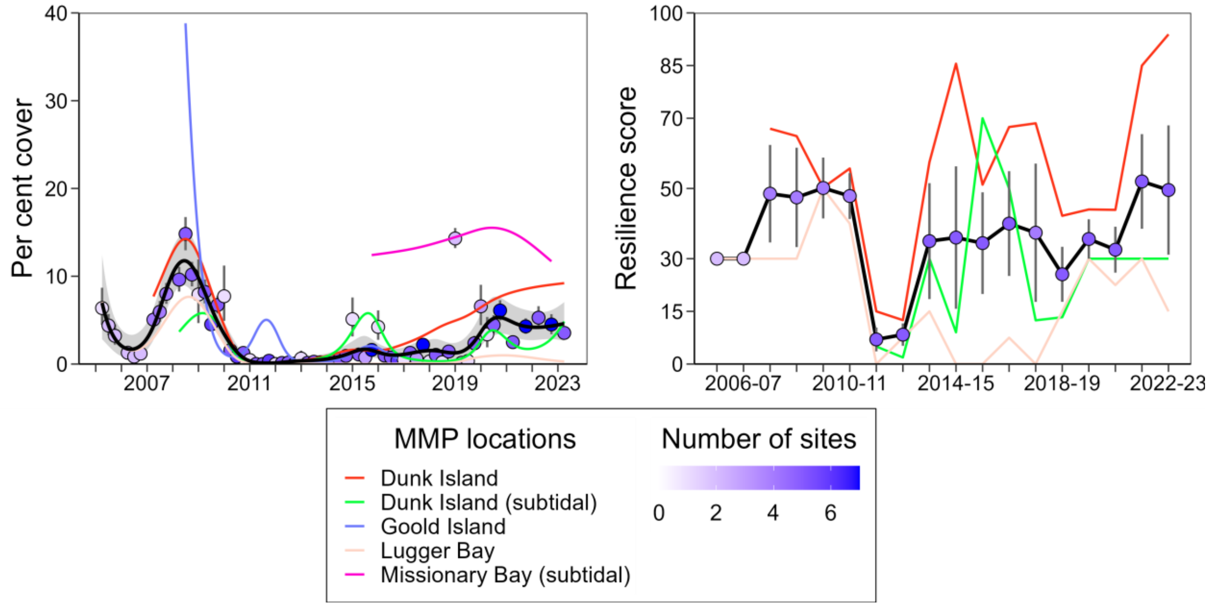


Figure 37. Temporal trends in the southern Wet Tropics seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area defining 95 per cent confidence intervals); b. average annual resilience score (±SE) and trends for each location (coloured lines). Colour of circles represents the number of sites assessed to calculate the average.

5.2.3.2 Seagrass abundance, community and extent

Seagrass meadows remain more abundant (higher per cent cover) across all habitats in the northern than the southern Wet Tropics (Figure 38, Figure 39). In the northern Wet Tropics, seagrass abundance over the long-term is higher at intertidal reef (27.6 ±2.1 per cent) than subtidal reef (17.3 ±2.3 per cent) or coastal habitats (15.7 ±1.6 per cent). In 2022–23, seagrass abundances slightly declined on average across the northern Wet Tropics (Figure 38). Despite seagrass abundances at the intertidal coastal meadows at Yule Point slightly increasing and remaining above the annual long-term average for the 8th consecutive year, the sub-regional decrease in abundance in 2022–23 appears driven changes at the reef habitats. At Green Island, subtidal seagrass abundances slightly improved to the highest annual average since monitoring was established, while intertidally there was a slight decrease in abundance (Figure 38). Conversely, at Low Isles the intertidal seagrass abundances slightly improved to the highest annual average since monitoring was established, however the subtidal abundances declined, particularly in the late wet 2023 (Figure 38).

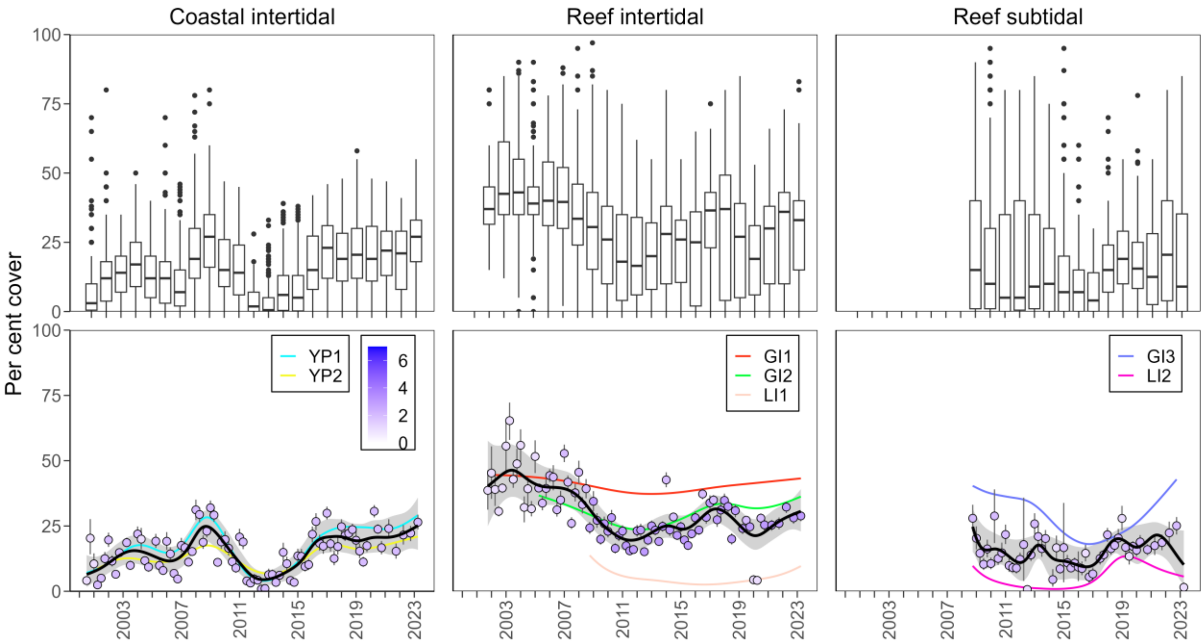


Figure 38. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends, for each habitat monitored in the northern Wet Tropics NRM region from 2001 to 2023. Whisker plots (top) show the box representing the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the dots represent outlying points. GAM plots (bottom), show trends for each habitat and coloured lines represent individual site trends

In the southern Wet Tropics, although long-term seagrass abundance is higher at intertidal reef (5.2 ±1.1 per cent) than at subtidal reef (2.0 ±0.8 per cent) or intertidal coastal habitats (1.6 ±0.6 per cent), the abundances were only a tenth of those observed in the north. This is a consequence of periods of complete loss occurring at all habitats for at least 3–6 months in early 2011. At coastal habitats in Lugger Bay, complete loss of meadows was sustained for years and 2022–23 marks the 14th consecutive year that abundances have been well below pre-2011 levels (Figure 39). Although recovery has been very slow, isolated seagrass shoots appeared at Lugger Bay sites in 2016–17, and by 2018–19 small patches had established which have changed little in the following years. Similarly, abundances improved at the reef habitats, with both intertidal and subtidal abundances having recovered to levels similar to the onset of monitoring in 2006 and remaining above the long-term average for the third consecutive year. Intertidal reef seagrass abundance remains on an increasing trajectory since 2012–13, with abundances in 2022–23 being the highest since 2009.

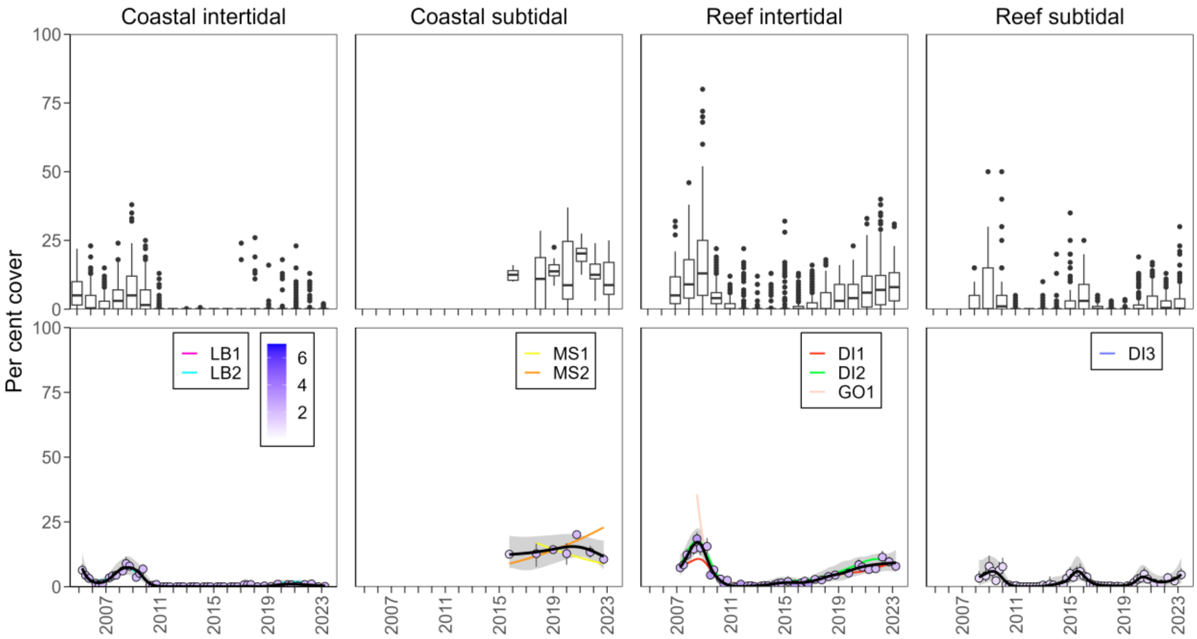


Figure 39. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends, for each habitat monitored in the southern Wet Tropics NRM region from 2001 to 2023. Whisker plots (top) show the box representing the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the dots represent outlying points. GAM plots (bottom), show trends for each habitat and coloured lines represent individual site trends.

The proportion of seagrass species displaying colonising traits in the northern Wet Tropics has remained above the long-term average at reef habitats in 2022–23 (Figure 40). At coastal intertidal habitats (Yule Point), the proportion of colonising species has slightly declined relative to the previous period, remaining below the long-term average.

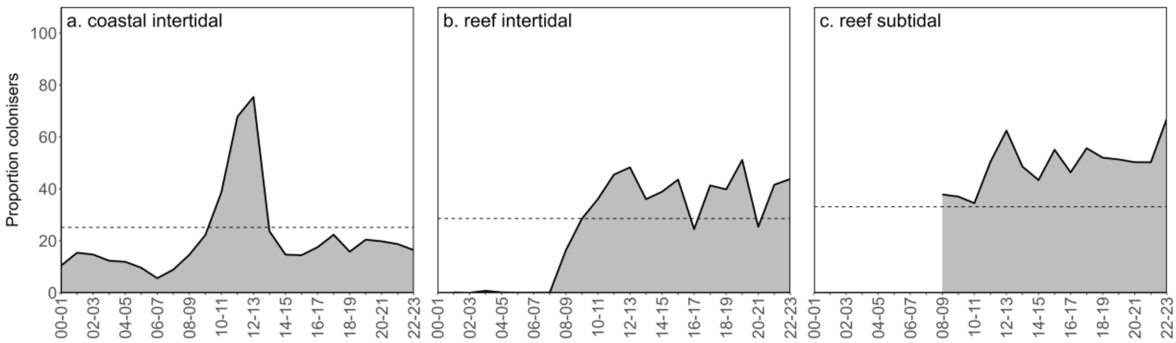


Figure 40. Proportion of seagrass abundance composed of colonising species at inshore intertidal habitats in the northern Wet Tropics region, 2001 to 2023. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

In the southern Wet Tropics, the proportion of seagrass species displaying colonising traits remains variable across habitats (Figure 41). Coastal habitats appear unchanged, remaining dominated by opportunistic species, with a higher proportion of colonising species in the subtidal. Colonising species remained in low proportions in reef habitats, however they increased intertidally while decreasing subtidally.

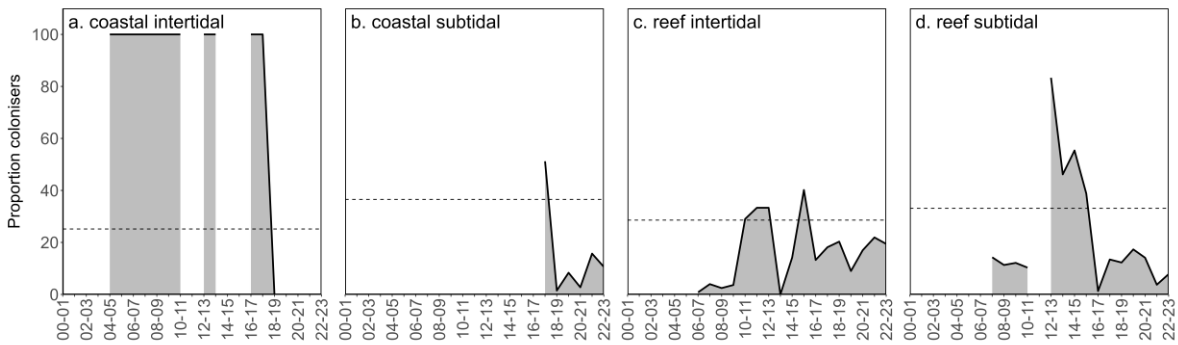


Figure 41. Proportion of seagrass abundance composed of colonising species at inshore intertidal habitats in the southern Wet Tropics region, 2001 to 2023. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

Seagrass meadow spatial extent within all monitoring sites continues to fluctuate within and between years. At intertidal coastal habitats in the northern Wet Tropics, meadow relative extent has continued to improve from the previous reporting period (Figure 42), where a slight decline was observed in the preceding year due to increasing prevalence of scars within the meadows (pers. obs.). Intertidal reef meadows changed little in 2022–23, after recovering in the previous year from declines in early 2020. The meadow at Green Island changes very little between years over the long-term, and the fluctuations in reef intertidal meadow extent in the northern Wet Tropics are driven by changes occurring at the Low Isles meadow. Similarly, the decline in extent of subtidal reef habitats in 2022–23 were driven by losses at Low Isles, which had been recovering in the previous year from losses in 2020–21 (Figure 42).

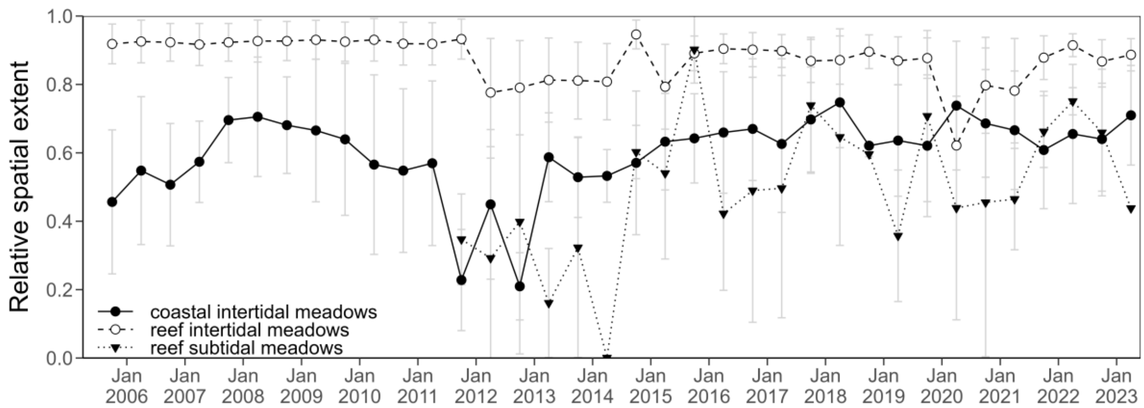


Figure 42. Change in relative spatial extent (±SE) of seagrass meadows within monitoring sites for each habitat and monitoring period across the northern Wet Tropics NRM region, 2005–2023.

In the southern Wet Tropics, seagrass meadows across all habitats were lost in early 2011 as a consequence of Tropical cyclone Yasi (Figure 43). Since then, intertidal reef meadows have progressively improved, reaching their greatest post–2011 extent in 2022–23, but with little change over the last 12 months (Figure 43). Subtidal reef meadows have fluctuated greatly over the last decade, showing significant recovery in both the previous and current reporting period (Figure 43). At intertidal coastal habitats, the meadows have had a severely protracted recovery since 2011, with colonisation delayed until mid-2018 (Figure 43), after which the isolated patches have laboured to expand and coalesce in a highly dynamic environment with mobile sediments (pers. obs.).

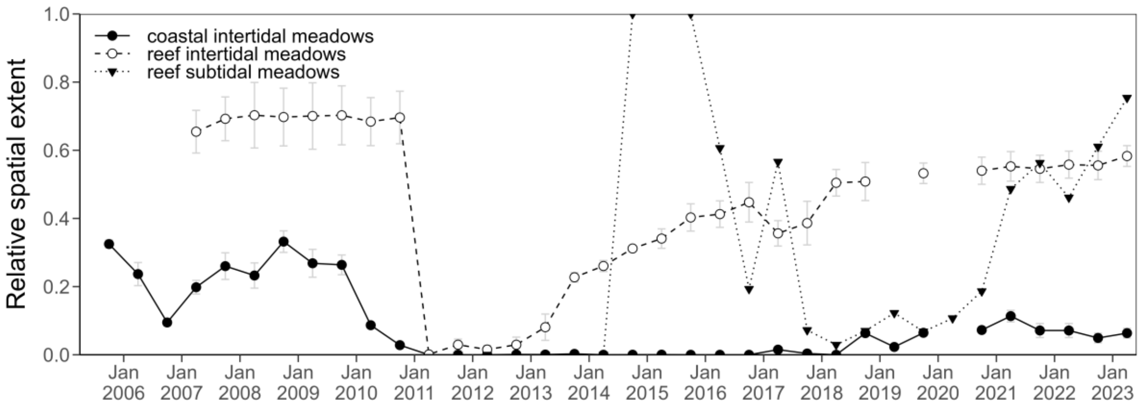


Figure 43. Change in relative spatial extent (±SE) of seagrass meadows within monitoring sites for each habitat and monitoring period across the southern Wet Tropics NRM region, 2005–2023.

5.2.3.3 Seagrass reproductive status

Reproductive effort is consistently higher in the northern sub-region than the southern sub-region. In general, reproductive effort and seed density have been buoyed in the northern Wet Tropics in the last five years, though with some variability among habitats and regions. In the northern Wet Tropics in coastal intertidal habitats (Yule Point), there were similar levels of reproductive effort in 2022–23 compared to 2021–22 but they were well below the peaks observed in 2018–19 and 2019–20 (Figure 44). Nevertheless, over the last decade, the number of reproductive structures reported in coastal habitats has been consistently higher than reef habitats, and over the long-term it is greater by a factor of approximately 50 fold. The number of reproductive structures was higher than those typically found in reef habitats. In intertidal reef habitats there were fewer reproductive structures than in the previous year and slightly lower than average for the sub-region. In reef subtidal habitats, reproductive effort was lower in 2022–23 than the previous year due to a large decline at Low Isles, but they increased slightly at Green Island (Figure 44).

Seed density was well below the long-term average in the northern Wet Tropics in the dry season, however they increased in the late wet season (Figure 44). To date, seed banks have remained very low across the region in reef habitats (Figure 44). The absence of seeds in the reef intertidal meadows examined in 2022–23, is likely the result of the greatly depressed reproductive effort in foundational species over the previous two years with most reproductive structures occurring on colonising species at Low Isles and the seeds of this species are not assessed in seed bank analysis because they are too small. Reef subtidal sites are not assessed for seed banks. Other possible explanations for the low seed bank include failure to set seed, particularly in low density dioecious species (Shelton 2008), or rapid loss of seeds after release from germination or grazing (Heck and Orth 2006).

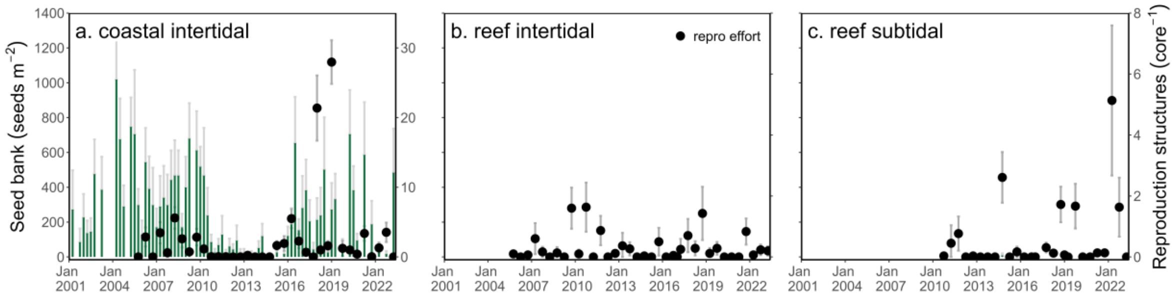


Figure 44. Seed bank and reproductive effort at inshore coastal intertidal and reef intertidal and subtidal habitats in the northern Wet Tropics region, 2001 to 2023.Seed banks presented as the total number of seeds per m^2 of sediment surface (green bars ±SE). Reproductive effort presented as the average number of reproductive structures per core (species and sites pooled) (dots ±SE). Y-axis labels are different in panel a to those in panels b and c. Seed banks were not assessed at subtidal sites.

In the southern Wet Tropics, sexually reproductive structures and seed banks were absent from coastal intertidal meadows for the 10th consecutive year, absent from reef subtidal habitats for the third year but present for foundational species at the reef intertidal sites (Figure 45). The absence of reproductive structures and seed banks may render the seagrass at risk from further disturbances, as recovery potential remains extremely low without a seed bank.

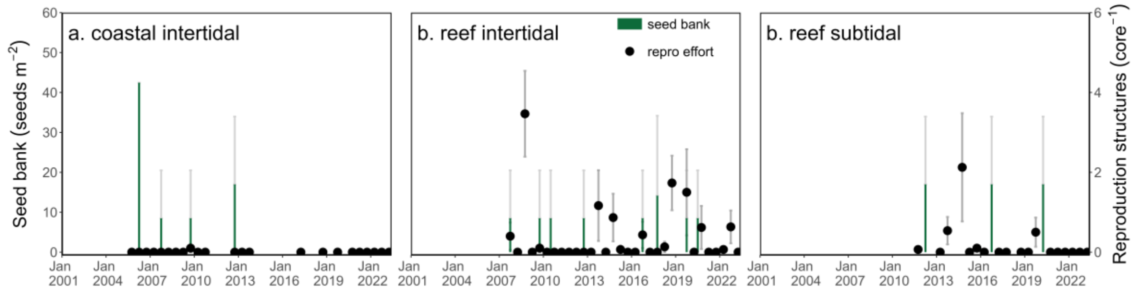


Figure 45. Seeds banks and reproductive effort for inshore coastal intertidal and reef intertidal and subtidal habitats in the southern Wet Tropics region for the late dry and late wet season, 2001 to 2023.Seed banks presented as the total number of seeds per m^2 sediment surface (green bars ±SE). Reproductive effort presented as the average number of reproductive structures per core (species and sites pooled) (dots ±SE).

5.2.3.4 Resilience

Resilience was moderate overall in the northern Wet Tropics and the third highest level over the last 13 years, but varied greatly among habitat and site (Figure 46). Resilience was highest in coastal sites at Yule Point because meadow condition was above critical thresholds for abundance and composition, and reproductive structures were present but they were lower than the maximum.

At reef intertidal resilience was increased in 2022–23 compared to the previous year but was below average. Meadow condition was above critical thresholds for abundance and composition, but reproductive structures were absent again at one of the sites (and absent for the last three years) and present only in very low density at the other. At Low Isles, colonising species continue to dominate the species composition, resulting in a low resilience score.

Resilience increased at Reef subtidal sites to the second highest on record, but there were large differences in resilience at the reef subtidal sites. The Green Island meadow condition was above critical thresholds for abundance and composition and there were reproductive structures of foundational species resulting in the equal highest score. At Low Isles, the meadow had continued to be comprised of only colonising species resulting in a low resilience score and rendering the meadow highly vulnerable to disturbances such as elevated discharge.

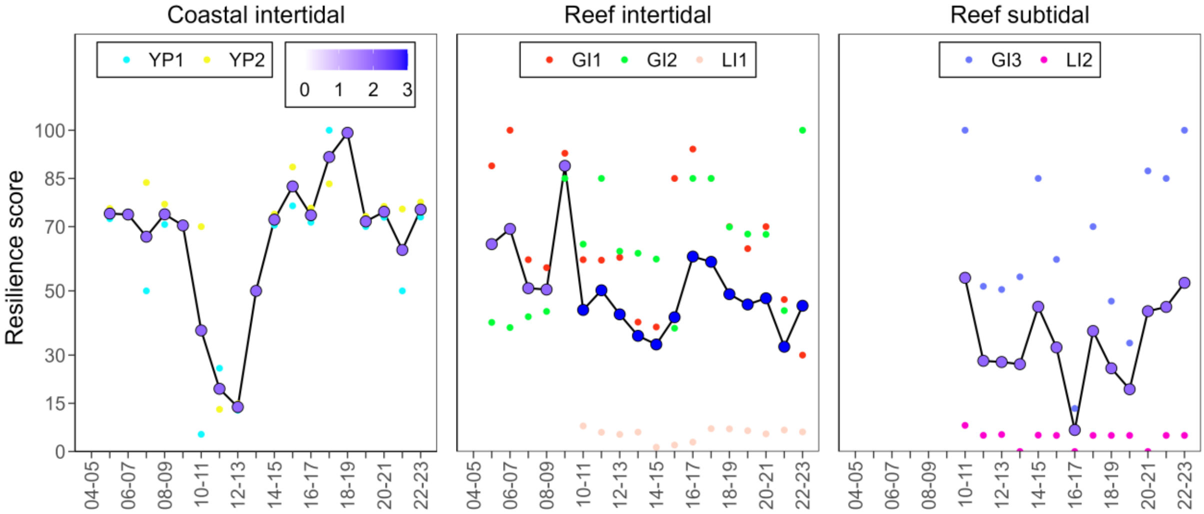


Figure 46. Resilience score for each habitat type in the northern Wet Tropics. Coloured small points represent different sites. Shades of blue for the larger points indicate the number of sites that contribute to the score.

In the southern Wet Tropics, resilience was the second highest level over the past 12 years, but there was a small decline from 2021–22 (Figure 47). At the coastal intertidal sites at Lugger Bay, the meadow was below critical per cent cover thresholds and comprised of only opportunistic species but they were not observed to be flowering nor was there any recent history of flowering.

At reef intertidal sites at Dunk Island resilience was the highest on record because meadow condition was above critical thresholds for species composition and per cent cover, there were reproductive structures and persistent species were present at one of the sites placing one of the sites in highest category for resilience and the other in the second highest category. While there were historically higher levels of reproduction at the site (Figure 45), the large historical values were mainly colonising species which do not contribute towards the resilience score in category 2. At the reef subtidal sites, the resilience score was similar to the previous three years as condition was above critical thresholds for species composition and per cent cover but there were no reproductive structures of foundational species observed again in 2022–23 or in the previous three years.

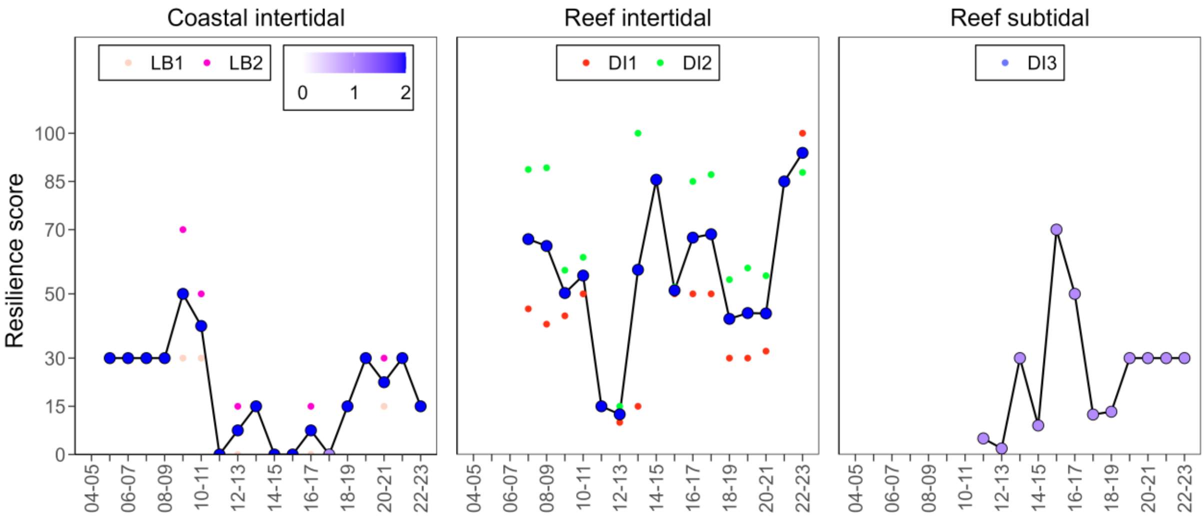


Figure 47 Resilience score for each habitat type in the southern Wet Tropics. Coloured small points represent different sites. Shades of blue for the larger points indicate the number of sites that contribute to the score.

5.2.3.5 Epiphytes and macroalgae

Epiphyte cover on seagrass leaves in the northern Wet Tropics, remained above the overall inshore Reef long-term average in all habitats for the second consecutive year in 2022–23 (Figure 48).

Macroalgae cover remained below the Reef long-term average in coastal intertidal and reef subtidal habitats in both the wet and dry season for the sixth consecutive year (Figure 48). However, macroalgae cover is typically higher in reef intertidal habitats, as it attaches to coarser sediments and coral rubble, and has remained above the long-term average for over a decade (Figure 48); only dropping below during the occasional wet season as a consequence of increased freshwater and reduced light. In 2022–23, macroalgae cover in reef intertidal habitats was slightly higher than the previous period (Figure 48).

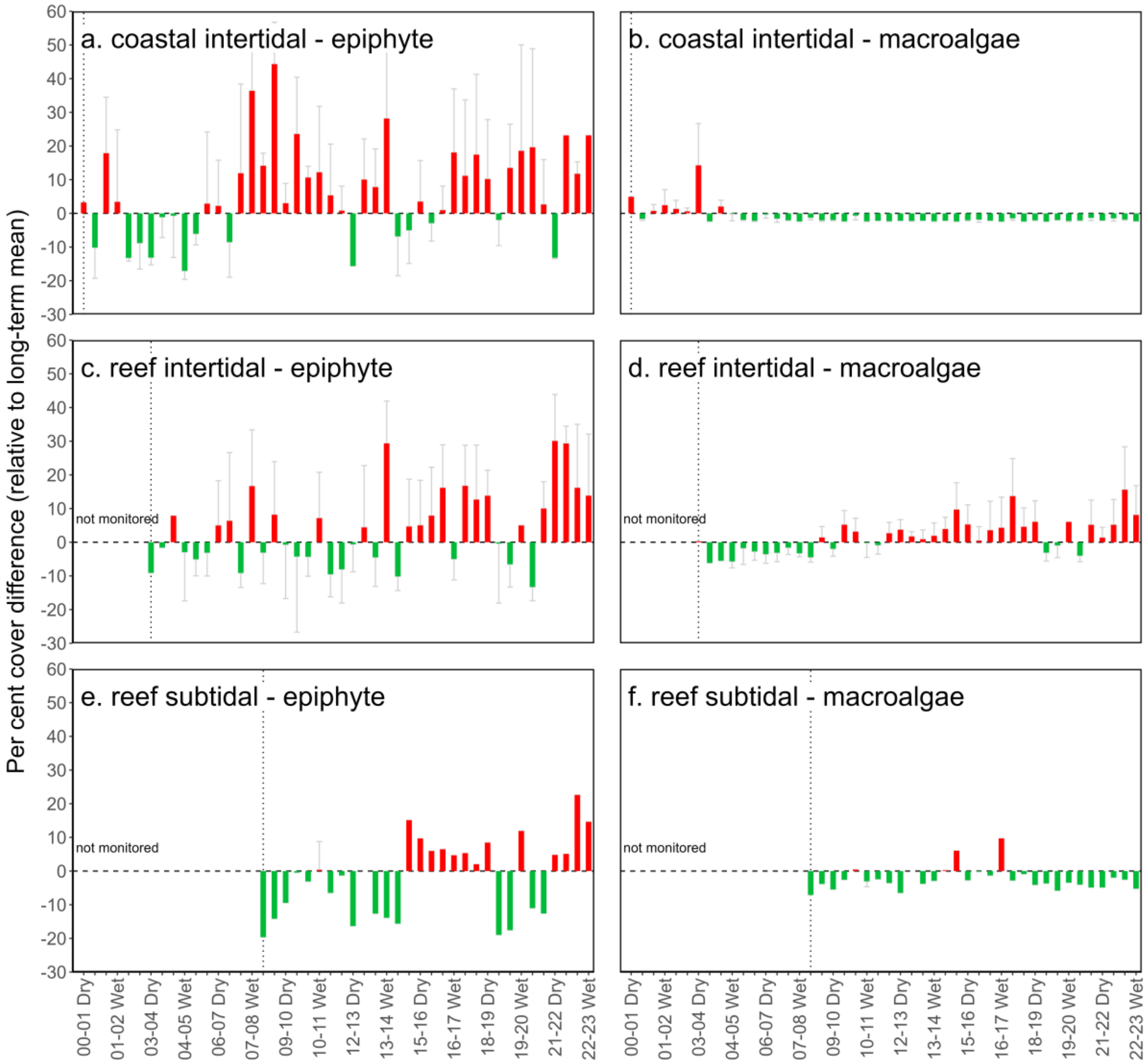


Figure 48. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the northern Wet Tropics region, 2001–2023 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

In the southern Wet Tropics, epiphyte cover in intertidal habitats (including coastal and reef) was below or at the Reef long-term average in 2022–23, which was slightly lower than the previous period (Figure 49d, f). Epiphyte cover in subtidal coastal habitats is generally low, however, it increased above the long-term average in the late dry 2022, similar to 2021 (Figure 49a). In subtidal reef habitats, epiphyte cover has fluctuated over the long term, and in 2022–23 was above the long-term average.

Macroalgae cover is generally below the Reef long-term average in all habitats except reef subtidal in the southern Wet Tropics (Figure 49). Macroalgae cover at the reef subtidal site has varied greatly over the last decade and has remained above the long-term average for the last couple of years, increasing in 2022–23 (Figure 49g).

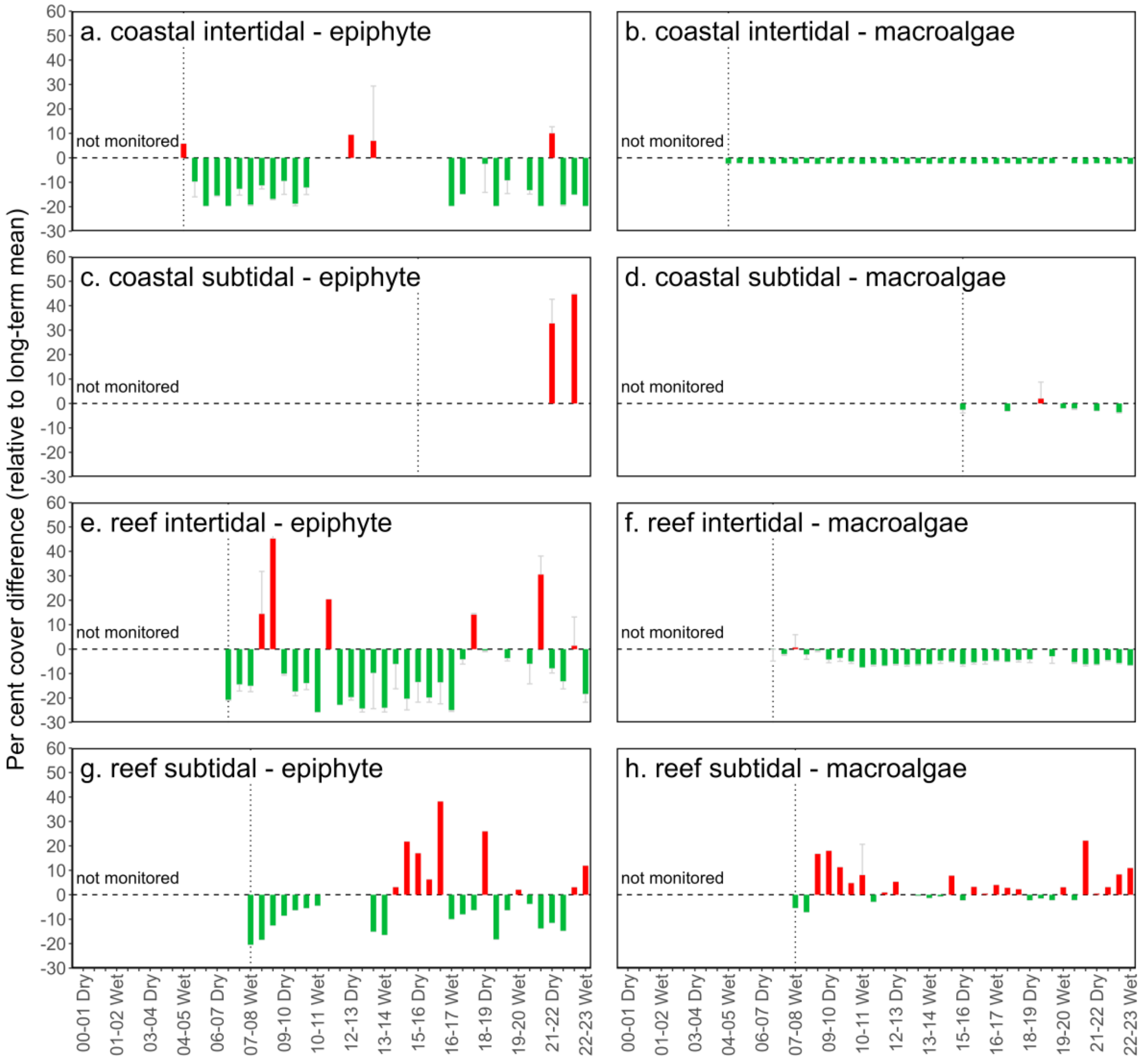


Figure 49. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the southern Wet Tropics region, 2001–2023 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

5.3 Burdekin

5.3.1 2022–23 Summary

In 2022–23, wet season rainfall across the Burdekin catchments was above the long-term average and river discharge was more than double the median for the region. Typical of the region, inshore seagrass sites were exposed to turbid waters (water types I and II) throughout the wet season.

The condition of seagrass meadows across the Burdekin NRM region in 2022–23 deteriorated overall and remained **moderate** (Figure 50). Condition indicators contributing to this were:

- abundance score was moderate
- resilience score was moderate.

Seagrass abundance marginally decreased relative to the previous period and remains lower than historical records. The low abundances observed at certain sites may be a legacy from the events of the 2018–19 wet season. During this time, there were significant losses due to discharge from the Burdekin River combined with unusually large discharges from smaller creeks and rivers that flowed into Cleveland Bay.

Compared with the previous reporting period, seagrass resilience slightly decreased in 2022–23 and remained moderate. Coastal habitats declined in resilience score, while reef intertidal areas have improved and reef subtidal remained stable. Although seagrass abundance and composition exceeded thresholds in coastal intertidal habitats, reproductive structures were absent or low compared to historical levels. At reef intertidal habitats, colonising species increased at one site while there were reproductive structures present at the other site for the first time in three years. At the reef subtidal site there were no reproductive structures present, although there had been three years prior.

Seagrass meadows in the Burdekin region have demonstrated high resilience, particularly through their capacity for recovery, since the implementation of monitoring. This resilience is likely due to both high species diversity and a large seed bank, which have helped the meadows to adapt to disturbances. Additionally, the disturbances themselves, which are primarily caused by wind events and Burdekin River flows, are episodic in nature.

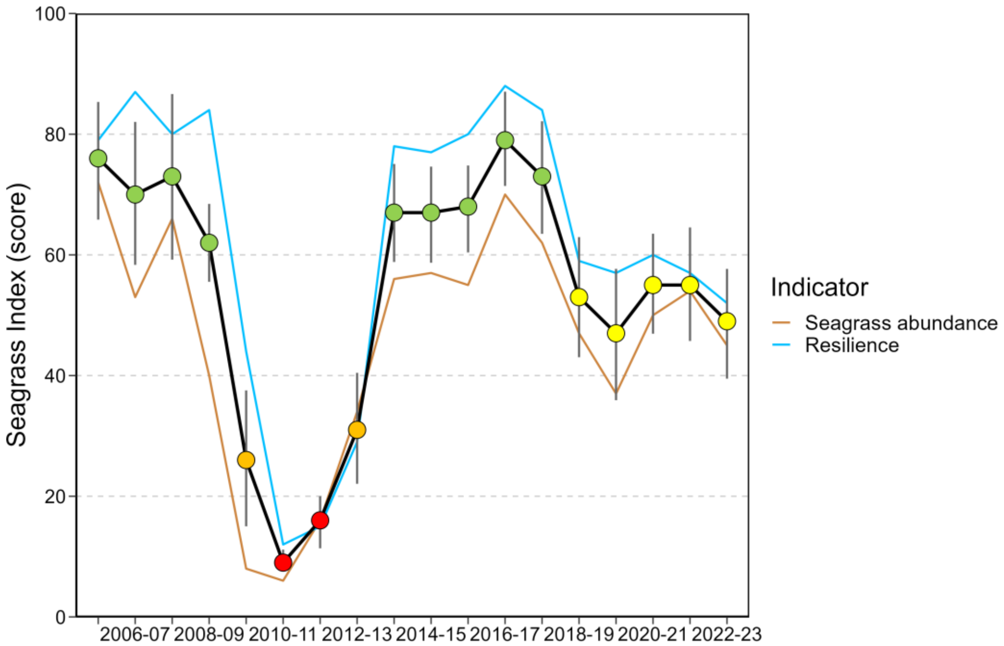


Figure 50. Temporal trend in the Seagrass Index (± SE) with contributing indicator scores for the Burdekin NRM region (averages across habitats and sites). Values are indexed scores scaled from 0–100 (± SE) and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40), ● = very poor (0–20). NB: Scores are unitless.

5.3.2 Climate and environmental pressures

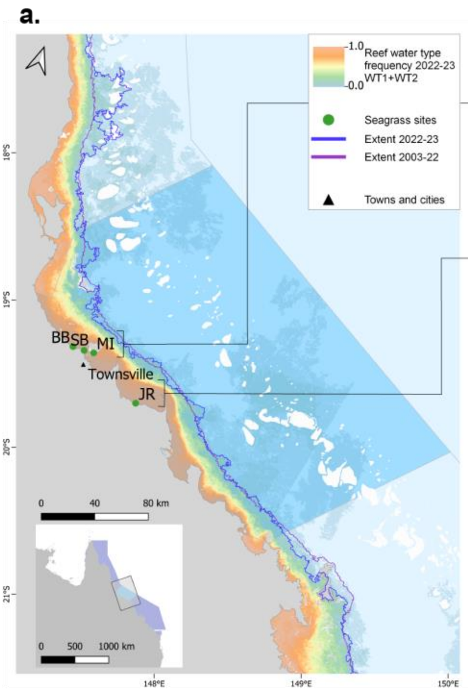
Tropical cyclones did not affect the Burdekin NRM region in 2022–23. Wet season rainfall across the region was above the long-term average in most catchments (Figure 6) and slightly above average overall (Figure 51). Annual river discharge was more than double the long-term median for the region. Inshore seagrass sites in the region were exposed to turbid waters (water types I and II) in all weeks of the wet season. In 2022–23, exposure to turbid water was around the long-term average with coastal sites (BB, SB and JR) exposed to water type I, while reef sites at Magnetic Island were exposed predominately to water type II for most of the wet season, except for two weeks of water type III with lower turbidity (Figure 51a, b).

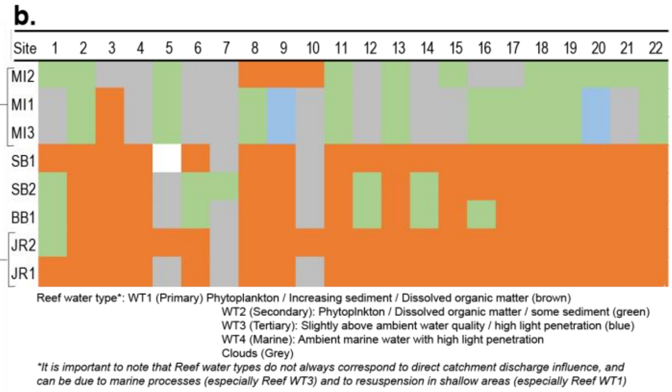
The risk of exposure of mapped seagrass to the water types was assessed in the water quality report (Gruber et al 2024). In the Burdekin NRM region, there was a small (4%) increase in exposure to the moderate risk category in 2022–23 compared to the long-term average.

Daily light levels at intertidal locations in the Burdekin region were 10.3 mol m^{-2} d^{-1} on average in 2022–23, and therefore higher than the long-term average (12.4 mol m^{-2} d^{-1}) (Figure 51c, d). Daily light levels were the highest just prior to the wet season and lowest during the wet season. There was limited data available for the year from some sites due to logger failure (Figure 101). Of sites with adequate data for the year, daily light levels at the reef intertidal site at Cockle Bay (MI2) was lower than the long-term average for the site, but they were around average at Shelley Beach (SB1).

After the warmest period in 2021–22 since the MMP commenced, intertidal within-canopy temperatures decreased this year but remained above the long-term average (Figure 51c, f). On average, 2022–23 was the fifth warmest period since 2005–06, with maximum intertidal within-canopy temperatures exceeding 35°C for a total of 37 days, with 2 days reporting maximums above 38°C. The highest temperature for the period was 39.5°C (Magnetic Island, 24Sep22), which was the fifth highest annual maximum in the last 10 years (Figure 51e, f). Daytime tidal exposure was below the long-term median at all sites for the 7th consecutive year (Figure 51c, Figure 93, Figure 94), alleviating some of the stresses (e.g., carbon limitation and desiccation) to seagrasses across the region.

The proportion of mud at Jerona (Barratta Creek) coastal meadows remains much higher than Townsville meadows (Bushland Beach and Shelley Beach) and has persisted well above the Reef long-term average (Figure 110). Post 2011, Townsville coastal meadows have been dominated by fine sediments, and although the proportion of mud fluctuated at Bushland Beach between 2018 and 2020, over the last couple of years it has remained below the long-term average (Figure 110). Conversely, reef habitats remain dominated by sand sediments, and the composition of mud which had persisted at Cockle Bay (MI2) in the last five years appears to be abating (Figure 111, Figure 112).





c.

	Long-term average	2022-23
Rainfall (1961-1990)	3.3 mm d^{-1}	3.8 mm d^{-1}
River discharge (1990-2020)	5,970,450 L yr^{-1}	12,485,244 L yr^{-1}
Turbid water exposure (2006-2018)	100%	96%
Daytime tidal exposure (1999-2022)	93 hr yr^{-1}	47 hr yr^{-1}
Within-canopy temperature (max) (2003-2022)	26.5°C (46.6°C)	26.8°C (43.2°C)
Within-canopy light (2008-2022)	12.4 mol m^{-2} d^{1}	10.3 mol m^{-2} d^{1}

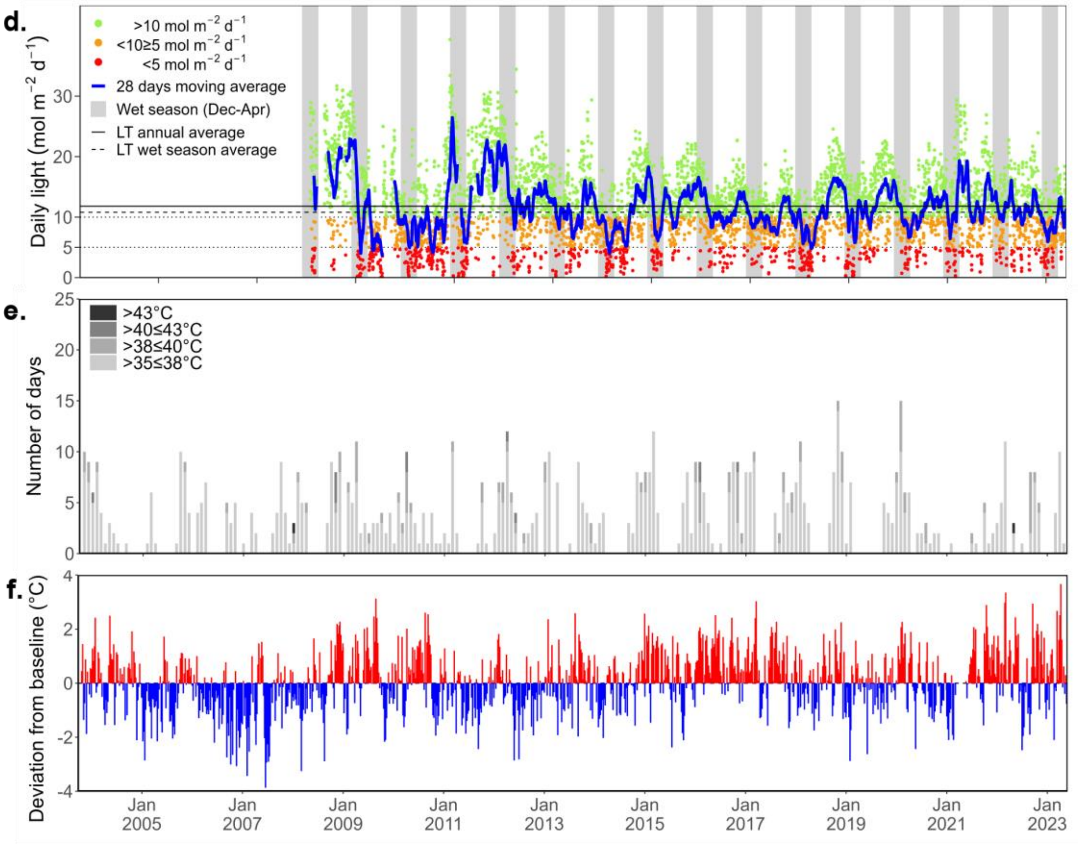


Figure 51. Environmental pressures in the Burdekin region including: a. frequency of exposure to primary (WT1) and secondary (WT2) water from December 2022 to April 2023 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the long-term average (2003–2018) exposure boundary (purple line), and the first (blue line) and third quartile (white line) of the long-term average (from Gruber *et al.* 2024); b. wet season water type at each site; c. average conditions and max temperature over the long-term and in 2022–23; d. daily light and the 28-day rolling mean of daily light for all intertidal sites; e. number of days intertidal site temperature exceeded 35°C, 38°C, 40°C and 43°C, and; f. deviations from 13-year mean weekly temperature records at intertidal sites.

5.3.3 Inshore seagrass and habitat condition

Three seagrass habitat types were assessed across the Burdekin region in 2022–23, with data from 10 sites (Table 15, Table 20).

Table 15. List of data sources of seagrass and environmental condition indicators for each seagrass habitat type in the Burdekin NRM region. Blank cell indicates data not usually collected/measured at site *Seagrass-Watch. For site details see Table 5 and Table 6.

Habitat	Site code and location		abundance	composition	distribution	reproductive effort	seed banks	meadow sediments	epiphytes & macroalgae
coastal intertidal	BB1	Bushland Beach (Townsville)	■	■	■	■	■	■	■
	BW1*	Front Beach (Bowen)	■	■			■	■	■
	BW2*	Front Beach (Bowen)	■	■			■	■	■
	JR1	Jerona (Barratta CK, Bowling Green Bay)	■	■	■	■	■	■	■
	JR2	Jerona (Barratta CK, Bowling Green Bay)	■	■	■	■	■	■	■
	SB1	Shelley Beach (Townsville)	■	■	■	■	■	■	■
	SB2*	Shelley Beach (Townsville)	■	■			■	■	■
reef intertidal	MI1	Picnic Bay (Magnetic Island)	■	■	■	■	■	■	■
	MI2	Cockle Bay (Magnetic Island)	■	■	■	■	■	■	■
reef subtidal	MI3	Picnic Bay (Magnetic Island)	■	■	■	■		■	■

5.3.3.1 Seagrass Index and indicator scores

In the 2022–23 monitoring period, the Seagrass Index for the Burdekin region slightly decreased, but remained **moderate** (Figure 50). The grade continued to appear a legacy of the previous monitoring periods, which were influenced by region-wide above average wet season rainfall and river discharge in early 2019, and have carried into the 2022–23 reporting period. The Seagrass Index in the Burdekin NRM is highly variable and it responds rapidly to changing pressures. It is the only region to have scores that varied from good to very poor since monitoring began in 2005.

Both indicators slightly declined in 2022–23 compared to the previous year. The declines in the abundance indicator appears to be influenced by lower than expected (relative to the long-term guidelines) abundances during the late wet 2023. The resilience indicator was variable between habitats and sites, and in 2022–23 appears influenced by declines at the coastal intertidal sites. Examination of the indicators over the long-term show declines from 2009–2011 as a consequence of the years of above-average rainfall and severe weather, proceeded by rapid recovery. Based on those previous trends, recovery of the seagrass habitats in 2022–23 appears to have stalled, with some sites remaining well below historical maxima (Figure 52).

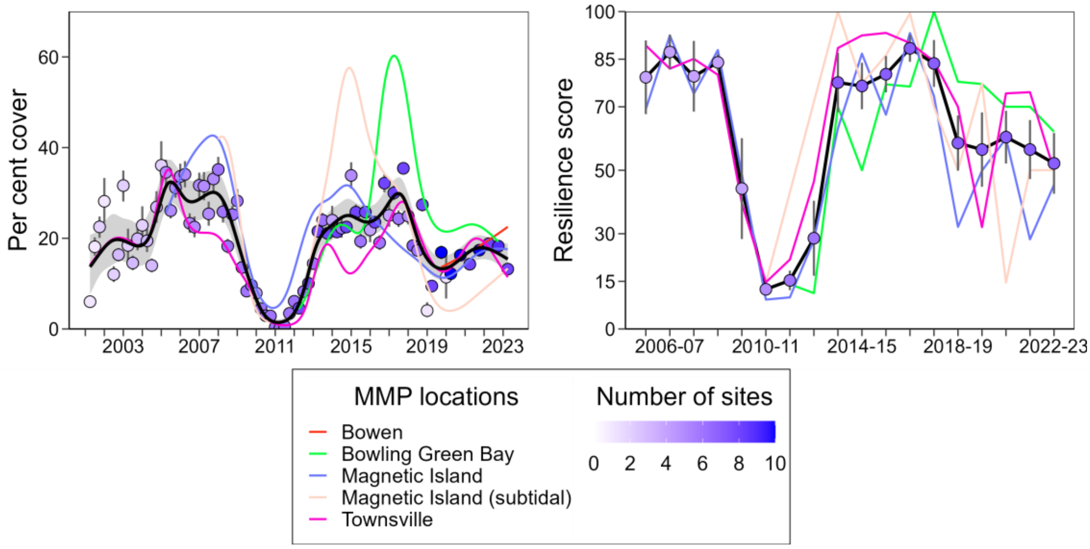


Figure 52. Temporal trends in the Burdekin seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area defining 95 per cent confidence intervals); b. average annual resilience score (±SE) and trends for each location (coloured lines). Colour of circles represents the number of sites assessed to calculate the average.

5.3.3.2 Seagrass abundance, composition and extent

Seagrass abundance in the Burdekin region has shown a pattern of loss and recovery over the duration of the MMP. Between 2008–09 and 2010–11, losses occurred as a result of multiple consecutive years of above-average rainfall (river discharge) and severe weather (cyclone Yasi). From 2011, seagrass rapidly recovered. However, since 2014, recovery has varied between habitats, with seagrass abundance progressively declining at reef (intertidal and subtidal) habitats since 2015. In 2017–18, coastal habitats increased to their highest abundance since 2001, immediately followed by large declines in 2018–19. Declines in abundances occurred across the region in 2018–19, with the largest losses in reef subtidal and coastal intertidal habitats. The onset of recovery occurred in coastal habitats within 12 to 18 months, with abundances remaining above the long-term average and continuing to improve in 2022, but subsequently declining in the late wet 2023. Recovery at reef habitats has been more protracted, with little change in intertidal and subtidal abundances over the last couple of years.

An examination of the long-term abundances across the Burdekin region indicates no significant regional trend (from first measure to 2022–23), although a significant long-term decline has occurred at Cockle Bay, Magnetic Island (reef intertidal, MI2) since monitoring began in 2005 (Table 22).

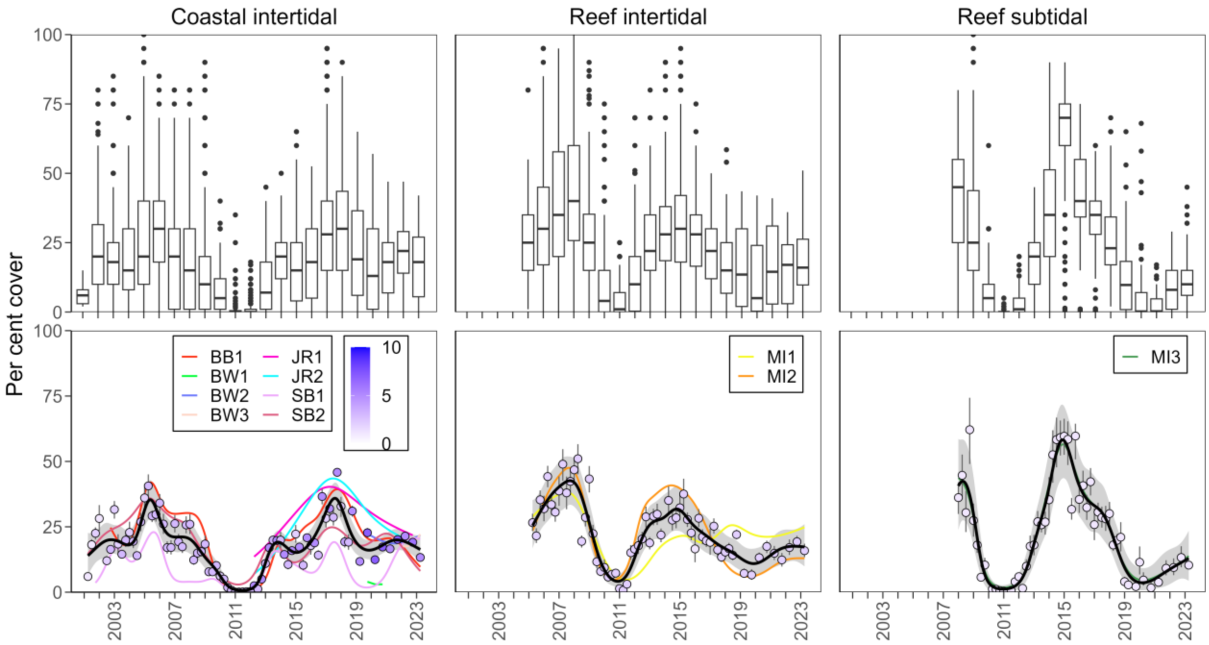


Figure 53. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends, for each habitat monitored in the Burdekin NRM region from 2001 to 2023. Whisker plots (top) show the box representing the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the dots represent outlying points. GAM plots (bottom), show trends for each habitat and coloured lines represent individual site trends.

This year was the third year since 2014, that the proportion of species displaying colonising traits (e.g. *H. ovalis*) increased, remaining above the Reef long-term average at reef intertidal habitats in the region (Figure 54). The intertidal reef habitat at Cockle Bay (MI2) has been dominated by *Halophila ovalis* since early 2019 when the location was severely impacted by floodwaters. Colonising species are important for recovery following loss (Kilminster *et al.* 2015), however, the increased proportion of colonising species suggests some level of localised disturbance which is delaying recovery. Conversely, coastal and reef subtidal habitats remained dominated by opportunistic species (*H. uninervis, N. muelleri, O. serrulata*). Opportunistic foundation species have a capacity to resist stress (survive, through reallocation of resources) caused by acute disturbances (Collier *et al.* 2012b), and therefore, current species composition in coastal and reef subtidal habitats provides greater overall resilience in Burdekin meadows.

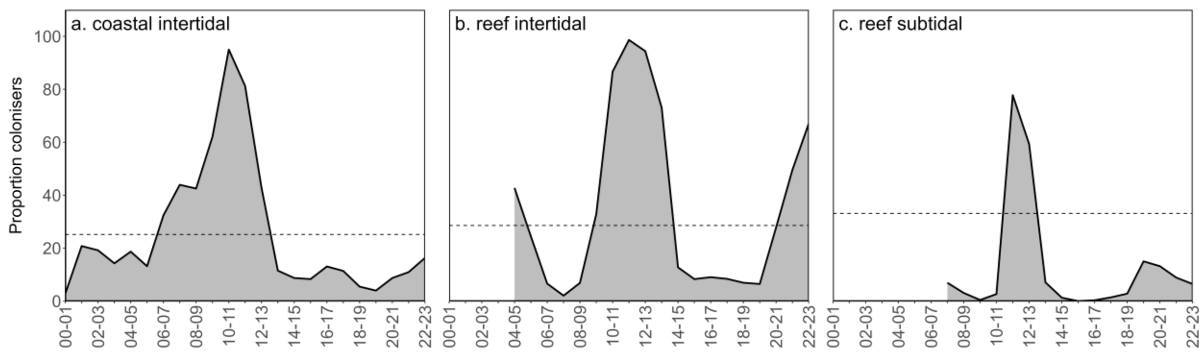


Figure 54. Proportion of seagrass abundance composed of colonising species at inshore intertidal habitats in the Burdekin region, 2001 to 2023. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

Meadow spatial extent continued to improve slightly in 2022-23 from the lowest level recorded in reef subtidal habitats in early 2020, recovering to extents prior the flood events in early 2019 (Figure 55). Intertidal meadows at coastal and reef sites improved marginally over the last 12 months, relative to the previous reporting period (Figure 55).

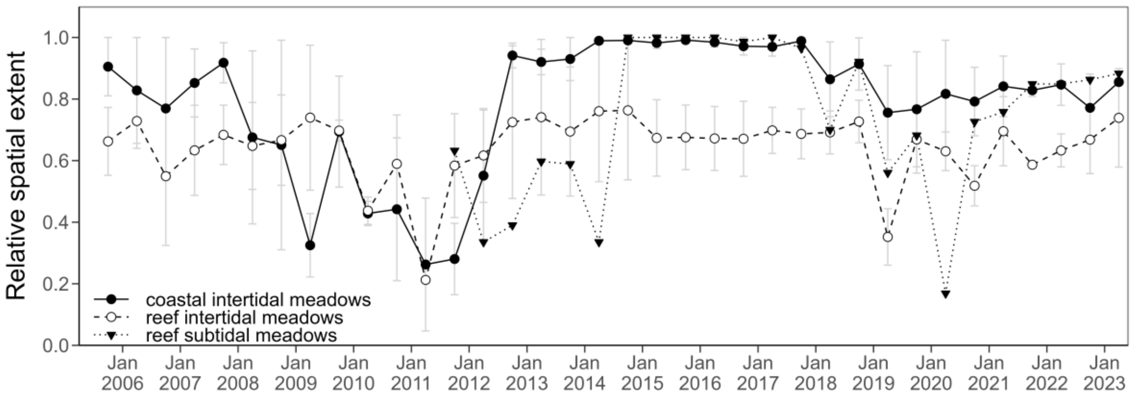


Figure 55. Change in spatial extent (± SE) of seagrass meadows within monitoring sites for each inshore intertidal habitat and monitoring period across the Burdekin region, 2005–2023.

5.3.3.3 Seagrass reproductive status

Reproductive effort has been highly variable across Burdekin region habitats over the long term, particularly in coastal habitats where very high and anomalous levels of reproductive effort can occur, usually at times when abundance is also very high (Figure 56). Reproductive effort in 2022–23 was low in coastal habitats (and predominantly from colonising species), absent at reef subtidal habitats and slightly higher at reef intertidal habitats in the late dry than in the previous seven years. Seed banks persisted across the region in 2022–23, however, seed densities were reduced in coastal and reef intertidal habitats compared to the previous reporting year when there was a record number of seeds in coastal habitats(Figure 56a). Seed banks are not measured at subtidal sites. Low reproductive effort in reef intertidal habitats will hinder replenishment of reduced seed banks, and seed banks are therefore likely to remain low in coming years. This may limit the capacity of meadows to recover from seed should reproductive effort and seeds banks continue to decline.

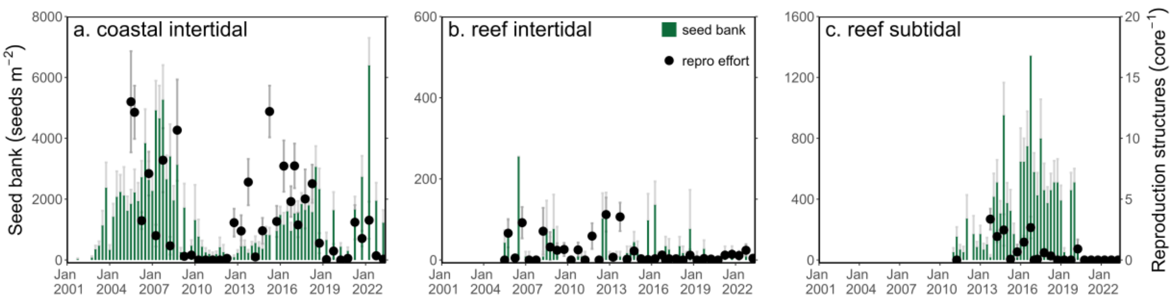


Figure 56. Seedbank and reproductive effort at inshore coastal intertidal and reef subtidal and intertidal habitats in the Burdekin region, for late dry season, 2002–23. Seed bank presented as the total number of seeds per m[2] sediment surface (green bars ±SE). Reproductive effort for the late dry season and late wet season presented as the average number of reproductive structures per core (species and sites pooled) (dots ±SE). NB: Y-axis scale for seed banks differs between habitats and seeds not assessed at subtidal sites since 2020.

5.3.3.4 *Resilience*

The overall resilience score for the Burdekin was moderate and similar amongst habitat types (Figure 57). At coastal intertidal sites, the resilience score declined. Seagrass condition exceeded abundance and composition thresholds but reproductive structures were absent at most sites and low compared to historical levels so the resilience score was in the low range for sites meeting these criteria. At reef intertidal sites the resilience score increased. At MI2 colonising species dominated the habitat and increased in proportion from the previous year to 99% of total cover resulting in the lowest ever recorded resilience score for the sites. This was not the case at MI1 where reproductive structures were present for the first time in three years.

At the reef subtidal site the resilience score was stable in 2022–23 (Figure 57). Abundance was above the per cent cover threshold. There were no reproductive structure present, but there had been three years prior.

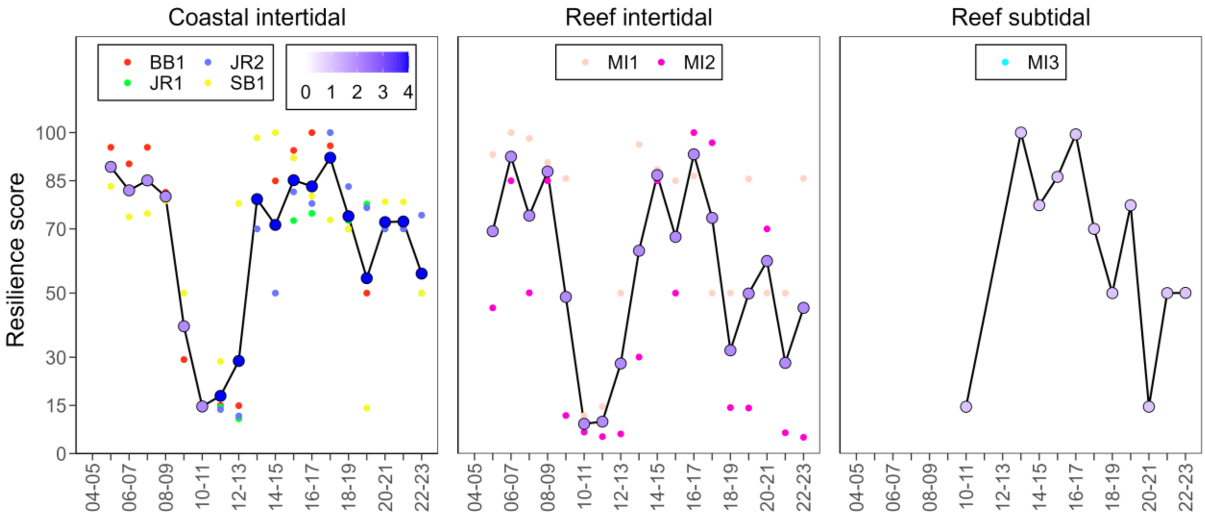


Figure 57. Resilience score in each habitat in the Burdekin, 2006 to 2023. Coloured small points represent different sites. Shades of blue for the larger points indicate the number of sites that contribute to the score.

5.3.3.5 *Epiphytes and macroalgae*

Epiphyte cover on seagrass leaf blades in 2022–23 compared to the previous period, varied depending on habitat. At coastal intertidal habitats the cover was lower in 2022–23, with a slight increased during the late dry, followed by declines in the late wet (Figure 58a). At reef habitats, cover varied between seasons at intertidal habitats, but remained above the inshore Reef average throughout the year at subtidal meadows (Figure 58c, e). Conversely, macroalgae abundance in 2022–23 remained low and below the long-term average for the third consecutive year across the region at all seagrass habitats (Figure 58).

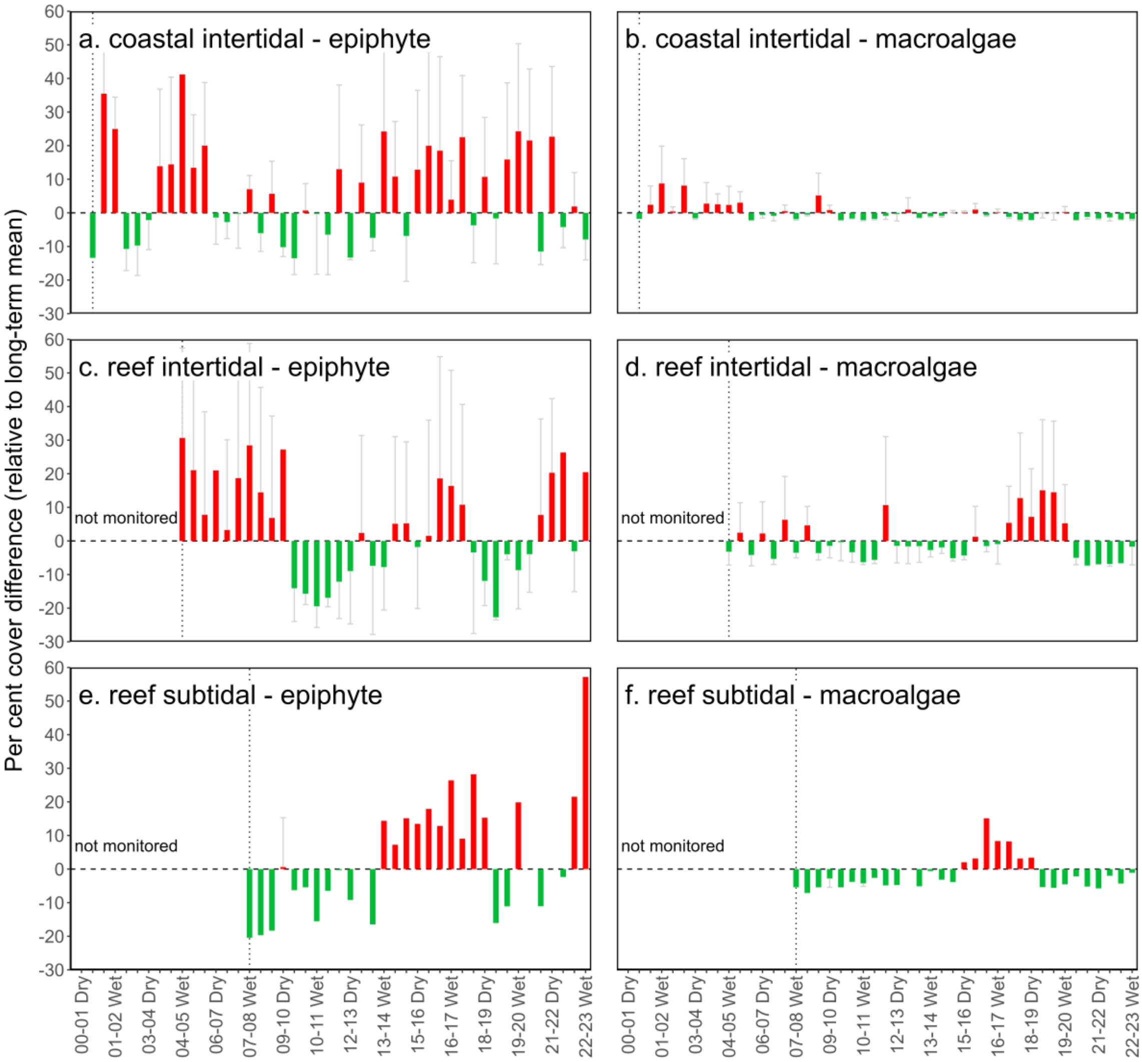


Figure 58. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Burdekin region, 2001–2023 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

5.4 Mackay–Whitsunday

5.4.1 2022–23 Summary

The 2022–23 monitoring period in the Mackay–Whitsunday region was relatively benign with environmental pressures around or below the long-term averages despite river discharge being more than two times the long-term average (Figure 6, Table 11, Figure 51). Exposure to turbid waters during the wet season was below long-term averages, and daily light was around average. Within-canopy temperatures were slightly cooler than the previous period and also around the long-term average.

Inshore seagrass meadows across the Mackay–Whitsunday NRM region improved in overall condition in 2022–23, and the condition grade remained **moderate** (Figure 59). There were improvements in both indicators. Indicators for the overall condition score were:

- abundance score was moderate
- resilience was moderate.

Seagrass condition in the Mackay–Whitsundays has fluctuated between poor and moderate since 2011–12 which appears to be due to a range of environmental pressures.

The seagrass abundance score increased in 2022–23, driven by increases in estuarine intertidal and coastal and reef subtidal habitats. Coastal and reef intertidal habitats remained relatively unchanged for the second consecutive year.

The overall resilience score for the Mackay–Whitsunday region was moderate in 2022–23, increasing to its highest level in six years. Trends were highly variable between habitats. There were large improvements in resilience at the estuarine intertidal habitat where foundational species became more prevalent and a high number of reproductive structures were observed. Coastal habitats at Midge Point also improved slightly due to an increase in reproductive structures. Despite these improvements in the resilience score, seed banks were generally unchanged, with the exception of estuarine sites where seed banks were absent.

Up until 2016–17, the Mackay–Whitsunday regional seagrass condition had been improving from 2010–2011, when it reached its lowest level since monitoring commenced. After this time, the recovery trend abated and condition dropped to poor, as a consequence of cyclone Debbie in March 2017. Since then, the Index had fluctuated between poor and moderate with recovery challenged across the region, until the current period. This appears the first indication that seagrass habitats in the region may be recovering from past disturbances. This is also likely due to alleviation of localised pressures and possibly chronic changes not easily identifiable in all sites and habitats.

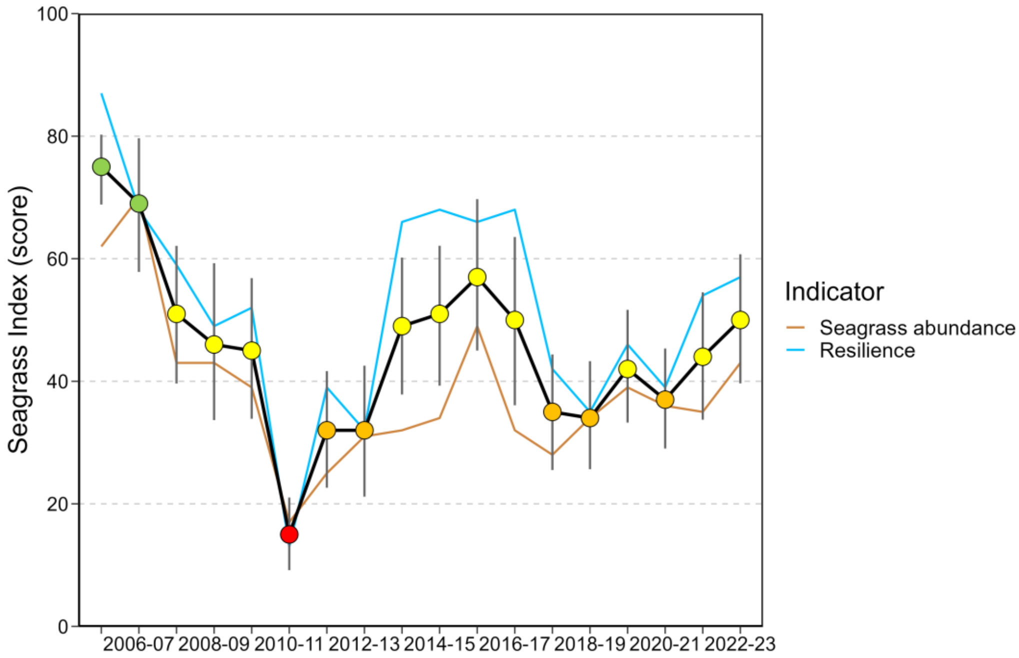


Figure 59. Temporal trend in the Seagrass Index (± SE) with contributing indicator scores for the Mackay–Whitsunday NRM region (averages across habitats and sites). Values are indexed scores scaled from 0–100 (± SE) and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40), ● = very poor (0–20). NB: Scores are unitless.

5.4.2 Climate and environmental pressures

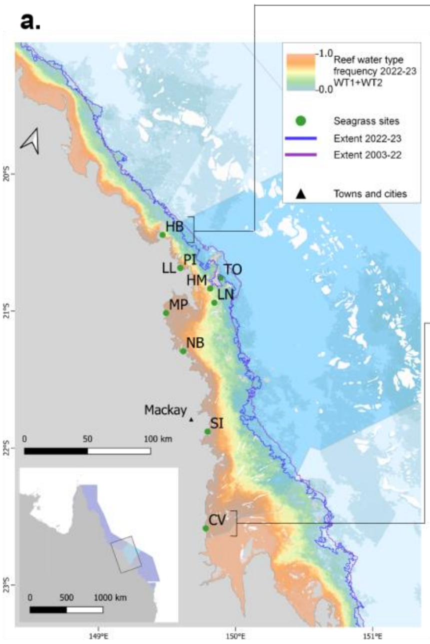
Environmental conditions were around the long-term average in the Mackay–Whitsunday region in 2022–23. There were no cyclones to affect the region and rainfall was around average. However, river discharge was more than two times the long-term average in the Proserpine and O'Connell Rivers, resulting in above average discharge for the region.

Exposure of inshore seagrass to turbid waters during the wet season were below the long-term averages (Figure 60a, c). Exposure to either WT1 or WT2 was also variable among seagrass habitats (Figure 60b). Estuarine and coastal sites from Midge Point and south exposed to turbid waters for the entire wet season. Midge Point and Clairview were exposed to WT1 waters for most of the wet season whereas Newry Bay and Sarina Inlet were exposed to a combination of WT1 and WT2 waters. North of Midge Point where reef habitats fringing the mainland (HB1 and HB2) and on offshore islands (HM1 and HM2, LN1 and LN2) are the dominant habitats surveyed, they were exposed to lower levels of turbid water, and predominantly WT2 which is less turbid (Figure 8, Figure 60b). Pioneer Bay (PI3) and Llewellyn Bay (LL1) were exposed to some WT1 as well.

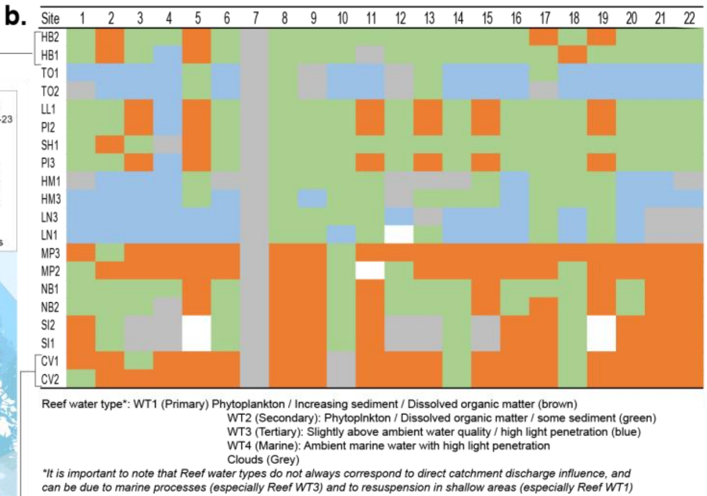
The risk of exposure of mapped seagrass to the water types are assessed in the water quality report (Gruber et al 2024). In the Mackay–Whitsunday NRM region in 2022–23, there was an increase (13%) in the likelihood that seagrass was not at risk to water quality exposure compared to the long-term average.

Daily light was around the long-term average combined within the region (Figure 8, Figure 60c, Figure 102). At Lindeman Island (LI3) light has only been measured for three years but daily light was lower in 2022–23 (13.6 mol m^{-2} d^{-1}) than the average of previous years (11.3 mol m^{-2} d^{-1}). At Hamilton Island, the average light level in 2022–23 (8.3 mol m^{-2} d^{-1}) was considerably lower than the long-term average (14.7 mol m^{-2} d^{-1}). This will be affected by some data loss due to logger failure, but there were also more low light days than previous years and fewer high light days (Figure 102). In contrast, average daily light at Midge Point was slightly higher than the long-term average (Figure 102).

a.



b.



c.

	Long-term average	2022-23
Rainfall (1961-1990)	7.7 mm d^{-1}	7.8 mm d^{-1}
River discharge (1990-2020)	3,014,809 L yr^{-1}	5,889,958 L yr^{-1}
Turbid water exposure (2006-2018)	91%	80%
Daytime tidal exposure (1999-2022)	49 hr yr^{-1}	73 hr yr^{-1}
Within-canopy temperature - intertidal (2003-2022)	25.5°C (42.7°C)	25.5°C (46.5°C)
Within-canopy light (2010-2022)	12.5 mol m^{-2} d^{1}	12.3 mol m^{-2} d^{1}

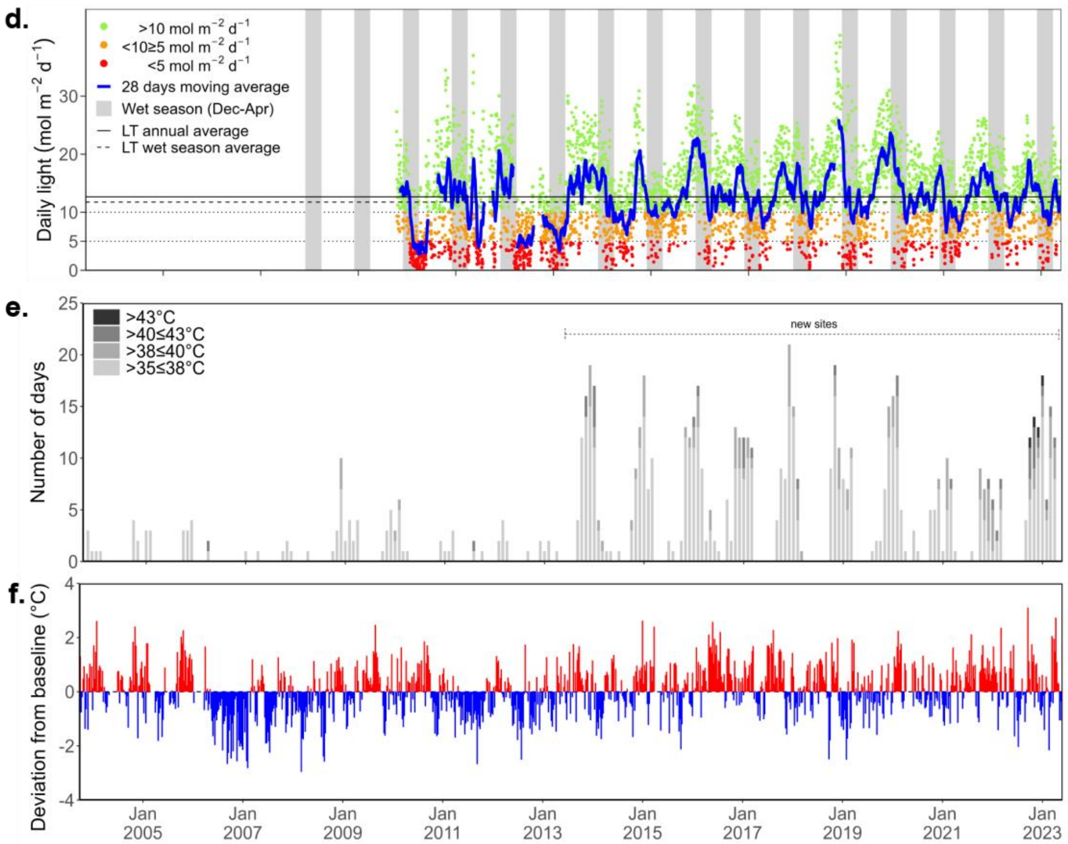


Figure 60. Environmental pressures in the Mackay–Whitsunday NRM region including: a. frequency of exposure to primary (WT1) and secondary (WT2) water from December 2022 to April 2023 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the long-term average (2003–2018) exposure boundary (purple line), and the first (blue line) and third quartile (white line) of the long-term average (from Gruber *et al.* 2024); b. wet season water type at each site; c. average conditions and max temperature over the long-term and in 2022–23; d. daily light and the 28-day rolling mean of daily light for all sites; e. number of day temperature exceeded 35°C, 38°C, 40°C and 43°C, and; f. deviations from 13-year mean weekly temperature records at intertidal sites.

During the 2022–23 reporting period, intertidal within-canopy temperatures were slightly cooler than the previous period and at the long-term average (Figure 60c,f). Maximum intertidal within-canopy temperatures exceeded 35°C for a total of 94 days during 2022–23, the greatest ever recorded for the region. Additionally, the region experienced 4 days where temperatures exceeded 43°C, including the highest ever at 46.5°C (Sarina Inlet, 29Oct22) (Figure 60e, f). This temperature anomaly occurred as part of a week-long event recorded from 26 October to the 01 November 2022, across a number of locations and habitats in the central and southern marine zones of the region, from Midge Point to Clairview. Daytime tidal exposure at all habitats was above the long-term average in 2022–23 and higher than the previous reporting period (Figure 60c, Figure 95), which may have resulted in increased desiccation stresses at these intertidal sites.

The proportion of fine grain sizes (fine sand and mud) increased in the sediments of estuarine and coastal seagrass monitoring sites in 2022–23, relative to the previous period (Figure 113). Although the proportion of mud in estuarine sediments increased, it continued to remain below the overall inshore Reef long-term average. In comparison, the proportion of mud has varied across coastal habitats, fluctuating over the long-term within and between both meadows and years, while remaining above the long-term average at most sites (Figure 114). The proportion of fine grain sizes decreased in the sediments of the seagrass monitoring sites with distance from the coast, with reef habitats being composed predominately of fine to medium sand, with little change in 2022–23 relative to the previous period (Figure 115).

5.4.3 Inshore seagrass and habitat condition

Five seagrass habitat types were assessed across the Mackay–Whitsunday region this year, with data from all 24 long-term monitoring sites in 2022–23 (Table 16, Table 20).

Table 16. List of data sources of seagrass and environmental condition indicators for each seagrass habitat type in the Mackay–Whitsunday NRM region. Blank cells indicate data not usually collected/measured at site. ▪ drop camera sampling (QPWS), *Seagrass-Watch. For site details see Table 5 and Table 6.

Habitat	Site		abundance	composition	distribution	reproductive effort	seed banks	meadow sediments	epiphytes	macroalgae
estuarine intertidal	SI1	Sarina Inlet	■	■	■	■	■	■	■	■
	SI2	Sarina Inlet	■	■	■	■	■	■	■	■
coastal intertidal	CV1*	Clairview	■	■			■	■	■	■
	CV2*	Clairview	■	■			■	■	■	■
	LL1*	Llewellyn Bay	■	■			■	■	■	■
	MP2	Midge Point	■	■	■	■	■	■	■	■
	MP3	Midge Point	■	■	■	■	■	■	■	■
	PI2*	Pioneer Bay	■	■			■	■	■	■
	PI3*	Pioneer Bay	■	■			■	■	■	■
	SH1*	St Helens	■	■			■	■	■	■
coastal subtidal	NB1▪	Newry Bay	■	■					■	■
	NB2▪	Newry Bay	■	■					■	■
reef intertidal	HM1	Hamilton Island	■	■	■	■	■	■	■	■
	HM2	Hamilton Island	■	■	■	■	■	■	■	■
	HB1*	Hydeaway Bay	■	■			■	■	■	■
	HB2*	Hydeaway Bay	■	■			■	■	■	■
	LN3	Lindeman Is	■	■	■	■	■	■	■	■

reef subtidal	CH4□	Cid Harbour	■	■					■	■
	CH5□	Cid Harbour	■	■					■	■
	LN1	Lindeman Is	■	■	■	■	■	■	■	■
	TO1□	Tongue Bay	■	■					■	■
	TO2□	Tongue Bay	■	■					■	■
	WB1□	Whitehaven Bch	■	■					■	■
	WB2□	Whitehaven Bch	■	■					■	■

5.4.3.1 Seagrass Index and indicator scores

In the 2022–23 monitoring period, the Mackay–Whitsunday region Seagrass Index continued to increase from the previous year, and remained **moderate** (Figure 61).

The improvement was due to a rise in both indicators. The abundance score increased from poor to moderate, driven by increases estuarine intertidal and coastal and reef subtidal habitats. The resilience score remained moderate, with variations in trends among habitats and sites.

The Index has been varying between poor and moderate since 2011–12 when it recovered from the impacts of the 2010–11 extreme weather events. In 2016–17 the improving trend abated and abundance declined as a consequence of Tropical cyclone Debbie (Figure 61). The following year both abundance and resilience declined, and in 2018–19 reached its lowest level since 2012–13, driven by declining resilience. Despite generally moderate environmental conditions, the Seagrass Index has been on an improving trajectory, particularly over the last two years. The rise in the resilience score is a positive sign that with continued moderate environmental conditions, further recovery may be possible.

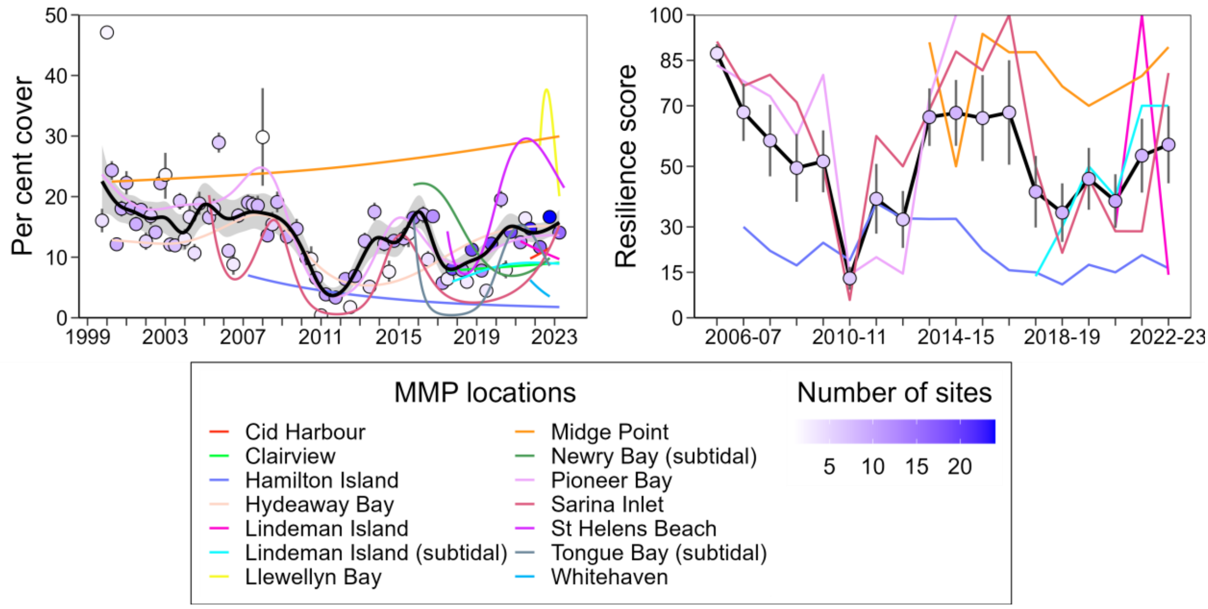


Figure 61. Temporal trends in the Mackay–Whitsunday seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area defining 95 per cent confidence intervals); b. average annual resilience score (±SE) and trends for each location (coloured lines). Colour of circles represents the number of sites assessed to calculate the average.

5.4.3.2 Seagrass abundance, community and extent

Overall, average seagrass abundance slightly improved in the Mackay–Whitsunday region in 2022–23, with little or no change in some habitats and minor gains in others (Figure 62). Estuary habitats continued to improve for the fourth consecutive year, after declines between 2017 and 2019, and subtidal coastal habitats improved from losses in the 2020–21 reporting period. Intertidal coast and reef habitats have remained relatively unchanged for the second consecutive year (Figure 62).

Seagrass abundance (per cent cover) in the Mackay–Whitsunday region in 2022–23 was higher in coastal habitats (intertidal = 21.5 ±1.5 per cent, subtidal = 13.4 ±2.9 per cent) than estuarine (13.5 ±1.7 per cent) or reef habitats (intertidal = 9.0 ±1.2 per cent, subtidal = 8.25 ±1.17 per cent), respectively. Seagrass per cent cover continued to differ seasonally in coastal intertidal meadows over 2022–23, being higher in the late dry than late monsoon (26.6 ±1.6 per cent, and 16.5 ±1.4 per cent, respectively). Little or no change was detected between seasons in all other habitats within 2022–23 (Figure 62).

Seagrass abundance at estuarine and coastal habitats has fluctuated greatly between and within years over the long-term, with some sites experiencing total or near total loss followed by recovery (Figure 62). The regional long-term trend continues to indicate a declining trajectory (Table 22), with habitats continuing to recover from repeated losses over the last decade.

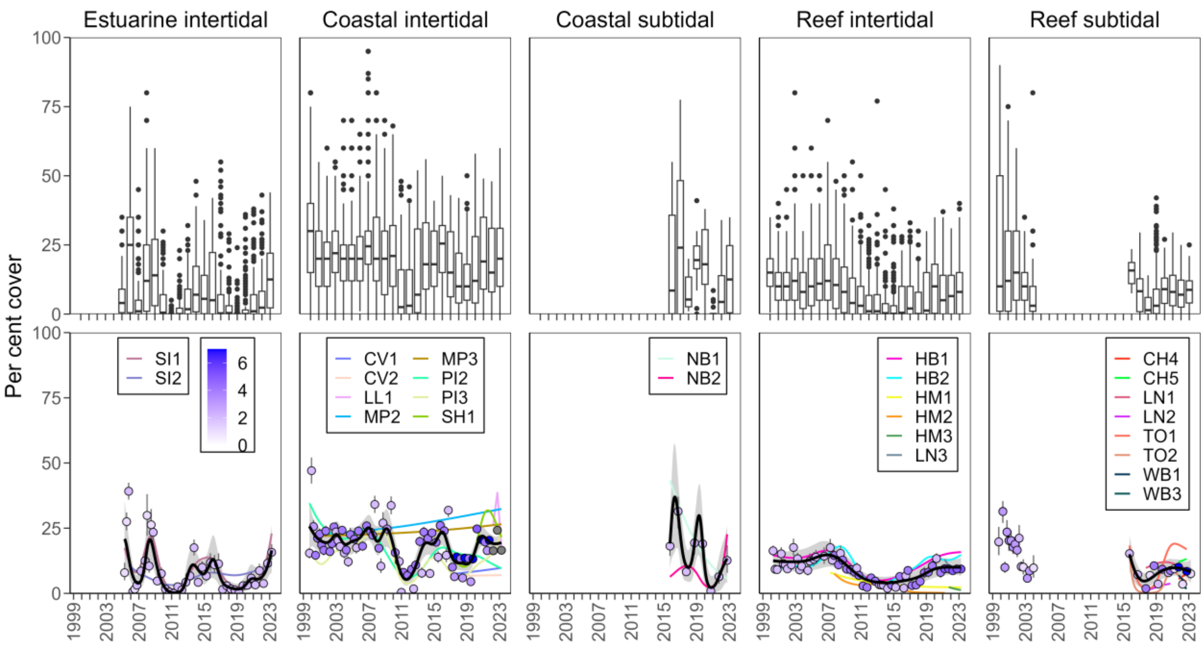


Figure 62. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends, for each habitat monitored in the Mackay–Whitsunday NRM region from 1999 to 2023. Whisker plots (top) show thee box representing the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the dots represent outlying points. GAM plots (bottom), show trends for each habitat and coloured lines represent individual site trends.

The most common seagrass species across all habitats in the Mackay–Whitsunday NRM region were *H. uninervis* and *N. muelleri*, mixed with the colonising species *H. ovalis*. Colonising species tend to dominate intertidal meadows across the Mackay–Whitsunday region in the first few years following extreme weather events (e.g. 2011 and 2017), however, there can be differences between habitats. Estuarine habitats can fluctuate greatly between and within years, and in the last couple of years the proportion of colonisers have been above the Reef long-term average (Figure 63). Coastal subtidal habitats have only been monitored over the last six years, but they are currently dominated by colonising species. These increases suggest some level of localised disturbance in these habitats.

In contrast, over the last few years, there has been a reduction in colonising species in intertidal coastal and reef habitats. With the exception of coastal subtidal, opportunistic foundational species (*H. uninervis* and *N. muelleri*) now dominate habitats across the region (Figure 63), suggesting meadows may have an improved ecosystem resistance to tolerate disturbances (Figure 63).

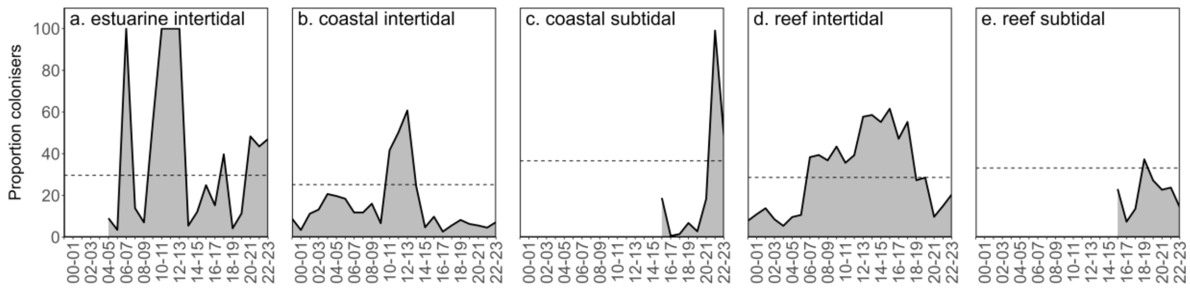


Figure 63. Proportion of seagrass abundance composed of colonising species at inshore intertidal habitats in the Mackay–Whitsunday region, 1999 to 2023. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

Seagrass meadow landscape mapping was conducted within all sentinel monitoring sites in October 2022 and April 2023 to determine if changes in abundance were a consequence of the meadow landscape changing (e.g. expansion or fragmentation) and to indicate if plants were allocating resources to colonisation (asexual reproduction). Over the past 12 months, spatial extent varied across the region, with seasonal declines in the late wet, particularly in reef intertidal habitats. At estuarine and reef subtidal meadows, extent slightly increased relative to the previous period (Figure 64), while remaining steady at coastal intertidal habitats.

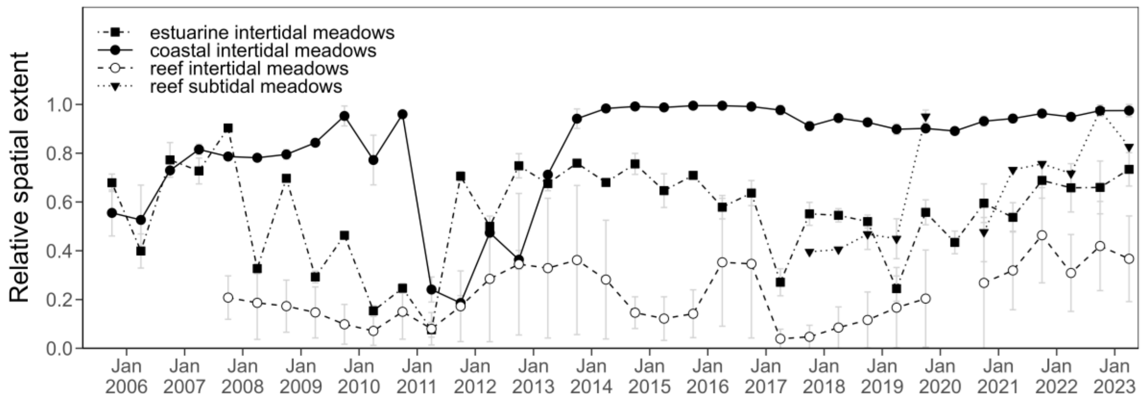


Figure 64. Change in spatial extent (± SE) of seagrass meadows within monitoring sites for each inshore intertidal habitat and monitoring period across the Mackay–Whitsunday NRM region, 2005-2023.

5.4.3.3 Seagrass reproductive status

Reproductive effort remained highly seasonal and highly variable between years and seagrass habitats in the Mackay–Whitsunday region, and was elevated in 2022–23 relative to the previous period (Figure 65). Reproductive effort increased in estuarine and coastal intertidal habitats and they were predominantly of foundational species (*Nanozostera muelleri*). Seed densities were similar to previous years' coastal sites but absent at estuarine sites. Reproductive effort remained low at reef intertidal and subtidal sites, although there were some foundational and colonising structures at the Lindeman Island subtidal site. There were however, some seeds at the Lindeman Island intertidal site, but they aren't measured at the subtidal site (Figure 65).

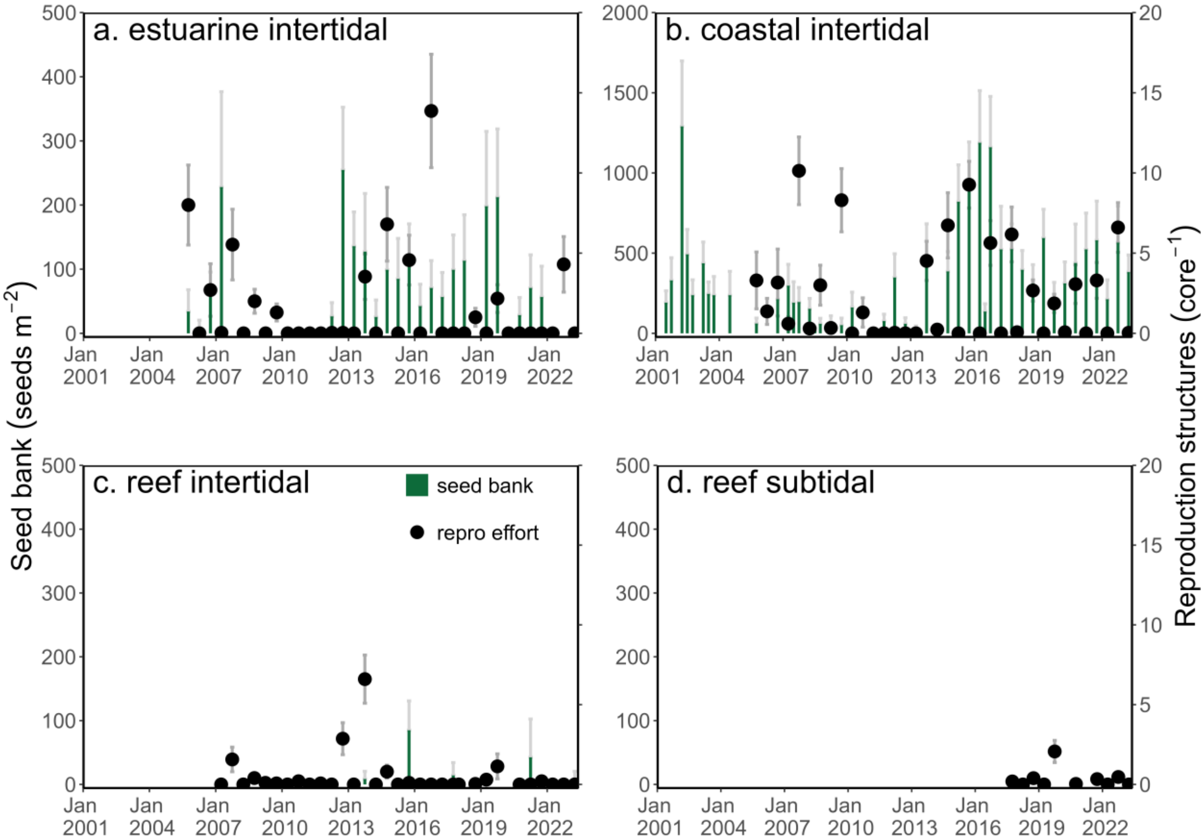


Figure 65. Seed bank and reproductive effort at inshore estuarine intertidal, coastal intertidal and reef intertidal and subtidal habitats in the Mackay–Whitsunday region, 2001–2023. Seed bank presented as the total number of seeds per m^2 sediment surface (green bars ±SE), and late dry season reproductive effort presented as the average number of reproductive structures per core (species and sites pooled) (dots ±SE). NB: Y-axis scale for seed banks differs between habitats.

5.4.3.4 Resilience

The overall resilience score for the Mackay–Whitsunday region was moderate and increased to its highest level in six years but still below the good scores from 2013–14 to 2016–17 (Figure 66). The trends were highly variable among habitats. In estuarine habitat at Sarina Inlet, there was a very large improvement in the score because both sites met thresholds for abundance and composition, and there were high numbers of reproductive structures on foundational species (*Nanozostera muelleri*). The resilience score also improved slightly at the coastal intertidal habitat for the fourth year in a row due to an increase in the number of reproductive structures.

Resilience declined at reef intertidal sites declined because the total percent cover of seagrass was below the threshold (20th percentile for the site) and therefore fell into the lowest category. There was also a very high proportion (85%) of colonising species at the Hamilton Island site (HM3). The resilience score was stable at the reef subtidal site where abundance and composition were above thresholds and there were reproductive structures present of foundation special species, but only one was observed so the score was on the lowest margin for category 2.2.1.

There are numerous sites in the Mackay–Whitsunday region assessed by the Reef Joint Field Management Program and Seagrass–Watch and where resilience cannot be evaluated.

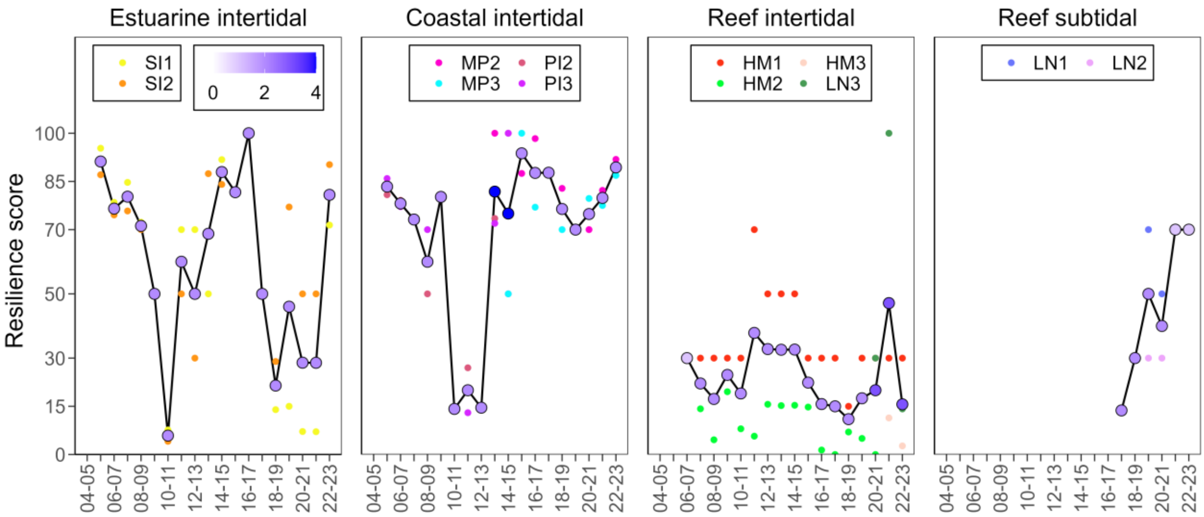


Figure 66. Resilience for each habitat type in the Mackay–Whitsunday region, 2006 to 2023. Coloured small points represent different sites. Shades of blue for the larger points indicate the number of sites that contribute to the score.

5.4.3.5 Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades in 2022–23 was at or below the long-term average during both the dry and wet seasons at all habitats, except coastal intertidal (Figure 67). At coastal habitats, epiphyte cover was above the long-term average during the late wet season, similar to 2021–22 (Figure 67c). Percentage cover of macroalgae remained unchanged, at or below the overall inshore Reef long-term average across all seagrass habitats throughout 2022–23 (Figure 67).

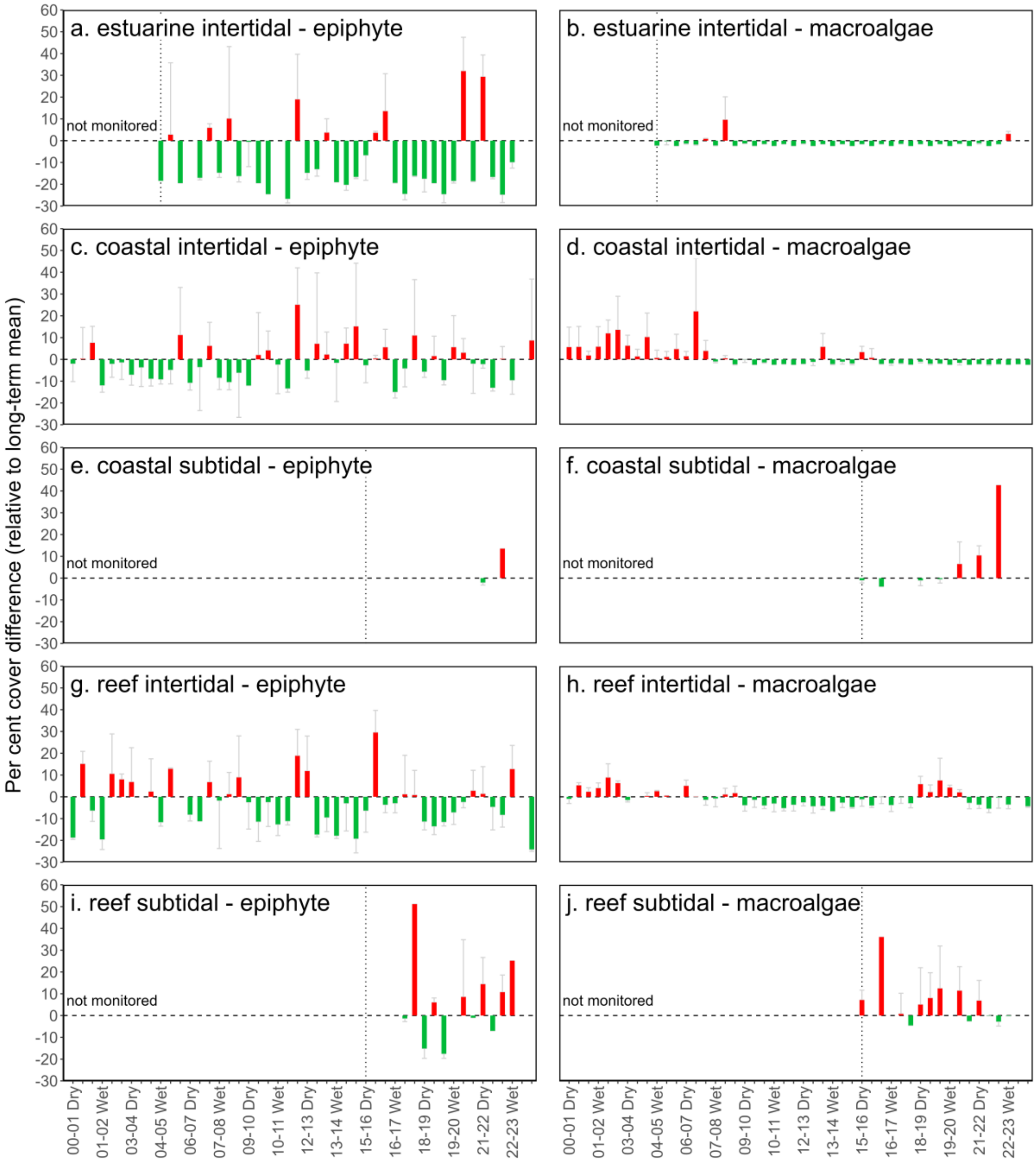


Figure 67. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Mackay–Whitsunday region, 1999–2023 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

5.5 Fitzroy

5.5.1 2022–23 Summary

Environmental pressures were relatively benign in 2022–23, with conditions around or below the long-term average. Rainfall was below average, river discharge from the Fitzroy River and exposure to turbid water (water types I and II) was around the annual median. Daily light levels were also around average. Average annual water temperatures were slightly cooler than the previous period and below the long term average for the 10th consecutive year. The Fitzroy NRM is surveyed in the late dry season before the wet season and therefore the Seagrass Index reflects a legacy of the environmental conditions in the previous year, which were more severe.

Overall, the seagrass condition score for the Fitzroy NRM region slightly deteriorated and remained **poor** in 2022–23 (Figure 68). Condition indicators contributing to this were:

- abundance score was poor
- resilience was poor.

Seagrass abundance score marginally improved from the previous period, but this was driven by only one site (estuarine intertidal). Average abundances (per cent cover) for all other sites continued to slightly decline, however, the overall score was unimpacted as the median abundances used to calculate individual scores were unchanged. Abundances remain very low at over half the sites in the region, particularly the reef intertidal sites.

The latest findings on resilience in the Fitzroy region show a decrease to the second lowest level recorded. However, the trend varies depending on the habitat and site. For estuarine and coastal habitats, one replicate site showed an improvement while the other declined. Increased resilience was noted in sites that were dominated by foundational species, with abundance exceeding the threshold for resistance, and reproductive structures present. In reef intertidal habitat, resilience fell to the lowest level in three years.

For the third year in a row, inshore seagrass meadows in the region have experienced a decline, despite gradual improvement from 2012-13 to 2019-20 after years of climate-related impacts. There are local-scale impacts and processes that are negatively affecting a few sites, while others within the same habitat are improving. Due to the limited number of sites in the Fitzroy region, changes in one site can have a significant influence on the overall score in comparison to other regions.

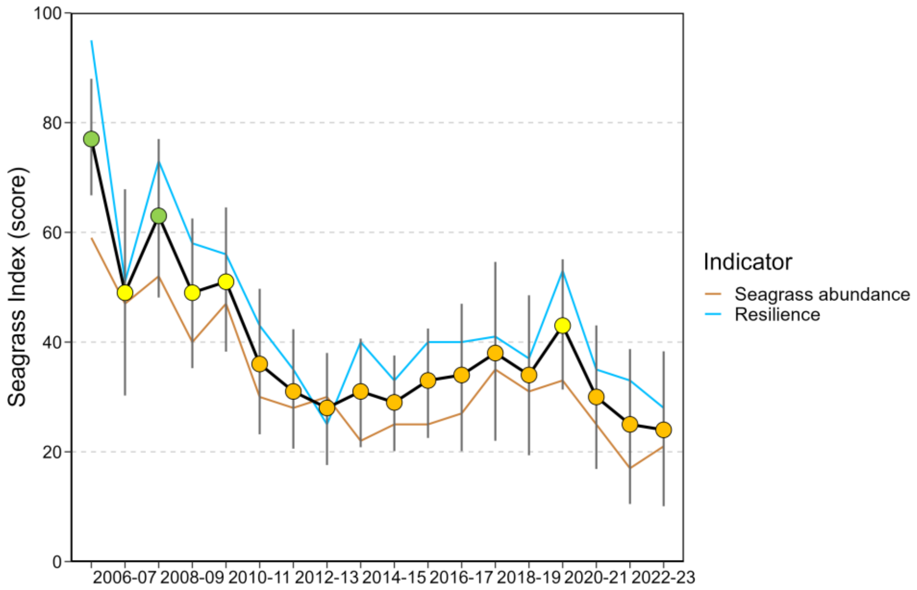


Figure 68. Temporal trend in the Seagrass Index (± SE) with contributing indicator scores for the Fitzroy NRM region (averages across habitats and sites). Values are indexed scores scaled from 0–100 (± SE) and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40), ● = very poor (0–20). NB: Scores are unitless.

5.5.2 Climate and environmental pressures

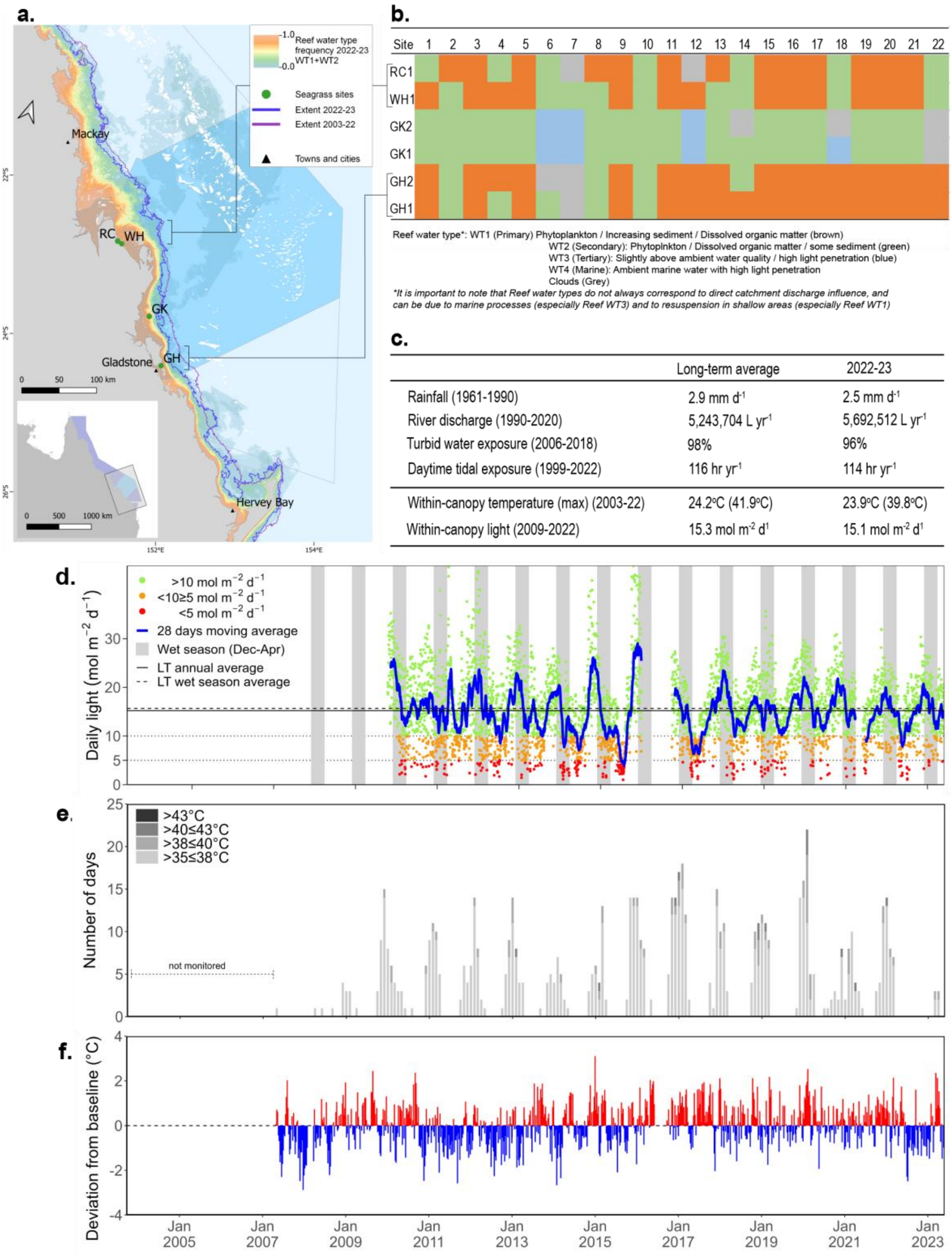
Wet season rainfall in the Fitzroy basins in 2022–23 was below the long-term average, and annual river discharge was around the annual median for the region (Figure 69c). Inshore coastal and estuarine seagrass habitats were exposed to turbid waters of water type I or II for all weeks during the wet season (Figure 69c). There was relatively more water type II waters at the reef sites at Great Keppel Island and a few weeks when there was water type III (less turbid, higher light) at the reef sites (Figure 69a, b). On average for the region, water type exposure was similar to the long-term average.

Annual averaged daily light availability in 2022–23 was similar to the long-term average for the region (Figure 8, Figure 69c, d). At Shoalwater Bay, daily light was lower than average especially in the late dry season but logger failure during the wet season resulted in some missing data (Figure 103). Daily light in Gladstone Harbour was similar to average. Daily light at Great Keppel Island in 2022–23 (16.7 mol m^{-2} d^{-1}) was higher than the long-term average (14.8 mol m^{-2} d^{-1}) (Figure 103).

2022–23 within-canopy temperatures were slightly cooler on average than the previous period and below the long-term average for the 10th consecutive year (Figure 69c,f). Maximum intertidal within-canopy temperatures exceeded 35°C for a total of 6 days during 2022–23, and the highest temperature was 39.8°C (Great Keppel Island, 08Apr23), which was the first time the annual maximum was below 40°C in eight years (Figure 69e). Daytime tidal exposure in 2022–23 was below the long-term average at estuarine and reef habitats, but above at coastal habitats for the eight consecutive year (Figure 69c, Figure 95), which may have exacerbated stresses experienced at these intertidal sites.

Estuarine habitat sediments in 2022–23 were composed primarily of finer sediments, with the mud portion remaining below the overall inshore Reef long-term average at one site (GH1), but above at the other (GH2) were seagrass had been lost (Figure 117). Coastal and reef habitat sediments were dominated by fine sand/sand, with the proportion of mud at coastal habitats declining since the previous period to below the long-term average (Figure 118, Figure 119).

It is, however, important to note that the Fitzroy is only surveyed once per year in the late dry season, before these wet season and summer impacts. Therefore, the seagrass results reflect a legacy of the environmental conditions into the previous year which were more severe.



	Long-term average	2022-23
Rainfall (1961-1990)	2.9 mm d^{-1}	2.5 mm d^{-1}
River discharge (1990-2020)	5,243,704 L yr^{-1}	5,692,512 L yr^{-1}
Turbid water exposure (2006-2018)	98%	96%
Daytime tidal exposure (1999-2022)	116 hr yr^{-1}	114 hr yr^{-1}
Within-canopy temperature (max) (2003-22)	24.2°C (41.9°C)	23.9°C (39.8°C)
Within-canopy light (2009-2022)	15.3 mol m^{-2} d^{-1}	15.1 mol m^{-2} d^{-1}

Figure 69. Environmental pressures in the Fitzroy region including: a. frequency of exposure to primary (WT1) and secondary (WT2) water from December 2022 to April 2023 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the long-term average (2003–2018) exposure boundary (purple line), and the first (blue line) and third quartile (white line) of the long-term average (from Gruber *et al.* 2024); b. wet season water type at each site; c. average conditions and max temperature over the long-term and in 2022–23; d. daily light and the 28-day rolling mean of daily light for all sites; e. number of day temperature exceeded 35°C, 38°C, 40°C and; 43°C, and f. deviations from 13-year mean weekly temperature records at intertidal sites.

5.5.3 Inshore seagrass and habitat condition

Three seagrass habitat types were assessed across the Fitzroy region in 2022–23, with data from all 6 long-term monitoring sites (Table 17).

Table 17. List of data sources of seagrass and environmental condition indicators for each seagrass habitat type in the Fitzroy NRM region. For site details see Table 5.

Habitat	Site		abundance	composition	distribution	reproductive effort	seed banks	meadow sediments	epiphytes	macroalgae
estuarine intertidal	GH1	Gladstone Hbr	■	■	■	■	■	■	■	■
	GH2	Gladstone Hbr	■	■	■	■	■	■	■	■
coastal subtidal	RC1	Ross Creek (Shoalwater Bay)	■	■	■	■	■	■	■	■
	WH1	Wheelans Hut (Shoalwater Bay)	■	■	■	■	■	■	■	■
reef intertidal	GK1	Great Keppel Is.	■	■	■	■	■	■	■	■
	GK2	Great Keppel Is.	■	■	■	■	■	■	■	■

5.5.3.1 Seagrass Index and indicator scores

In the 2022–23 monitoring period, the Seagrass Index remained a **poor** grading in a declining trend since 2019–20 (Figure 68). The Index was the lowest on record since 2005 for the Fitzroy NRM.

The abundance score marginally increased from the previous period, recovering back to a poor state after reaching very poor for the first time in the Fitzroy region (Figure 70). Unlike in other regions, there has been no change to the number of sites surveyed since 2008, so the trends reflect long-term changes at these sites.

In 2022–23, the resilience score continued to decline and was the lowest score in a decade (Figure 70). This was primarily driven by declining resilience at Great Keppel Island, and to a lesser extent at Shoalwater Bay.

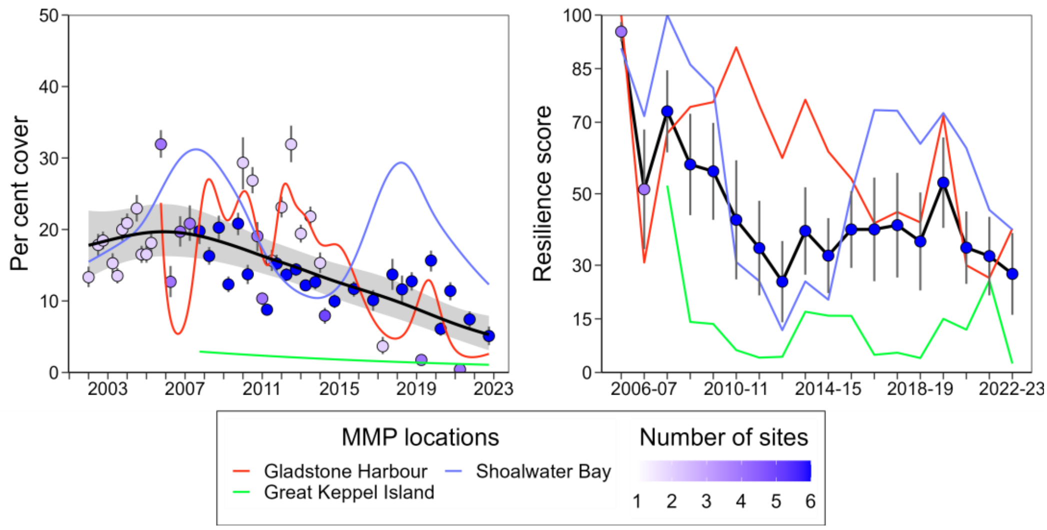


Figure 70. Temporal trends in the Fitzroy seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area defining 95 per cent confidence intervals); b. average annual resilience score (±SE) and trends for each location (coloured lines). Colour of circles represents the number of sites assessed to calculate the average.

5.5.3.2 Seagrass abundance, composition and extent

In 2022–23, seagrass abundances across the Fitzroy region continued to decline from the previous reporting period, with the exception of estuarine habitats which remained similar (Figure 71). At the estuarine sites, an increase at one site (GH1) was offset by the near loss of seagrass at the other (GH2). Seagrass abundance (per cent cover) in the Fitzroy region in 2022–23 was significantly higher in coastal (13.4 ±1.3 per cent) habitats than estuarine (2.5 ±0.7 per cent), and reef habitats (0.1 ±0.1 per cent) (Figure 71). Seagrass abundances at estuarine and coastal intertidal habitats have fluctuated greatly between years over the life of the monitoring program, with some sites experiencing total or near total loss followed by recovery (Figure 71). In reef and estuarine habitats, seagrass abundances remain below their long-term averages for the fourth and seventh consecutive years, respectively. In the coastal meadows of Shoalwater Bay, 2022–23 abundances remained below the long-term average for the second consecutive year, and were at their lowest in eight years (Figure 71).

Examination of the long-term trend in seagrass abundance (per cent cover) across the region reveals a significant decrease (Figure 70, Table 22). These decreases have primarily occurred in the estuarine and reef habitats, although two thirds of all monitoring sites in the region (including coastal) show no significant trend (Table 22).

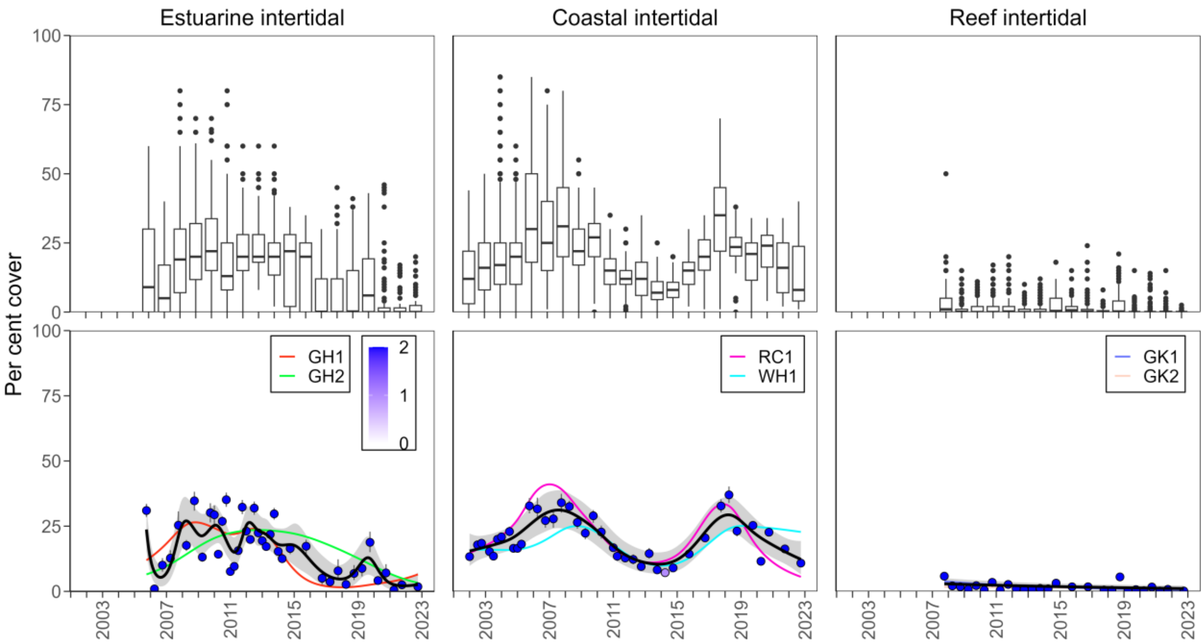


Figure 71. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends, for each habitat monitored in the Fitzroy NRM region from 2002 to 2023. Whisker plots (top) show the box representing the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the dots represent outlying points. GAM plots (bottom), show trends for each habitat and coloured lines represent individual site trends.

The seagrass species in the coastal meadows in Shoalwater Bay (Ross Creek and Wheelans Hut) remain dominated by *N. muelleri*, with low proportions of colonising species (*H. ovalis*). The proportion of colonising species (*H. ovalis*) peaked after the extreme climatic events of 2011, and has gradually been declining since (Figure 72). In 2022–23, the proportion of the opportunistic species increased, but remained below the Reef long-term average at estuarine sites (Figure 72), and the sites continued to be dominated by *N. muelleri*. Colonising species continued to dominate the reef habitat sites (well above the overall inshore Reef long-term average), however there has been an increase in the opportunistic *H. uninervis* over the last few years (Figure 72).

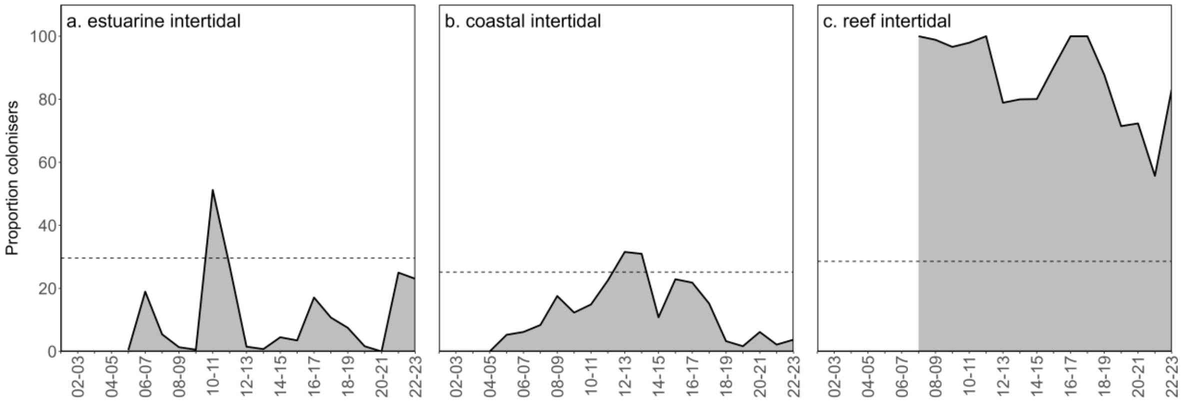


Figure 72. Proportion of seagrass abundance composed of colonising species in inshore intertidal habitats of the Fitzroy region, 2001–2023. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

Although there was a minor decrease in coastal meadow extent in late 2022 (relative to the previous period), the overall extent at the monitoring sites in Shoalwater Bay has changed little since monitoring commenced in 2005. Conversely, the extent of the estuarine meadows at Pelican Banks in Gladstone Harbour has fluctuated greatly since 2015–16 when there was a large reduction in one of the sites due to extensive scarring and sediment deposition. In 2019–20, the sediment deposition abated and the meadow was showing signs of recovering with shoot extension and improved meadow cohesion. However, from 2020–21 to 2021–22, increased erosion along drainage channels and increased scarring across the meadow reduced the overall meadow extent area (Figure 73). In 2022–23, the deterioration of the meadow seascape had abated and the overall meadow extent increased. Meadows on the reef flat at Great Keppel Island remained highly fragmented after the 2015–16 losses and continued to show little sign of recovery in 2022–23.

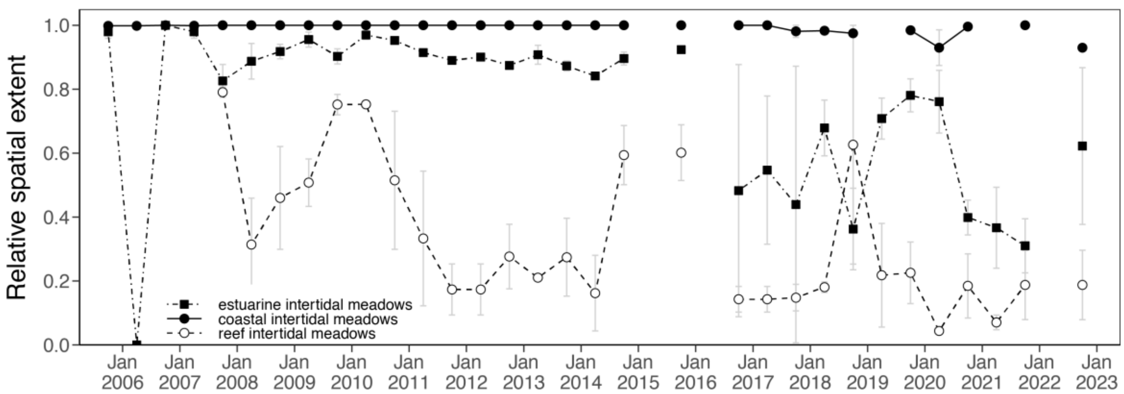


Figure 73. Change in spatial extent (± SE) of seagrass meadows within monitoring sites for each inshore intertidal habitat across the Fitzroy NRM region, 2005–2023.

5.5.3.3 Seagrass reproductive status

The abundance of reproductive structures has varied seasonally and interannually across habitats in the Fitzroy region over the life of the MMP particularly at estuarine and coastal habitats (Figure 74). Reproductive effort increased in estuarine sites in 2022–23 to the highest level since 2011–12 (Gladstone Harbour). However, reproductive effort remained low at coastal sites (Shoalwater Bay) (Figure 74). A seed bank has persisted over the last decade in estuarine and coastal intertidal habitats and increased in density at estuarine sites compared to those in the previous three years. Reproductive structures were absent at reef sites (Great Keppel Island) and no seeds have ever been observed in the reef meadows at

Great Keppel Island. This limits the meadow capacity to recover making them highly vulnerable to future disturbances. The absence of seeds in the reef meadows was likely the result of the chronic and greatly depressed reproductive effort. Other possible explanations for the low seed bank include failure to set seed, or rapid loss of seeds from germination or grazing (Heck and Orth 2006).

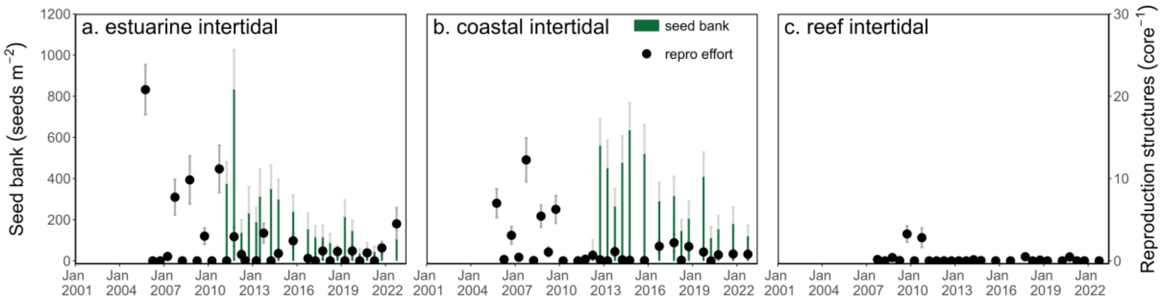


Figure 74. Seedbank and reproductive effort at inshore intertidal coastal, estuarine and reef habitats in the Fitzroy region, 2005–2023. Seed bank presented as the total number of seeds per m^2 of sediment surface (green bars ±SE). Reproductive effort for the late dry season presented as the average number of reproductive structures per core (species and sites pooled) (circles ±SE).

5.5.3.4 Resilience

Overall resilience in the Fitzroy region was poor and declined in 2022–23 to the second lowest level recorded but the trends in the resilience score varied among locations (Figure 75).

At estuarine intertidal habitats in Gladstone the score increased at GH1 where seagrass cover was above the threshold for resistance and there were some foundational species (*Nanozostera muelleri*) reproductive structures. AT GH2, there was no seagrass present in the transects and so it was in the lowest resilience category based on low resistance (1.1). However, there was seagrass surrounding the site that was flowering so the score was not zero.

At coastal intertidal sites in Shoalwater Bay, the resilience score declined at WH1 and increased at RC1. At WH1, the percent cover and abundance were above thresholds for resistance, but there were no reproductive structures although there had been in previous years so were in category 2.1.1. At RC1, abundance was below the low resistance threshold (<20th percentile), but it was dominated by foundational species and there were reproductive structures and so was in the highest level of category 1.2.

At reef intertidal sites (Great Keppel Island) resilience declined to the lowest recorded after having improved the highest score since 2008–09 into the previous year. This was due to declines in abundance to below the resistance threshold (average percent cover was less than 1%). Colonising species were also the only species present at GK1 and as such it declined to a 0 score for resilience. GK2 had some foundational species present even though cover was also below 1% on average so had a resilience score of 5.

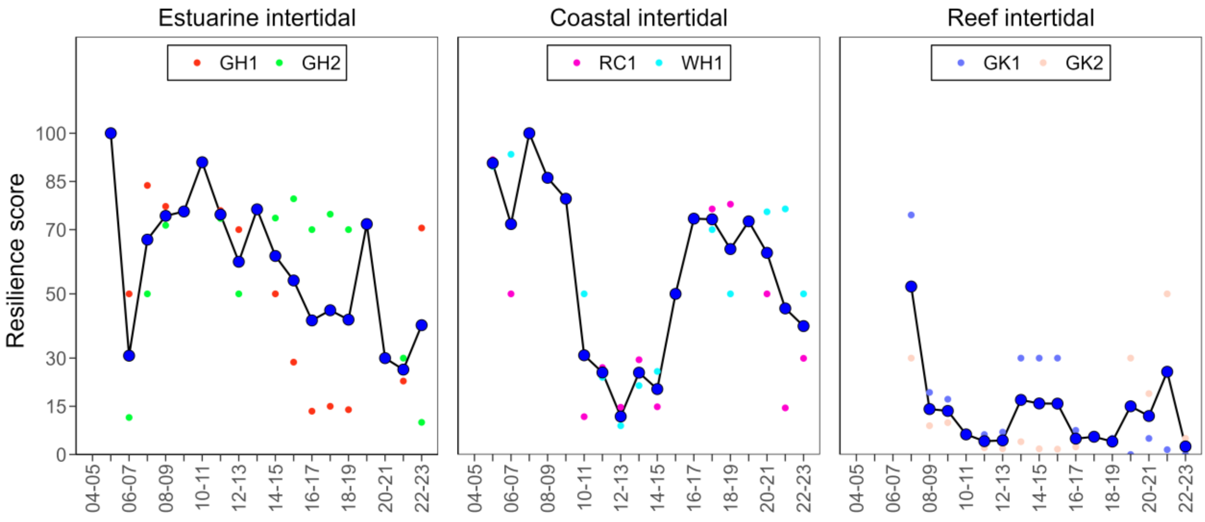


Figure 75. Resilience in each habitat in the Fitzroy region 2006 to 2023. Coloured small circles represent different sites. Shades of blue for the larger circles indicates the number of sites that contributed to the score.

5.5.3.5 Epiphytes and Macroalgae

Epiphyte cover on seagrass leaves generally decreased across the region in 2022–23, with covers below the overall inshore Reef long-term average for all habitats (Figure 76).

Macroalgae cover similarly remained below the overall inshore Reef long-term average at all habitats in the Fitzroy region, for the fourth consecutive year (Figure 76).

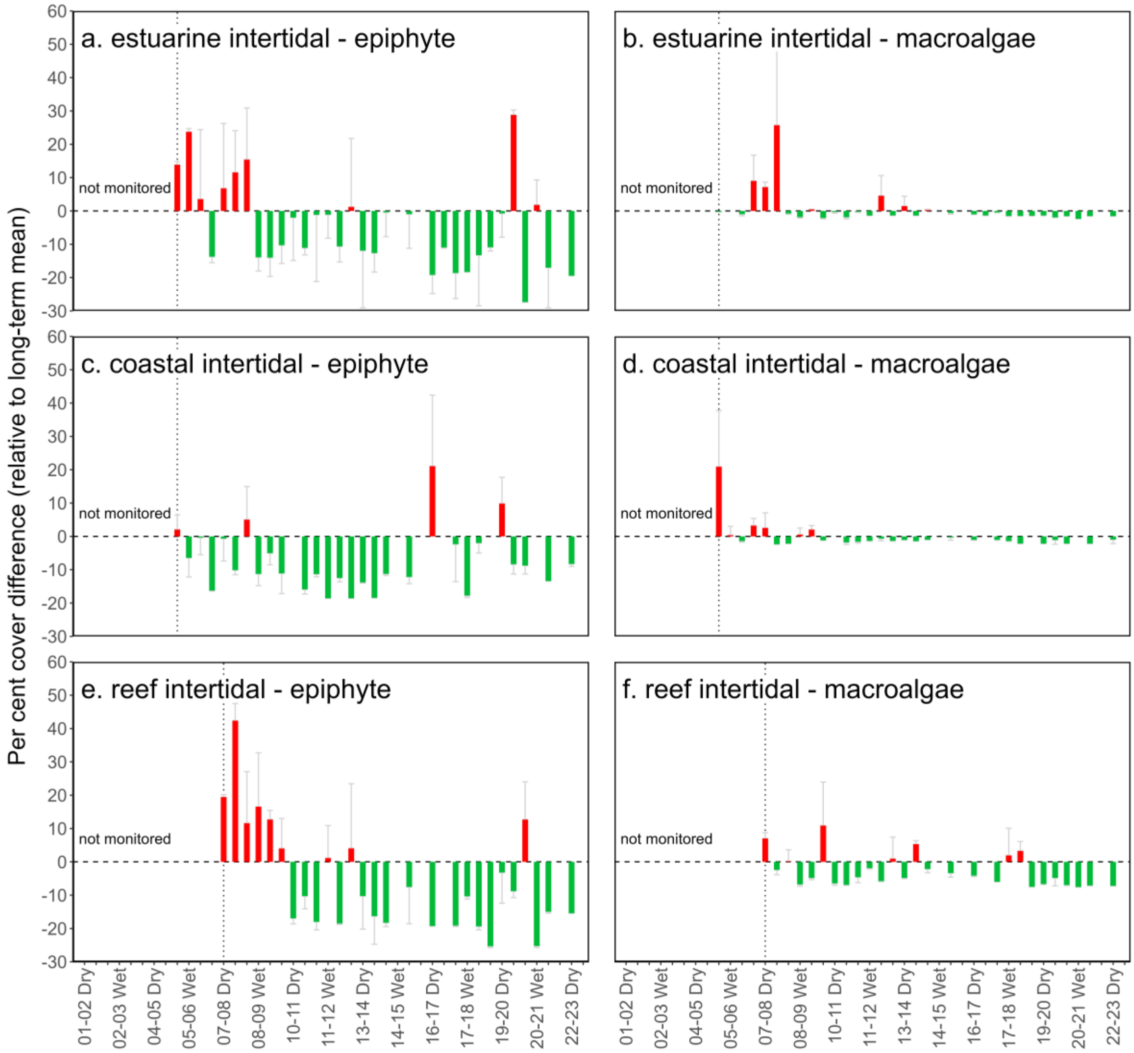


Figure 76. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Fitzroy region, 2005–2023 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

5.6 Burnett–Mary

5.6.1 2022–23 Summary

Although the 2022-23 monitoring period in the Burnett-Mary NRM region was relatively benign with environmental pressures around or below the long-term averages, the legacy of extreme weather events in 2021-22 continue to influence the region. Annual river discharge in early 2022 was nine times greater than the long-term median and was affected by late periods of elevated rainfall after the wet season (i.e. in May). In 2022-23 rainfall and river discharge was below long-term averages and exposure to turbid water (WT1 and WT2) was around average. Within canopy daily light and water temperature were below the long-term term average, and daytime tidal exposure was also below average.

Inshore seagrass meadows across the Burnett–Mary NRM region declined in overall condition in 2022–23, with the Seagrass Index decreasing to a **very poor** grade for the first time in 16 years (Figure 77). Contributing indicators to the overall score were:

- abundance score was very poor
- resilience score was poor.

The seagrass abundance score remained very poor for the second consecutive year. The decline is a continuing trend that has been occurring for the NRM region since 2015–16. Estuarine habitat abundances have been declining since 2015–16 and coastal habitats since 2019–20. In 2022-23, abundances in coastal habitats were the lowest since the MMP was established, while in estuarine habitats they were the lowest in the last decade. Spatial extent in estuarine habitat also declined to the lowest level since 2008.

Resilience declined and remained poor overall in the Burnett–Mary NRM region. It is the fourth time this decade that the score has declined below moderate. The decline was primarily influenced by the estuarine habitats at Urangan and Rodds Bay. While resilience in the coastal intertidal habitat at Burrum Heads remained unchanged from the previous year, sites differed in their level of resistance and presence of reproductive structures. Despite this, meadows throughout the region have a higher capacity to recover as seed banks persist, although replenishment ability has been reduced, making the meadows susceptible to future significant disturbances.

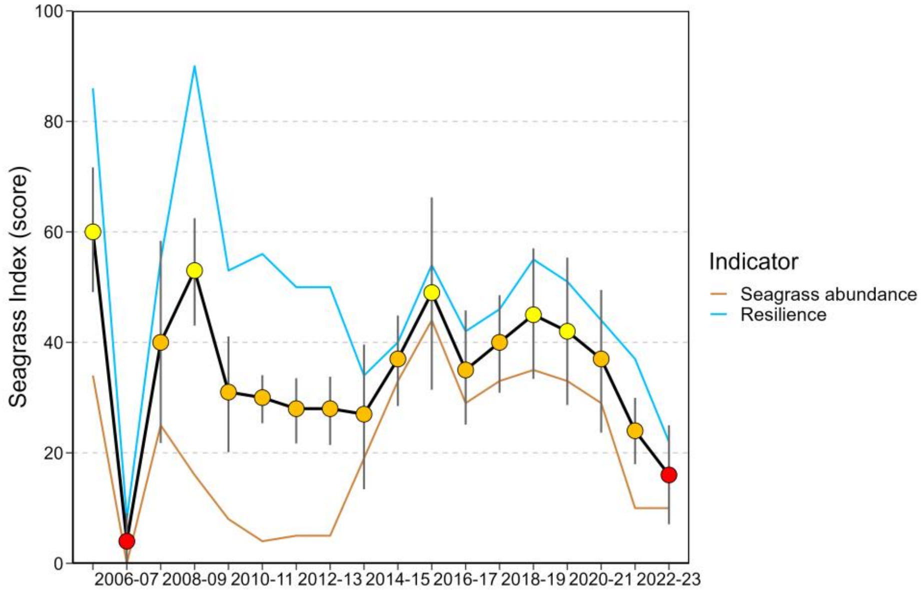


Figure 77. Temporal trend in the Seagrass Index (± SE) with contributing indicator scores for the Burnett–Mary region (averages across habitats and sites). Values are indexed scores scaled from 0–100 (± SE) and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40), ● = very poor (0–20). NB: Scores are unitless.

5.6.2 Climate and environmental pressures

During 2022–23, rainfall and river discharge were below long-term averages in the Burnett–Mary region. This followed elevated rainfall and river that was more than 9 times greater than the long-term median in the previous year and legacy effects of those events are likely to have affected environmental conditions in 2022–23 (Figure 78c, Table 9). In the Burnett-Mary region there are only estuarine and coastal monitoring locations, and these are generally exposed to high frequencies of turbid waters (WT1 and WT2) and in 2022–23 it was for 99% of weeks in the wet season which is consistent with the long-term average (Figure 78a, b). Within-canopy daily light levels in 2022–23 (9.9 mol m^{-2} d^{-1}) were below the long-term average (13.1 mol m^{-2} d^{-1}). This was due predominantly to lower than average light at Burrum Heads in 2022-23 (10.7 mol m^{-2} d^{-1}) compared to the long-term average (14.9 mol m^{-2} d^{-1}), while at Urangan light levels were only slightly below average (Figure 104).

Within-canopy temperatures in 2022–23 were nearly half a degree lower than the previous year and marginally below the long-term average for the first time in nearly a decade (Figure 78c,f). Maximum intertidal within-canopy temperatures exceeded 35°C for a total of 2 days during 2022–23 (the lowest since 2007) (Figure 78e), with the highest temperature recorded at 37.3°C (Urangan, 25Nov22).

Daytime tidal exposure was below the regional long-term average in 2022–23 (Figure 78c), with meadows being exposed less often than the previous two periods (Figure 97). The less than long-term average exposure may have reduced the risk of temperature and desiccation stress, but may also have increased the risk of light limitation in the turbid water areas.

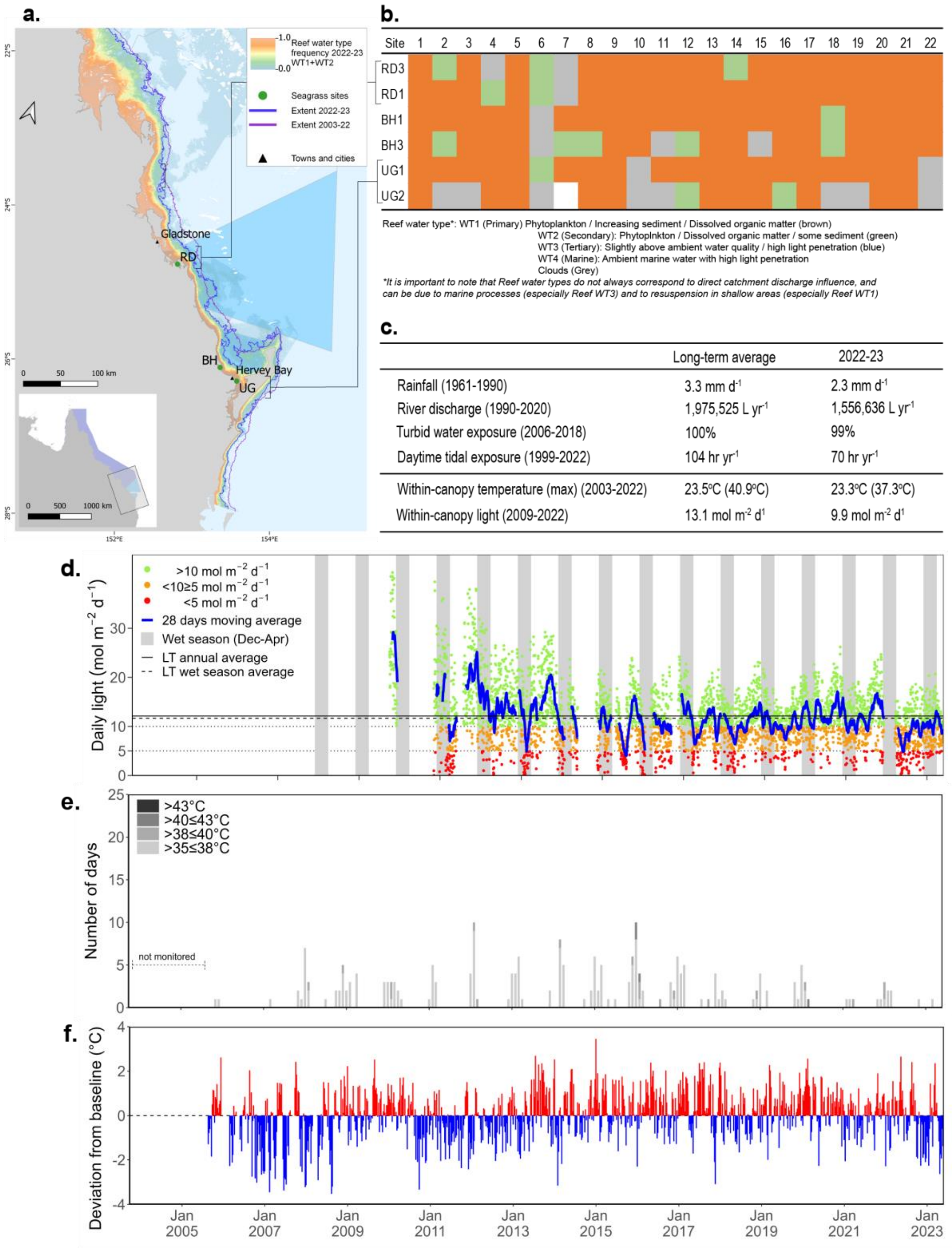
Sediments in the estuarine seagrass habitats of the Burnett–Mary region are generally dominated by mud. In 2022–23, however, the proportion of mud in the estuarine habitats decreased for the second consecutive year. Meadows in the north varied, with a noticeable increase in mud content at one site (RD2), while the other site remained unchanged and dominated by mud (Figure 120). Coastal meadows in 2022–23 continued to be dominated by fine sand with little change from the previous year (Figure 121).

5.6.3 Inshore seagrass and habitat condition

Only estuarine and coastal habitats were assessed across the Burnett–Mary region in 2022–23, with data from all 6 long-term monitoring sites (Table 18).

Table 18. List of data sources of seagrass and environmental condition indicators for each seagrass habitat type in the Burnett–Mary NRM region. For site details see Table 5.

Habitat	Site		abundance	composition	distribution	reproductive effort	seed banks	meadow sediments	epiphytes & macroalgae
estuarine intertidal	RD1	Rodds Bay	■	■	■	■	■	■	■
	RD3	Rodds Bay	■	■	■	■	■	■	■
	UG1	Urangan	■	■	■	■	■	■	■
	UG2	Urangan	■	■	■	■	■	■	■
coastal intertidal	BH1	Burrum Heads	■	■	■	■	■	■	■
	BH3	Burrum Heads	■	■	■	■	■	■	■



	Long-term average	2022-23
Rainfall (1961-1990)	3.3 mm d^{-1}	2.3 mm d^{-1}
River discharge (1990-2020)	1,975,525 L yr^{-1}	1,556,636 L yr^{-1}
Turbid water exposure (2006-2018)	100%	99%
Daytime tidal exposure (1999-2022)	104 hr yr^{-1}	70 hr yr^{-1}
Within-canopy temperature (max) (2003-2022)	23.5°C (40.9°C)	23.3°C (37.3°C)
Within-canopy light (2009-2022)	13.1 mol m^{-2} d^{1}	9.9 mol m^{-2} d^{1}

Figure 78. Environmental pressures in the Burnett–Mary region including: a. frequency of exposure to primary (WT1) and secondary (WT2) waters from December 2022 to April 2023 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the long-term average (2003–2018) exposure boundary (purple line), and the first (blue line) and third quartile (white line) of the long-term average (from Gruber *et al.* 2024); b. wet season water type at each site; c. average conditions and max temperature over the long-term and in 2022–23; d. daily light and the 28-day rolling mean of daily light for all sites; e. number of day temperature exceeded 35°C, 38°C, 40°C and 43°C, and; f. deviations from 13-year mean weekly temperature records at intertidal sites.

5.6.3.1 Seagrass Index and indicator scores

In the 2022–23 monitoring period, the Burnett–Mary region Seagrass Index declined to a **very poor** grade, which was the second lowest on record (Figure 77). The decline continues a trend that occurred since 2015–16 and changes in both indicators contributed to this result (Figure 79).

Over the long-term the average seagrass abundance in the region has varied significantly. This includes periods of loss and subsequent recovery. Between 2012 and 2016, Urangan experienced a notable increase in seagrass abundance, which ultimately declined from 2017 and was completely lost by 2022. Recently trends have also been influenced by changes in abundances at the other locations, with wet season abundance being a significant factor (Figure 79).

Seagrass resilience continued to decline in 2022–23 to reach the second lowest score on record and the fourth time to reach poor or very poor in the Burnett–Mary region. This was driven by large declines in estuarine habitats at Urangan and Rodds Bay (Figure 79).

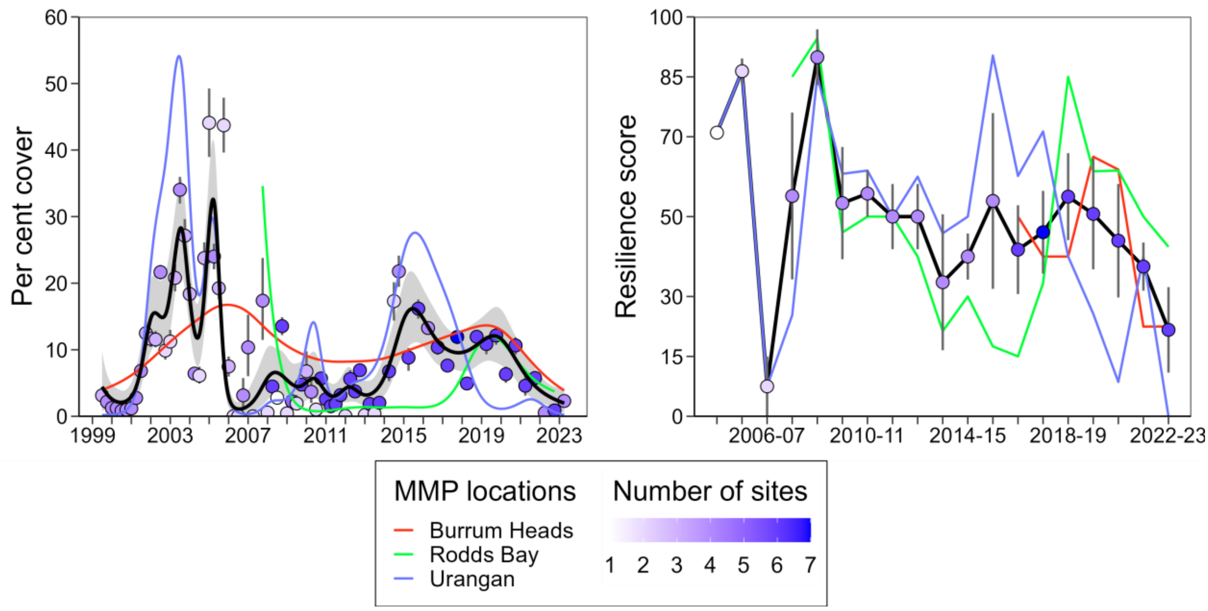


Figure 79. Temporal trends in the Burnett–Mary seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area defining 95 per cent confidence intervals); b. average annual resilience score (±SE) and trends for each location (coloured lines). Colour of circles represents the number of sites assessed to calculate the average.

5.6.3.2 Seagrass abundance, composition and extent

Since monitoring was established, the estuarine meadows across the Burnett–Mary region have come and gone on an irregular basis, with no apparent long-term trend as of 2022–23 (Table 22). The coastal meadows at Burrum Heads have been slightly more steady, except one of the sites (BH3) which has significantly increased over the long-term (Table 22).

Historically, seagrass abundances (per cent cover) across the Burnett–Mary region are generally greater on average in estuarine than coastal habitats (10.4 ±1.5 per cent and 9.4 ±0.9 per cent long-term average, respectively). In 2022–23, however, seagrass abundance was greater at coastal habitats (3.2 ±0.4 per cent), as estuarine abundances (0.7 ±0.4 per cent) remained below their long-term average for the sixth consecutive year (Figure 80). Overall, seagrass abundances continued to decline across the Burnett–Mary region during 2022–23 for the fourth consecutive year. The largest decline was in the estuarine meadows at Urangan, which were completely lost in the late dry 2022, with no shoots present across the entire bank. The onset of seagrass recovery in the Urangan meadows was observed in the late wet 2023 (Figure 80). This represents the most significant decline in inshore seagrass resources across the region since the start of the MMP.

Until 2022–23, the estuarine and coastal seagrass habitats have remained dominated by *N. muelleri* or *H. uninervis*, with varying components of *H. ovalis*. In 2022–23, the proportion of colonising species increased at estuarine meadows compared to the previous monitoring year (Figure 81). An increase in the proportion of colonising species in the meadows suggests the onset of seagrass recovery where the meadows have been lost however, the ability to resist moderate disturbances in future remains very low.

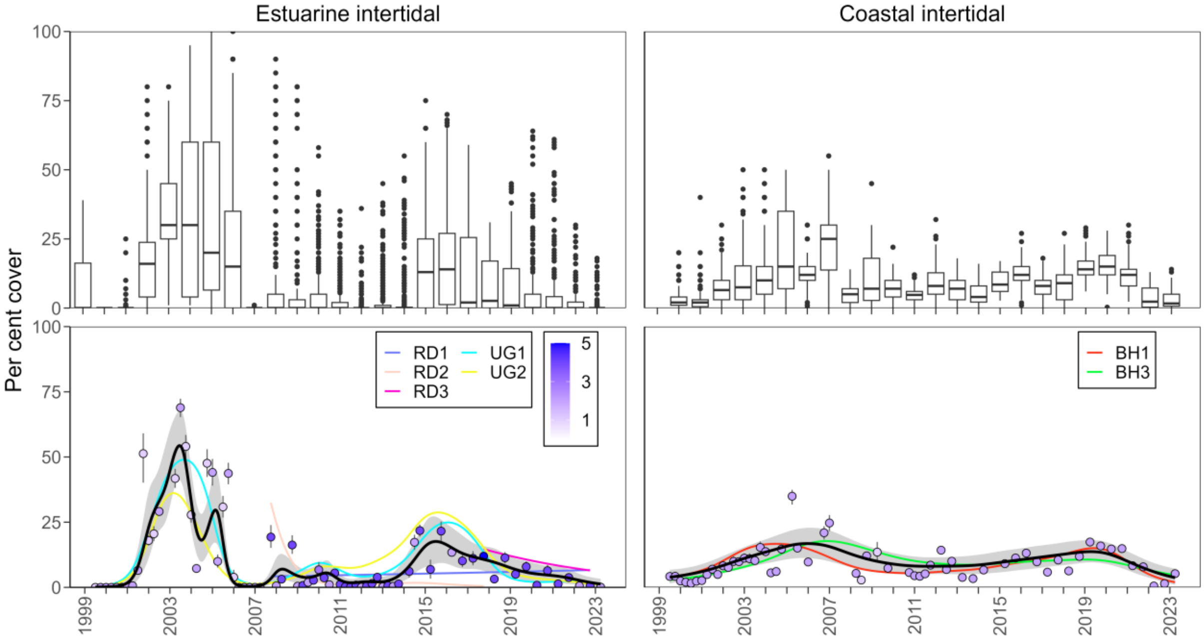


Figure 80. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends, for each habitat monitored in the Burnett–Mary NRM region from 1999 to 2023. Whisker plots (top) show the box representing the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the dots represent outlying points. GAM plots (bottom), show trends for each habitat and coloured lines represent individual site trends.

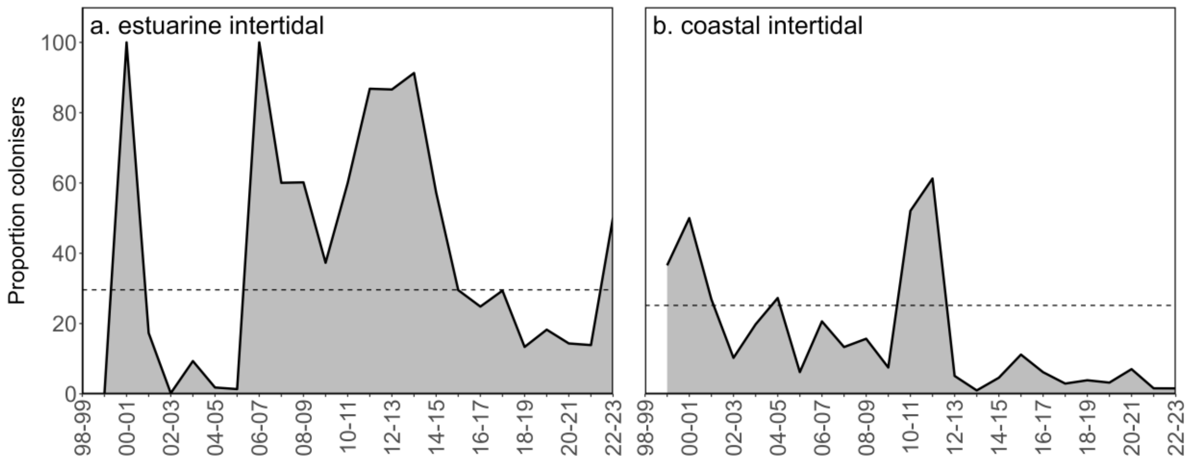


Figure 81. Proportion of seagrass abundance composed of colonising species at: a. estuarine and b. coastal habitats in the Burnett–Mary region, 1998 to 2023. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

Meadow spatial extent slightly decreased at coastal meadows relative to the previous year (Figure 82). Estuarine meadows, similarly continued to decline, although the levels differed between the north and the south of the region. In the north, meadows are surveyed only once per year in the late dry season and while one meadow (RD3) changed little, the other (RD1) declined after a brief period of recovery following the meadow loss in late wet 2021. The greatest losses were at the southern located sites, where the meadows at Urangan, adjacent to the Mary River, were completely lost in November 2022, a legacy of the severe flooding events in the south of the region in early 2022.

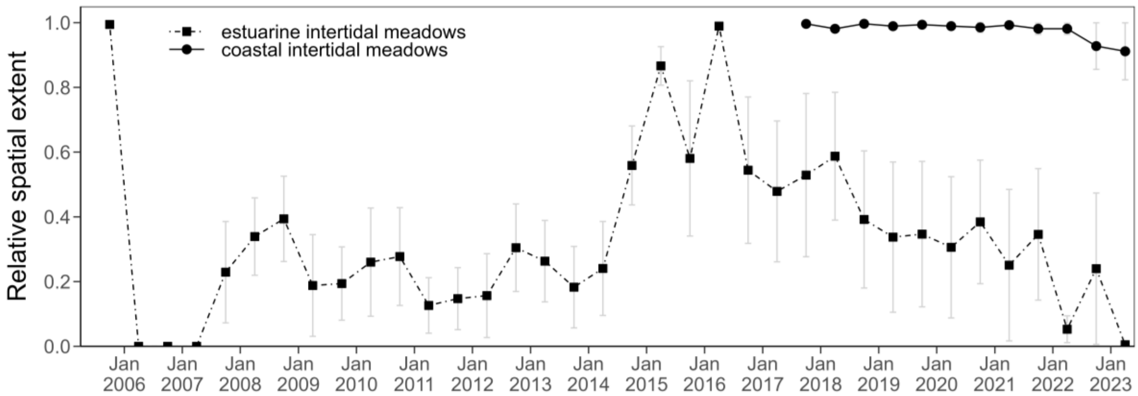


Figure 82. Change in spatial extent (± SE) of estuarine seagrass meadows within monitoring sites for each habitat and monitoring period across the Burnett–Mary NRM region, 2005-2023.

5.6.3.3 Seagrass reproductive status

Over the last five years, reproductive effort has remained below the Reef baseline and in 2022–23 was very low with only one reproductive structure reported from all sites at Rodds Bay in estuarine intertidal sites (Figure 83). Over the previous three years, reproductive effort has been extremely low. Despite this, in 2022–23 seed banks were present and increased to the highest dry season levels observed at estuarine sites and the third highest since the early 2000s in coastal sites (Figure 83). This suggests that reproduction had occurred but not at the time of sampling.

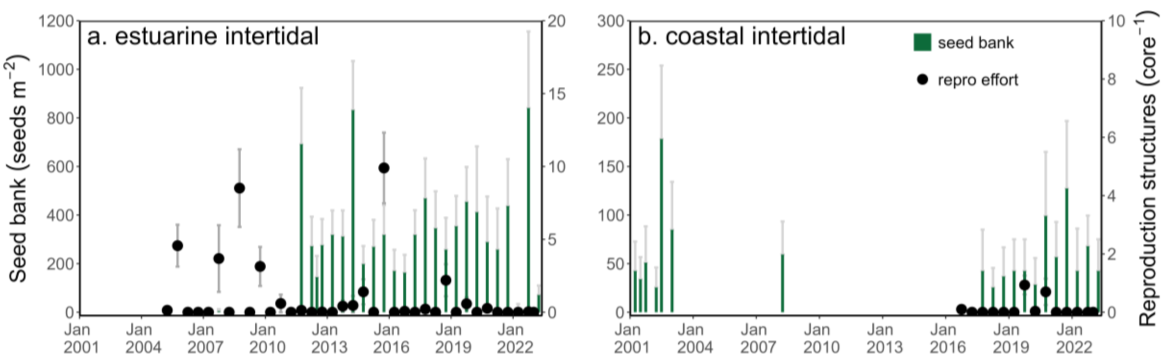


Figure 83. Seedbank and reproductive effort at inshore estuarine (a.) and coastal (b.) intertidal habitats in the Burnett–Mary region, 2001-2023. Seed bank presented as the total number of seeds per m^2 sediment surface (green bars ±SE). Reproductive effort for late dry season presented as the average number of reproductive structures per core (species and sites pooled) (circles ±SE). NB: Y-axis scale for seed banks and reproductive structures differ between the two habitats.

5.6.3.4 Resilience

Resilience was poor overall in the Burnett–Mary NRM region in 2022–23 and declined to the second lowest level recorded, and lowest since 2006–07 (Figure 84).

At both Urangan sites, percent cover and composition were below thresholds for resistance (percent cover was <1%) and only colonising species were present so they were both in category 1.1 with a score of 0. At Rodds Bay, there were large differences in the resilience score between sites. At RD3, cover was also below the low resistance threshold but it was composed of only foundational species with no reproductive structures. At RD1, abundance and composition were above low resistance thresholds and there was reproduction observed, but only one for the site so it was the lowest score within 2.2.1.

At coastal intertidal sites at Burrum Heads, there had in recent years been a large difference in resilience between the two sites, but in 2022–23, both sites had low resilience. At BH1, abundance declined below the threshold indicative of low resistance and there were no reproductive structures. At BH2 cover was above the resistance threshold but there were no reproductive structures and none had been observed for the past three years so resilience was category 2.1.1.

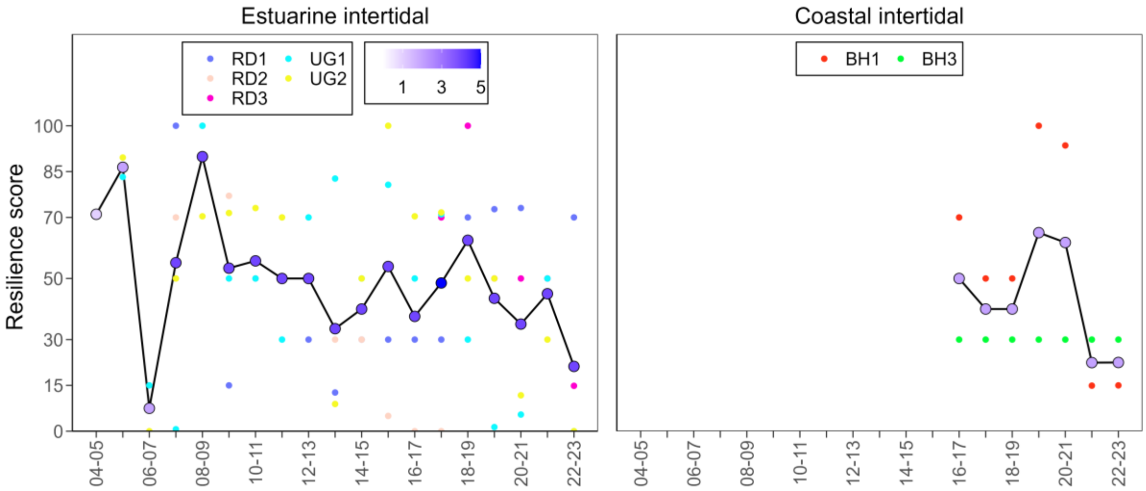


Figure 84. Resilience score in each habitat in the Burnett–Mary region from 2006 to 2023. Coloured small circles represent different sites. Shades of blue for the larger circles indicate the number of sites that contributed to the score.

5.6.3.5 Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades in 2022–23 generally increased, remaining well above the long-term average for the ninth consecutive year at estuarine habitats (Figure 85). At coastal habitats, epiphyte abundance went above the long-term average in the late dry for the first time in six years (Figure 85).

Per cent cover of macroalgae remained below the long-term average across the habitats monitored for the fourth consecutive year (Figure 85).

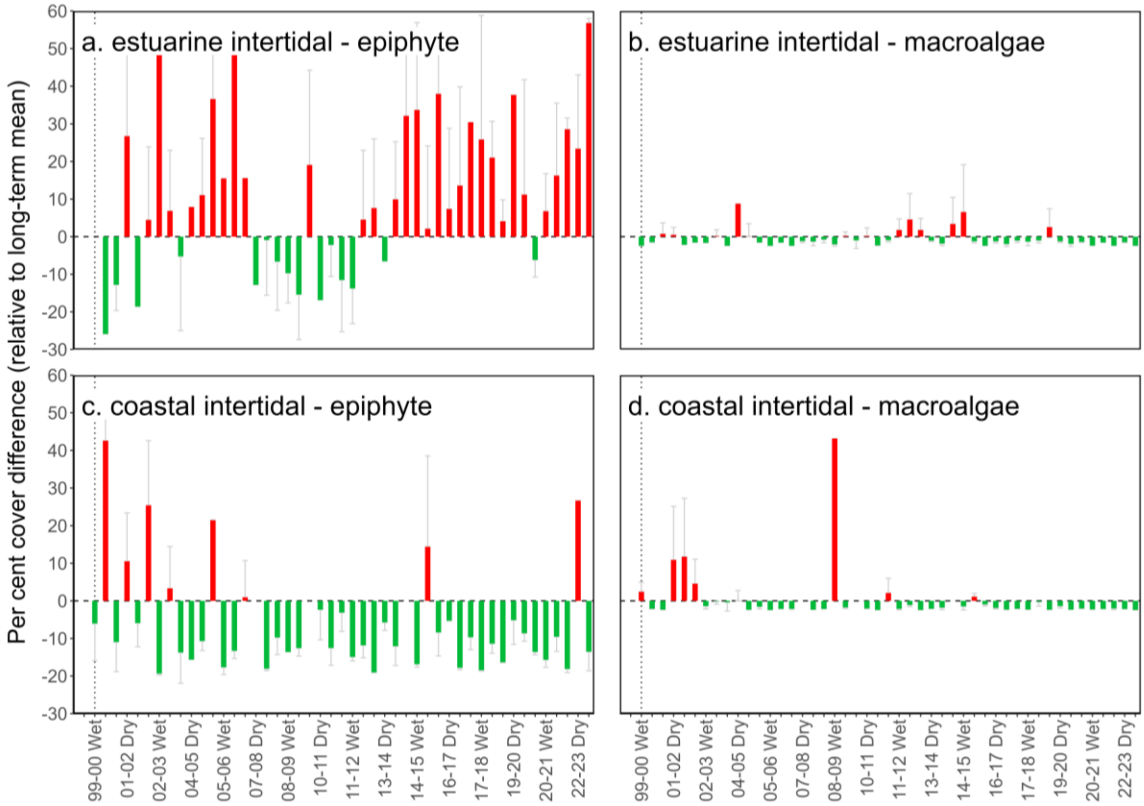


Figure 85. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Burnett–Mary region, 2000–2023 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

6 Discussion

Inshore seagrass condition was largely unchanged in 2022–23 with increases in the overall seagrass abundance score offset by declines in the resilience score. However, there were regional differences, with deterioration of condition in the southern NRM regions (Fitzroy and Burnett–Mary) while northern and central regions remained unchanged.

In 2022–23, the Seagrass Index declined to the lowest and second lowest levels on record in the Fitzroy and Burnett–Mary regions, respectively. Resilience declined in both regions while abundance either marginally increased or remained **very poor**. In fact, abundance had been declining at some sites since early 2018. In 2021–22 environmental pressures in the southern NRM regions were relatively benign, with rainfall and river discharges below average, and slightly cooler temperatures. These would have been more conducive to seagrass growth. However, light availability was either around or below average. With the severe loss of all or some of the meadows, destabilisation of the sediments may hinder the ability of seagrass to establish and begin recovery. At Urangan, highly dispersive sodic sediments at the sites, which are easily resuspended, are also delaying the onset of recovery. These trends highlight that there is an interplay between local-scale processes, and region wide pressures influencing seagrass condition.

There were also positive signs of recovery. In Mackay–Whitsunday, the Seagrass Index reached it highest level since 2016-17, following the losses experienced as a consequence of cyclone Debbie in March 2017. This appears the first indication that seagrass habitats in the region may be recovering from past disturbances. This is also likely due to alleviation of localised pressures and possibly chronic changes not easily identifiable in all sites and habitats. Recovery has been buoyed by relatively benign environmental pressures around or below the long-term averages during 2022–23. Of concern, however, is the increase in extreme temperature events, particularly in the Mackay-Whitsunday southern sub-region. Although, within-canopy temperatures on average were slightly cooler than the previous period and around the long-term, maximum temperatures exceeded 35°C for the greatest number of days ever for the region. Additionally, the region experienced a week-long anomalous event (heatwave) in late October 2022 where temperatures exceeded 43°C, including the highest ever at 46.5°C. These anomalous events appear to be not only increasing in frequency over the last decade, but also shifting earlier (i.e. pre-summer), into the main seagrass growing season.

Rising temperatures are a Reef-wide trend in seagrass habitats. In northern regions, within-canopy temperatures were again higher than average in 2022–23, and a majority of locations across the Reef had higher than average temperatures (Figure 7). The largest rise above long-term average was in Cape York where it was 0.7ºC above average for the region. Temperature extremes (>40ºC) are also becoming more common, particularly in the Mackay–Whitsunday region. The impact of temperature extremes are relatively easy to assess (e.g. experiment papers) and to identify in the field (e.g. burning) (Campbell *et al.* 2006; Collier and Waycott 2014). By contrast, the impact of chronic rises in temperature are difficult to discern in seagrass habitat. Rises in temperature increase net productivity in seagrasses up to their thermal optima after which net productivity and potential for growth decline. These thresholds are only known for a few species. The influence of temperature on other biological processes critical to resilience are unknown. For example, temperature is likely to affect flowering onset, flowering density, seed development, condition of the sediment, seed viability and seed germination. These are information gaps that are becoming increasingly urgent to address as rising temperatures continue to dominate the pressures of the inshore Reef, and they may influence resilience of habitats to other pressures such as water quality.

Site-scale monitoring is sensitive to site-scale pressures in addition to the regional pressures of water quality and thermal stress. There are local-scale processes that appear to have had a substantial influence in the past decade. For example, changes in the sediment or substrate have been observed at sites in all NRM regions. For example, in Cape York, one of the sites at each of Shelburne Bay and Bathurst Bay had a drainage channel from nearby tidal inlets moving through the site, which eroded sediment and brought more organic rich deposits. In the Wet Tropics at Lugger Bay the sediment height dropped following cyclone Yasi, and became too deep for rapid colonisation in the turbid waters and at Dunk Island, removal of sand from the reef substrate following the cyclone also slowed recovery. In Gladstone Harbour at Pelican Banks, deep mud banks with high levels of bioturbation moved through one of the sites. At Urangan, sediments became highly dispersive and easily resuspended over the site as seagrass abundance declined. Low seagrass cover can make sediments more unstable and create negative feedbacks to accelerate decline (Maxwell *et al.* 2016). Quantitative indicators of local-scale processes would enable these to be integrated into routine pressures analysis affecting the inshore seagrass habitats. This would be comparable to the inclusion of Crown of Thorn Starfish pressures at inshore reefs in the coral monitoring program (Thompson *et al.* 2022), which is a site-level pressure. In some cases, there may be no suitable management action to respond to local-scale processes, however, understanding their role in seagrass trends is important contextual information. In other cases, management actions could target these local-scale issues or processes to facilitate recovery. Such localised actions could include using seed-based or transplant-based restoration approaches, or ecological engineering to elucidate conditions where growth, settlement and/or colonisation of seagrass can be promoted (Tan *et al.* 2020).

Daily light is affected by concentrations of suspended sediments, nutrients and organic matter in the water and these are in turn affected by river discharge, resuspension and biological processes (Bainbridge *et al.* 2018; Lewis *et al.* 2021; Fabricius *et al.* 2016). Inshore seagrass monitoring sites are exposed to a very high frequency of turbid water even in low discharge years (Figure 25, Figure 34, Figure 35, Figure 51, Figure 60, Figure 69, Figure 78). These turbid waters constrain the depth limit of seagrasses, therefore influencing their spatial extent and also influence changes in abundance and resilience.

Daily light levels were around average for the Reef in 2022–23, but were below average in most NRM regions, with the exception of Mackay–Whitsunday and Fitzroy. Light is measured only at intertidal sites starting with this reporting year i.e. not at any subtidal sites. Intertidal sites can be exposed to very high light during low tide and on either side of the low tide when water level is shallow. The long-term regional and Reef-wide daily light averages were updated so that those baselines are comparable to current sites. Even the level and frequency of exposure can influence the average daily light of a site, and so comparisons are made with the long-term conditions of each site (Figure 7).

Benthic light is a pressure of concern in intertidal seagrass habitats, as they are rarely exposed to air/shallow water especially in the wet season when they are only exposed at night due to the annual luna and tidal cycles. Therefore, in terms of daily light, intertidal habitats are much like subtidal habitats during the wet season when the risk of light stress is also the highest due to river discharge and resuspension associated with storms. In previous reports, daily light has been reported against light thresholds that indicate acute stress and an increased probability of seagrass loss (6 mol m^{-2} d^{-1}) and an estimate of a light threshold to support optimum growth over the long-term (10 mol m^{-2} d^{-1}). These values were developed for shallow subtidal habitats from *in situ* measures or experimental testing (Collier *et al.* 2012a; Collier *et al.* 2016a) or *in situ* experiments in very turbid habitats (Chartrand *et al.* 2016) as summarised in (Collier *et al.* 2016b). Frequent or prolonged exposure to high light increases average daily light levels when averaged over months or a year as they are reported here. This likely underestimates the risk of light stress in shallow intertidal turbid habitats. There is a need to develop light thresholds that accommodate the exposure regime of intertidal habitats.

The depth limit of seagrass and deeper or subtidal seagrass habitats tend to be more susceptible to changes in daily light as they grow in conditions that are near to their minimum light requirements (for example, the subtidal habitats of the Burdekin region undergo large changes in abundance when there is elevated discharge (Petus *et al.* 2014)). There is an information gap between daily light in intertidal habitats (currently measured with *in situ* loggers) and mid-shelf and offshore daily light that is modelled from remote sensing or with eReefs. These models are less accurate in shallow inshore optically complex waters despite the importance of light as pressure in those habitats (Robson *et al.* 2019; Lambert *et al.* 2020).

Except for extreme events (very large discharge and cyclones), it is difficult to ascribe cause to any one pressure when there are many occurring successively or concurrently. However, through targeted research, cumulative pressures can be quantified and cumulative indices of pressure developed (Uthicke *et al.* 2016; Lawrence 2019; Uthicke *et al.* 2020).

Securing a future for seagrasses on the Great Barrier Reef

Resilience-based management places a strong emphasis on the use of forecasting tools to inform planning and actions, together with monitoring and diagnostic tools to adjust actions. These actions need to be designed to retain resistance capacity (e.g. maintain foundational species), maximise recovery and limit disturbances or impacts.

Resilience-based management also recognises that ecological health is influenced by processes at a range of spatial and temporal scales. This program focusses on site-level monitoring, representative of habitats and gradients of pressure across the entire inshore Reef in the late dry season and the late wet season in some locations. Integrating this level of information with spatial data on pressures provides a mean to examine how management initiatives, such as reversing wider-scale catchment degradation and poor water quality (i.e. Paddock to Reef Program) influence habitat condition. This is achieved through examination of exposure to turbid water types I and II. This information is also used to assess the extent to which seagrass habitat is affected by turbidity across the region (Moran *et al.* 2023).

Within canopy temperature is influenced by tides, changes in sea level and weather, so the risk of thermal stress will vary across habitats that have gradients of exposure to these. Existing spatial products (e.g. eReefs, ReefTemp) do not model these tidal changes or provide thorough coverage of the inshore Reef. Therefore, there is a need to develop a fit for purpose spatial model of inshore thermal risk, which is currently under development.

Improving the accuracy of indicators, and refining thresholds and indices of pressures, including cumulative stress, will improve our understanding of the processes of resilience to guide management actions and adaptation responses. For example, as temperatures continue to rise, there is also a need to examine how long-term averages compare to setting a fixed average (*sensu.* climatology) so that pressures indicators continue to be sensitive and informative.

Practicable conservation opportunities exist, which can make substantial and quantifiable improvements to seagrass condition. In addition to managing pressures, there are direct actions that can be taken to facilitate recovery. Some of these include:

1. Developing accurate models of seagrass recovery to identify when recovery is on track or when intervention actions may be required.
2. Improving identification and evidence base of the drivers of recovery. For example, if improvements in water quality are helping seagrass recovery, then the evidence base of this provides justification for continued water quality improvements.
3. Improving our understanding of poor and variable reproductive effort through focussed research, as reproduction underpins the capacity for meadows to recover naturally, and seeding offers a potential restoration strategy.
4. Active seagrass restoration or enhancement of resilience may be of benefit, but significant research is required before techniques can be operationalised (see also Tan *et al.* 2020). This may include active environmental engineering in localised areas to improve habitat suitability, by mitigating limiting factors (e.g. wave energy, erosion) or creating new habitat.

Continuous revision and examination of opportunities for improvement of the monitoring program will also ensure that the information is current, relevant, and makes the most for emerging technologies.

Some of the most pressing updates include:

1. Developing a spatial inshore thermal stress risk model (under way).
2. Updating the light indicators and thresholds to be more suitable for *in situ* light monitoring of intertidal habitats and explore ways to apply existing information (e.g. eReefs) to complement the current pressures reporting for inshore subtidal habitats.
3. Development of a fragmentation index based on the current and historical seagrass extent data, and development of protocols for using drones to complement spatial extent/fragmentation monitoring.
4. Scaling monitoring undertaken in this program to broader-levels (e.g. RIMReP) to fully capture the extent of habitat decline and recovery so that the potential ecological consequences can be more accurately inferred. For example, continuous improvements in earth observing (airborne and spaceborne) image capture of the Reef using Unoccupied Aerial Vehicles (UAV) and Autonomous Underwater Vehicles (AUV), along with advances in machine- and deep-learning to process images, offer opportunities for broad-scale assessment of seagrass condition and health in some habitat types that were not available in the past.

7 Conclusion

In 2022–23 inshore seagrass meadows across the Reef remained unchanged in overall condition, with the Seagrass Index remaining **moderate**. The improvement in seagrass abundance being offset by a similar decline in the resilience indicator. The abundance indicator remained moderate, however the resilience indicator deteriorated back to poor in 2022–23 after improving to moderate over the last two years.

Environmental conditions were generally around long-term averages across the Reef, with the exception of river discharge and temperatures which were above average in the northern NRM regions.

In 2022–23, the inshore seagrass of the Reef was in a **moderate** condition in all northern and central NRM regions, but **poor** or **very poor** and declining in the two southern most regions. The score increased in the far northern and central regions compared to the previous monitoring period, but declined in southern regions.

Seagrass meadows of the Reef are dynamic, with large changes in abundance being seemingly typical in some regions (e.g. Birch and Birch 1984; Preen *et al.* 1995; Campbell and McKenzie 2004; Waycott *et al.* 2007), but the timing and mechanisms that cause these changes (i.e. declines and subsequent recovery) are complex.

Inshore seagrass meadows of the Reef were in an overall **good** state in late 2008. In particular, locations in the northern Wet Tropics and Burdekin regions were in a **good** state of health with abundant seagrass and seed banks. In contrast, locations in the southern Mackay–Whitsunday and Burnett–Mary regions were in a **poor** and **moderate** state, respectively, with low abundance, reduced reproductive effort and small or absent seed banks (Figure 86).

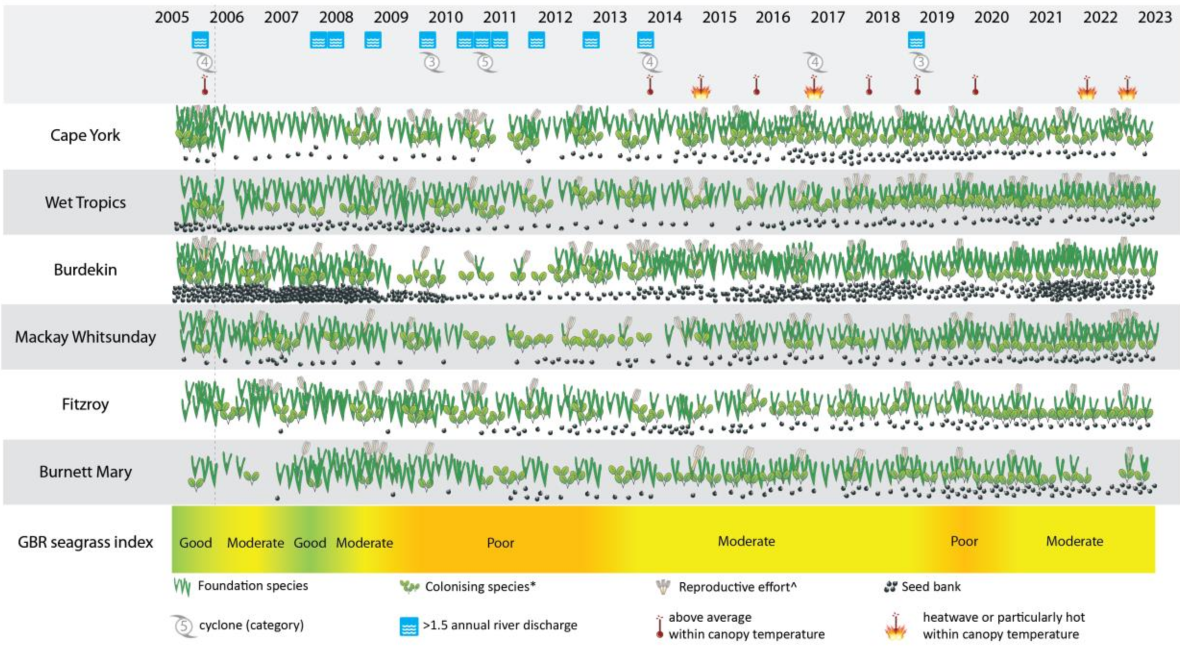


Figure 86. Summary of inshore seagrass state illustrating pressures, abundance of foundation / colonising species, seed bank and reproductive effort in each NRM from 2005 to 2023. * colonising species are represented by the genus *Halophila*, however, *Nanozostera* and *Halodule* can be both colonising and foundational species depending on meadow state. ^ not conducted in 2005.

In 2009 with the onset of the La Niña, the decline in seagrass state steadily spread across the Burdekin region and to locations within the Fitzroy and Wet Tropics where discharges from large rivers and associated catchments occurred (McKenzie *et al.* 2010a; McKenzie *et al.* 2012). The only locations of better seagrass state were those with relatively little catchment input, such as Gladstone Harbour and Shoalwater Bay (Fitzroy region), Green Island (northern Wet Tropics), and Archer Point (Cape York) (McKenzie *et al.* 2012).

By 2010, seagrasses of the Reef were in a poor state with declining trajectories in seagrass abundance, reduced meadow extent, limited or absent seed production and increased epiphyte loads at most locations. These factors would have made the seagrass populations particularly vulnerable to large episodic disturbances, as demonstrated by the widespread and substantial losses documented after the floods and cyclones of early 2011.

Following the extreme weather events of early 2011, seagrass habitats across the Reef further declined, with severe losses reported from the Wet Tropics, Burdekin, Mackay–Whitsunday and Burnett–Mary regions. By 2011–12, the onset of seagrass recovery was observed across some regions, however a change had occurred where colonising species dominated many habitats.

The majority of meadows appeared to allocate resources to vegetative growth rather than reproduction, indicated by the lower reproductive effort and seed banks. In 2016–17, recovery had slowed or stalled across most of the regions, and seagrass condition began the gradually decline. Cumulative pressures, including severe climatic events (Tropical Cyclone Debbie), continued to undermine the resilience of inshore seagrass meadows of the Reef. Frequent and repeated disturbances seemed to be maintaining lower seagrass abundance at some locations, perpetuated by feedbacks, which in turn may be reducing capacity of the plants to expand and produce viable seed banks. By 2019–20, the inshore Reef seagrass had fallen back to a poor state. Since then, recovery has been buoyed across northern regions by a couple of years of low to negligible climatic pressures and more recently by recovery of seagrass in the Mackay–Whitsunday region. However, improvements in several NRM regions are offset by consistent declines, particularly in the most southern regions (Fitzroy and Burnett–Mary).

The sustained improvement of the Reef's inshore seagrass meadows relies on several factors, including favourable growth conditions and environmental protection measures. Although weather patterns are beyond our control, we can mitigate their impact on seagrasses by implementing initiatives that curtail terrestrial runoff to the Reef, such as the Paddock to Reef Program. It's crucial to maintain a focus on the resilience of seagrass meadows, including their ability to recover from damage, when prioritizing research and management efforts.

To ensure the long-term health of the Reef's seagrass ecosystems, it is imperative to advance ecosystem science related to resilience and recovery. In addition to comprehensive research, adaptive resilience-based management is crucial. This involves prioritizing the use of forecasting tools to inform planning and actions, coupled with monitoring and diagnostic tools to refine and execute actions that promote resilience, optimize recovery, and minimize disturbances or impacts.

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Appendix 1 Seagrass condition indicator guidelines

A1.1 Seagrass abundance

The status of seagrass abundance (per cent cover) was determined using the seagrass abundance guidelines developed by McKenzie (2009). The seagrass abundance measure in the MMP is the average per cent cover of seagrass per monitoring site. Individual site and subregional (habitat type within each NRM region) seagrass abundance guidelines were developed based on per cent cover data collected from individual sites and/or reference sites (McKenzie 2009). Guidelines for individual sites were only applied if the conditions of the site aligned with reference site conditions.

A reference site is a site whose condition is considered to be a suitable baseline or benchmark for assessment and management of sites in similar habitats. Ideally, seagrass meadows in near pristine condition with a long-term abundance database would have priority as reference sites. However, as near-pristine meadows are not available, sites which have received less intense impacts can justifiably be used. In such situations, reference sites are those where the condition of the site has been subject to minimal/limited disturbance for 3-5 years. The duration of 3-5 years is based on recovery from impact times (Campbell and McKenzie 2004).

There is no set/established protocol for the selection of reference sites and the process is ultimately iterative. The criteria for defining a minimally/least disturbed seagrass reference site is based on Monitoring River Health Initiative (1994) and includes some or all of the following:

- beyond 10 km of a major river: as most suspended solids and particulate nutrients are deposited within a few kilometres of river mouths (McCulloch *et al.* 2003; Webster and Ford 2010; Bainbridge *et al.* 2012; Brodie *et al.* 2012)
- no major urban area/development (>5000 population) within 10 km upstream (prevailing current)
- no significant point source wastewater discharge within the estuary
- has not been impacted by an event (anthropogenic or extreme climate) in the last 3-5 years
- where the species composition is dominated by the foundation species expected for the habitats (Carruthers *et al.* 2002)
- does not suggest the meadow is in recovery (i.e. dominated by early colonising).

The 80th, 50th and 20th percentiles were used to define the guideline values as these are recommended for water quality guidelines (DEHP 2009), and there is no evidence that this approach would not be appropriate for seagrass meadows in the Reef. At the request of the Paddock to Reef Integration Team, the 80th percentile was changed to 75th to align with other Paddock to Reef report card components. By plotting the percentile estimates with increasing sample size, the reduction in error becomes apparent as it moves towards the true value (e.g. Figure 87).

Across the majority of reference sites, variance for the 50th and 20th percentiles levelled off at around 15–20 samples (i.e. sampling events), suggesting this number of samples was sufficient to provide a reasonable estimate of the true percentile value. This sample size is reasonably close to the ANZECC (2000) Guidelines recommendation of 24 data values. If the variance had not plateaued, the percentile values at 24 sampling events was selected to best represent the variance as being captured. This conforms with Kiliminster *et al.* (2015) definition where an enduring meadow is present for 5 years.

Nonlinear regressions (exponential rise to maximum, two parameter) were then fitted to per cent cover percentile values at each number of sampling events using the following model:

$$y = a\left(1 - e^{-bx}\right)$$

where *y* is the seagrass cover percentile at each number of sampling events (*x*), *a* is the asymptotic average of the seagrass cover percentile, and *b* is the rate coefficient that determines how quickly (or slowly) the maximum is attained (i.e. the slope). The asymptotic average was then used as the guideline value for each percentile (Table 19).

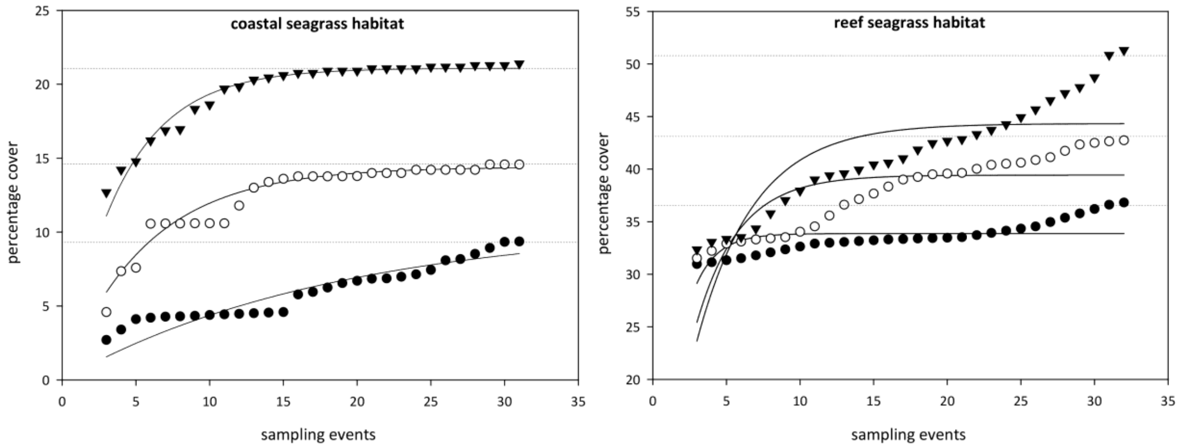

Figure 87. Relationship between sample size and the error in estimation of percentile values for seagrass abundance (per cent cover) in coastal and reef seagrass habitats in the Wet Tropics NRM. ▼ = 75th percentile, ○ = 50th percentile, ● = 20th percentile. Horizontal lines are asymptotic averages for each percentile plot.

As sampling events occur every 3-6 months depending on the site, this is equivalent to 3–10 years of monitoring to establish percentile values. Based on the analyses, it was recommended that estimates of the 20th percentile at a reference site should be based on a minimum of 18 samples collected over at least three years. For the 50th percentile a smaller minimum number of samples (approximately 10–12) would be adequate but in most situations it would be necessary to collect sufficient data for the 20th percentile anyway. For seagrass habitats with low variability, a more appropriate guideline was the 10th percentile primarily the result of seasonal fluctuations (as nearly every seasonal low would fall below the 20th percentile). Percentile variability was further reduced within a habitat type of each region by pooling at least two (preferably more) reference sites to derive guidelines. The subregional guideline is calculated from the mean of all reference sites within a habitat type within a region.

Using the seagrass guidelines, seagrass state can be determined for each monitoring event at each site and allocated as:

- good (median abundance at or above 50th percentile)
- moderate (median abundance below 50th percentile and at or above 20th percentile)
- poor (median abundance below 20th or 10th percentile).

For example, when the median seagrass abundance for Yule Point is plotted against the 20th and 50th percentiles for coastal habitats in the Wet Tropics (Figure 88), it indicates that the meadows were in a poor condition in mid-2000, mid-2001 and mid-2006 (based on abundance).

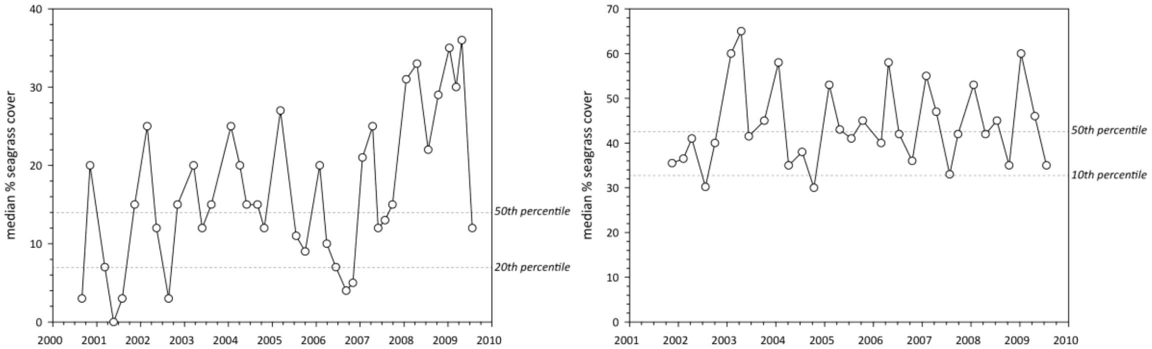

Figure 88. Median seagrass abundance (per cent cover) at Yule Point (left) and Green Island (right) plotted against the 50th and 20th percentiles for coastal and intertidal reef seagrass habitat in the Wet Tropics.

Similarly, when the median seagrass abundance for Green Island is plotted against the 20th and 50th percentiles for intertidal reef habitats in the Wet Tropics, it indicates that the meadows were in a poor condition in the middle of most years (based on abundance). However, the poor rating is most likely a consequence of seasonal lows in abundance. Therefore, in this instance, it was more appropriate to set the guideline at the 10th rather than the 20th percentile.

Using this approach, subregional seagrass abundance guidelines (hereafter known as "the seagrass guidelines") were developed for each seagrass habitat type where possible (Table 19). If an individual site had 18 or more sampling events and no identified impacts (e.g. major loss from cyclone), an abundance guideline was determined at the site or location level rather than using the subregional guideline from the reference sites (i.e. as more guidelines are developed at the site level, they contribute to the subregional guideline).

After discussions with GBRMPA scientists and the Paddock to Reef integration team, the seagrass guidelines were further refined by allocating the additional categories of:

- very good (median abundance at or above 75th percentile)
- very poor (median abundance below 20th or 10th percentile and declined by >20 per cent since previous sampling event).

Seagrass state was then rescaled to a five point scale from 0 to 100 to allow integration with other components of the Paddock to Reef report card (Department of the Premier and Cabinet 2014). Please note that the scale from 0 to 100 is unitless and should not be interpreted as a proportion or ratio.

Table 19. Seagrass percentage cover guidelines ("the seagrass guidelines") for each site/location and the subregional guidelines (bold) for each NRM habitat. Values in light grey not used. ^ denotes regional reference site, * from nearest adjacent region. For site details, see Tables 3 & 4.

NRM region	site/ location	Habitat	percentile guideline			
			10th	20th	50th	75th
Cape York	AP1^	reef intertidal	11	16.8	18.9	23.7
	AP2	reef intertidal	11		18.9	23.7
	FR	reef intertidal		16.8	18.9	23.7
	ST	reef intertidal		16.8	18.9	23.7
	YY	reef intertidal		16.8	18.9	23.7
	NRM	***reef intertidal***	***11***	***16.8***	***18.9***	***23.7***
	FG	reef subtidal		26	33	39.2
	NRM	***reef subtidal****	***22***	***26***	***33***	***39.2***
	BY*	coastal intertidal		6.6	12.9	14.8
	SR*	coastal intertidal		6.6	12.9	14.8
	NRM	***coastal intertidal****	***5***	***6.6***	***12.9***	***14.8***
	BY*	coastal subtidal		6.6	12.9	14.8
	LR*	coastal subtidal		6.6	12.9	14.8
	MA*	coastal subtidal		6.6	12.9	14.8
	NRM	***coastal subtidal****		***6.6***	***12.9***	***14.8***
Wet Tropics	LB	coastal intertidal		6.6	12.9	14.8
	YP1^	coastal intertidal	4.3	7	14	15.4

NRM region	site/ location	Habitat	percentile guideline 10th	20th	50th	75th
	YP2^	coastal intertidal	5.7	6.2	11.8	14.2
	NRM	***coastal intertidal***	***5***	***6.6***	***12.9***	***14.8***
	MS	coastal subtidal		6.6	12.9	14.8
	NRM	***coastal subtidal***		***6.6***	***12.9***	***14.8***
	DI	reef intertidal	27.5		37.7	41
	GI1^	reef intertidal	32.5	38.2	42.7	45.5
	GI2^	reef intertidal	22.5	25.6	32.7	36.7
	LI1	reef intertidal	27.5		37.7	41
	GO1	reef intertidal	27.5		37.7	41
	NRM	***reef intertidal***	***27.5***	***31.9***	***37.7***	***41***
	DI3	reef subtidal		26	33	39.2
	GI3^	reef subtidal	22	26	33	39.2
	LI2	reef subtidal		26	33	39.2
	NRM	***reef subtidal***	***22***	***26***	***33***	***39.2***
Burdekin	BB1^	coastal intertidal	16.3	21.4	25.4	35.2
	SB1^	coastal intertidal	7.5	10	16.8	22
	SB2	coastal intertidal		10	16.8	22
	JR	coastal intertidal		15.7	21.1	28.6
	BW	coastal intertidal		13.2	19.1	22.2
	NRM	***coastal intertidal***	***11.9***	***15.7***	***21.1***	***28.6***
	MI1^	reef intertidal	23	26	33.4	37
	MI2^	reef intertidal	21.3	26.5	35.6	41
	NRM	***reef intertidal***	***22.2***	***26.3***	***34.5***	***39***
	MI3^	reef subtidal	18	22.5	32.7	36.7
	NRM	***reef subtidal***	***18***	***22.5***	***32.7***	***36.7***
Mackay–Whitsunday	SI	estuarine intertidal		18	34.1	54
	NRM	***estuarine intertidal***	***10.8****	***18****	***34.1****	***54****
	PI2^	coastal intertidal	18.1	18.7	25.1	27.6
	PI3^	coastal intertidal	6.1	7.6	13.1	16.8
	MP2	coastal intertidal		18.9	22.8	25.4
	MP3	coastal intertidal		17.9	20	22.3
	CV	coastal intertidal		13.2	19.1	22.2
	LL	coastal intertidal		13.2	19.1	22.2
	SH1	coastal intertidal		13.2	19.1	22.2
	NRM	***coastal intertidal***	***12.1***	***13.2***	***19.1***	***22.2***
	NB	coastal subtidal		13.2	19.1	22.2
	NRM	***coastal subtidal***	***12.1***	***13.2***	***19.1***	***22.2***
	HB1^	reef intertidal		10.53	12.9	14.2
	HB2^	reef intertidal		7.95	11.59	13.4
	HM	reef intertidal		9.2	12.2	13.8
	LN3	reef intertidal		9.2	12.2	13.8
	NRM	***reef intertidal***		***9.2***	***12.2***	***13.8***
	CH	reef subtidal		22.5	32.7	36.7
	LN	reef subtidal		22.5	32.7	36.7
	TO	reef subtidal		22.5	32.7	36.7
	WB	reef subtidal		22.5	32.7	36.7
	NRM	***reef subtidal****	***18****	***22.5****	***32.7****	***36.7****
Fitzroy	GH	estuarine intertidal		18	34.1	54
	NRM	***estuarine intertidal***	***10.8****	***18****	***34.1****	***54****
	RC1^	coastal intertidal	18.6	20.6	24.4	34.5
	WH1^	coastal intertidal	13.1	14.4	18.8	22.3
	NRM	***coastal intertidal***	***15.85***	***17.5***	***21.6***	***28.4***
	GK	reef intertidal		9.2	12.2	13.8
	NRM	***reef intertidal***		***9.2****	***12.2****	***13.8****
Burnett–Mary	RD	estuarine intertidal		18	34.1	54
	UG1^	estuarine intertidal	10.8	18	34.1	54
	UG2	estuarine intertidal		18	34.1	54
	NRM	***estuarine intertidal***	***10.8***	***18***	***34.1***	***54***
	BH1^	coastal intertidal		7.8	11.9	21.6
	BH3	coastal intertidal		7.8	11.9	21.6
	NRM	***coastal intertidal***		***7.8***	***11.9***	***21.6***

A1.2 Seagrass resilience

The status of seagrass resilience was determined using a multi-faceted resilience metric informed by existing metrics, historical data, and a conceptual understanding of resilience. Resilience can be considered as having two main elements (e.g. Timpane-Padgham *et al.* 2017; Connolly *et al.* 2018): an ability to resist disturbance, and an ability to recover from disturbances. We used a decision tree approach, which includes thresholds defining the splits, and methods for calculating scores (Figure 89). The main splits in the tree are based around:

- a ‘resistance’ component that assesses the seagrass meadow capacity to cope with disturbance based on their seagrass abundance and species composition. A low resistance site is one that has very low abundance based on the history of that site and/or has a high proportion of colonising species. These meadows are considered to be highly vulnerable to disturbances and, therefore, to have very low resilience.
- a ‘reproduction' component that is based around likelihood of producing seed banks given the presence and count of reproductive structures. These are scored based on the levels of expected reproductive effort given the life history strategy of the species present. For example, some ‘persistent’ species such as *Thalassia* are not expected to have a high number of reproductive structures, and nor does it depend on them quite as much for long-term survival compared to ‘colonising’ species.

Those two components work both individually and in collaboration, thus giving the best estimate of resilience using the existing data and indicators. The metric is scored linearly from 0 to 100. The 0–100 scale was split into thirds (rounded to the nearest ten score). This resulted in the following:

- Low resistance sites = 0–30
- Non-reproductive high resistance site = 30–70
- Reproductive high resistance site = 70–100

The methods used to arrive at each step are outlined in detail in Collier *et al*. (2021a).

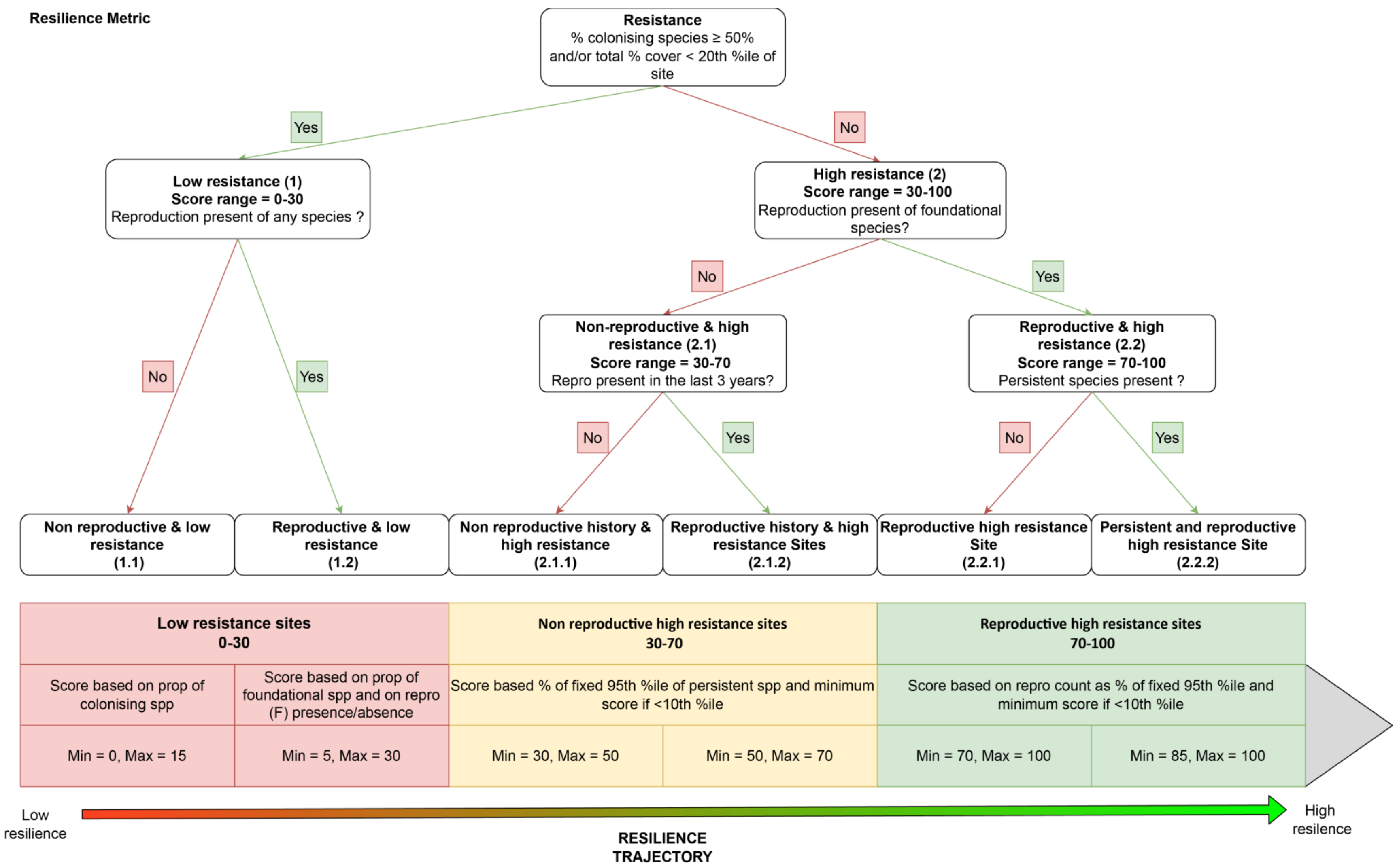

Figure 89. Overall structure of the proposed MMP resilience metric. The score ranges from 0 to 100. Splits in the tree are used to place a site in a grouping (red, yellow, or green), with grading within each grouping based on species composition and reproductive effort. Reproduction refers to sexual reproduction. From Collier *et al.* (2021a).

Appendix 2 Detailed data

Table 20. Samples collected at each inshore monitoring site per parameter for each season. Activities include: SG = seagrass cover & composition, SB=seed bank monitoring, EM=edge mapping, RH=reproductive effort, TL=temperature loggers, LL=light loggers. ^=subtidal.

Reef region	NRM region	Basin	Monitoring location		late dry Season (2022)						late wet Season (2023)					
					SG	SB	EM	RH	TL	LL	SG	SB	EM	RH	TL	LL
Far Northern	Cape York	Jacky Jacky / Olive Pascoe	Shelburne Bay	**SR1**	33	30	✓	15	✓							
				SR2	33	30	✓	15	✓	✓						
			Margaret Bay	**MA1**	10											
				MA2	11											
			Piper Reef	**FR1**	33	30	✓	15	✓							
				FR2	33	30	✓	15	✓	✓						
		Lockhart	Weymouth Bay	**YY1**												
			Lloyd Bay	**LR1^**	17											
				LR2^	10											
		Normanby / Jeanie	Flinders Group	**ST1**	33	30	✓	15	✓	✓						
				ST2	33	30	✓	15	✓							
				FG1^	10											
				FG2^	10											
			Bathurst Bay	**BY1**	33	30	✓	15	✓							
				BY2	33	30	✓	15	✓	✓						
				BY3^	10											
				BY4^	8											
		Endeavour	Archer Point	**AP1**												
				AP2												
Northern	Wet Tropics	Daintree	Low Isles	**LI1**	33	30	✓	15	✓	✓	33	30	✓	15	✓	✓
				LI2^	33			15			33		✓	15		
		Mossman / Barron / Mulgrave - Russell / Johnstone	Yule Point	**YP1**	33	30	✓	15	✓		33	30	✓	15	✓	
				YP2	33	30	✓	15	✓	✓	33	30	✓	15		
			Green Island	**GI1**	33	30	✓	15	✓	✓	33	30	✓	15	✓	✓
				GI2	33	30	✓	15	✓		33	30	✓	15	✓	
				GI3^	33		✓	15								
		Tully / Murray / Herbert	Mission Beach	**LB1**	33	30	✓	15			33	30	✓	15		
				LB2	33	30	✓	15			33	30	✓	15		
			Dunk Island	**DI1**	33	30	✓	15	✓		33	30	✓	15	✓	
				DI2	33	30	✓	15	✓	✓	33	30	✓	15	✓	✓
				DI3^	33		✓	15			33		✓	15		
			Rockingham Bay	**GO1**												
			Missionary Bay	**MS1^**	13											
				MS2^	11											
Central	Burdekin	Ross / Burdekin	Magnetic Island	**MI1**	33	30	✓	15	✓		33	30	✓	15	✓	
				MI2	33	30	✓	15	✓	✓	33	30	✓	15	✓	✓
				MI3^	43		✓	15			33		✓	15		
			Townsville	**SB1**	33	30	✓	15	✓	✓	33	30	✓	15	✓	✓
				SB2					✓		33	30	✓	15	✓	
				BB1	33	30	✓	15	✓	✓	33	30	✓	15	✓	✓
			Bowling Green Bay	**JR1**	33	30	✓	15	✓	✓					✓	✓
				JR2	33	30	✓	15	✓						✓	
		Don	Bowen	**BW1**	33	30										

Reef region	NRM region	Basin	Monitoring location		late dry Season (2022)						late wet Season (2023)					
					SG	SB	EM	RH	TL	LL	SG	SB	EM	RH	TL	LL
				BW3	33	30										
	Mackay–Whitsunday	Don	Shoal Bay	**HB1**	33	30			✓						✓	
				HB2	33	30			✓						✓	
		Proserpine	Pioneer Bay	**PI2**	33	30			✓						✓	
				PI3	33	30			✓						✓	
		Proserpine / O'Connell	Repulse Bay	**MP2**	33	30	✓	15	✓	✓	33	30	✓	15	✓	✓
				MP3	33	30	✓	15	✓		33	30	✓	15	✓	
			Hamilton Is.	**HM1**	33	30	✓	15	✓		33	30	✓	15	✓	
				HM2	30	30	✓	15	✓	✓	30	30	✓	15	✓	✓
			Whitsunday Island	**TO1^**	10											
				TO2^	10											
			Lindeman Island	**LN1^**	37		✓	15			33	30	✓	15	✓	✓
				LN3	33	30	✓	15	✓	✓	33	30	✓	15	✓	✓
		O'Connell	St Helens Bay	**SH1**	33											
			Newry Islands	**NB1^**	11											
				NB2^	11											
		Plane	Sarina Inlet	**SI1**	33	30	✓	15	✓	✓	33	30	✓	15	✓	✓
				SI2	33	30	✓	15	✓		33	30	✓	15	✓	
			Clairview	**CV1**	33											
				CV2	33											
Southern	Fitzroy	Fitzroy	Shoalwater Bay	**RC1**	33	30	✓	15	✓						✓	✓
				WH1	33	30	✓	15	✓	✓					✓	✓
			Great Keppel Island	**GK1**	33	30	✓	15	✓	✓					✓	✓
				GK2	33	30	✓	15	✓						✓	
		Boyne	Gladstone Harbour	**GH1**	33	30	✓	15	✓	✓					✓	✓
				GH2	33	30	✓	15	✓						✓	
	Burnett–Mary	Burnett	Rodds Bay	**RD1**	33	30	✓	15	✓	✓					✓	✓
				RD3	33	30	✓	15	✓						✓	
		Burrum	Burrum Heads	**BH1**	33	30	✓	15	✓		33	30	✓	15	✓	
				BH3	33	30	✓	15	✓		33	30	✓	15	✓	
		Mary	Hervey Bay	**UG1**	33	30	✓	15	✓		33	30	✓	15	✓	
				UG2	33	30	✓	15	✓	✓	33	30	✓	15	✓	✓

A2.1 Environmental pressures

A2.1.1 Tidal exposure

Table 21. Height of intertidal monitoring meadows/sites above lowest astronomical tide (LAT) and annual daytime tidal exposure (total hours) when meadows become exposed at a low tide. Year is June–May. Observed tidal heights courtesy Maritime Safety Queensland, 2022. * are predicted. NB: Meadow heights have not yet been determined in the far northern Cape York.

NRM	Site	**Meadow height** (above LAT)	**Site depth** (bMSL)	**Meadow height (above LAT) relative to Standard Port**	**Annual median hours exposed during daylight** (long-term)	**Per cent of annual daylight hours meadow exposed** (long-term)	**Annual daytime exposure 2022–23** (hrs)	**Per cent of annual daylight hours meadow exposed (2022–23)**
Cape York	AP1	0.46	1.02	0.46	49.67	1.27	48.83	1.11
	AP2	0.46	1.02	0.46	49.67	1.27	48.83	1.11
Wet Tropics	LI1	0.65	0.90	0.65	164.51	3.71	93.83	2.14
	YP1	0.64	0.94	0.64	157.5	3.55	89.67	2.05
	YP2	0.52	1.06	0.52	90	1.99	56.83	1.3
	GI1	0.51	1.03	0.61	113.83	2.56	81.33	1.86
	GI2	0.57	0.97	0.67	151.83	3.4	101	2.31
	DI1	0.65	1.14	0.54	73.67	1.62	19.5	0.45
	DI2	0.55	1.24	0.44	41	0.91	10.67	0.24
	LB1	0.42	1.37	0.31	16.58	0.39	2.17	0.05
	LB2	0.46	1.33	0.35	18.33	0.45	4.67	0.11
Burdekin	BB1	0.58	1.30	0.58	79.67	1.7	44.67	1.02
	SB1	0.57	1.31	0.57	63.83	1.42	43	0.98
	MI1	0.65	1.19	0.67	154.17	3.41	75.83	1.73
	MI2	0.54	1.30	0.56	141.75	2.89	40.5	0.92
	JR1	0.47	1.32	0.47	54.33	1.25	38.33	0.88
	JR2	0.47	1.32	0.47	54.33	1.25	38.33	0.88
Mackay–Whitsunday	PI2*	0.28	1.47	0.44	80.67	1.84	117.33	2.68
	PI3*	0.17	1.58	0.33	40	0.93	65.83	1.5
	HM1*	0.68	1.52	0.38	56.67	1.26	88.33	2.02
	HM2*	0.68	1.52	0.38	56.67	1.26	88.33	2.02
	SI1	0.60	2.80	0.54	26.33	0.61	39.67	0.91
	SI2	0.60	2.80	0.54	26.33	0.61	39.67	0.91
Fitzroy	RC1	2.03	1.30	1.06	170.58	4.19	194.5	4.44
	WH1	2.16	1.17	1.19	252.08	5.91	263.67	6.02
	GK1	0.52	1.93	0.43	33	0.75	27.67	0.63
	GK2	0.58	1.87	0.49	48.92	1.11	40.67	0.93
	GH1	0.80	1.57	0.69	95.58	2.22	79	1.8
	GH2	0.80	1.57	0.69	90.42	2.12	79	1.8
Burnett–Mary	RD1	0.56	1.48	0.56	66.58	1.58	44.33	1.01
	RD2	0.63	1.41	0.63	93.17	2.26	65	1.48
	UG1	0.70	1.41	0.70	142.83	3.18	101.83	2.32
	UG2	0.64	1.47	0.64	101.83	2.22	68.33	1.56

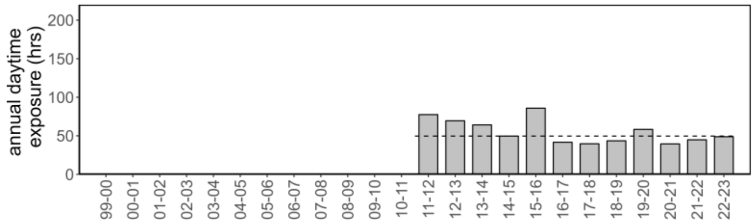

Figure 90. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of reef intertidal seagrass meadows at Archer Point, Cape York NRM region; 2011–2023. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2023. NB: Meadow heights have not yet been determined in the far northern Cape York sites.

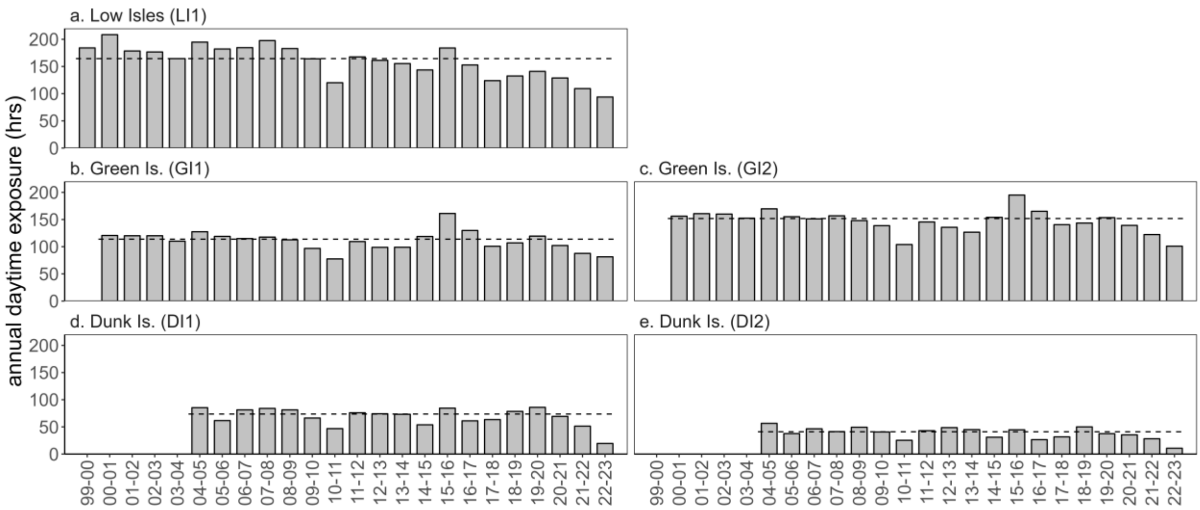

Figure 91. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of reef intertidal seagrass meadows in the Wet Tropics NRM region; 1999–2023. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2023.

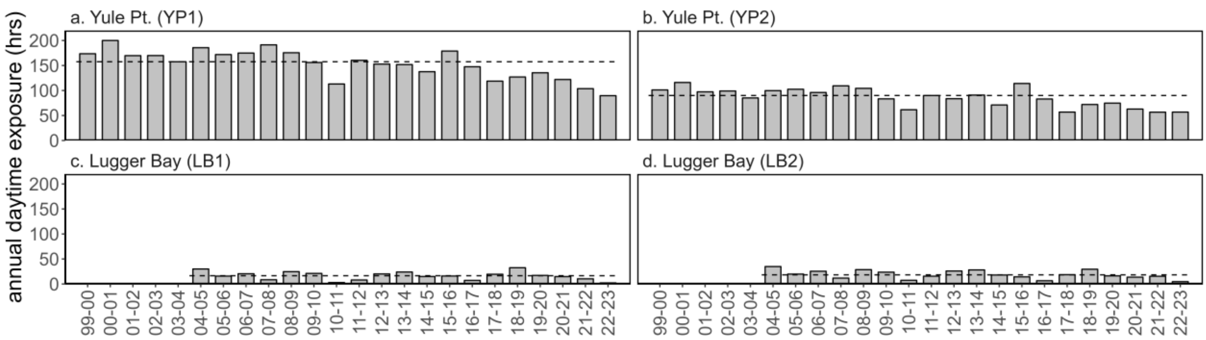

Figure 92. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of coastal intertidal seagrass meadows in Wet Tropics NRM region; 1999–2023. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2023.

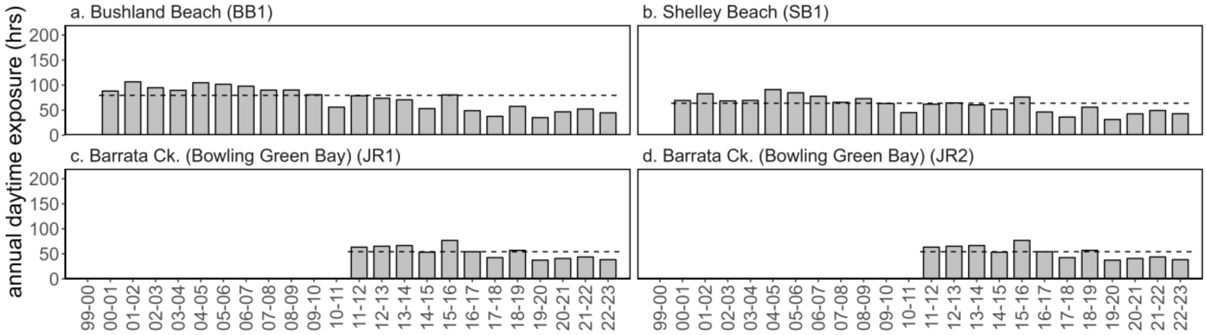

Figure 93. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of coastal intertidal seagrass meadows in Burdekin NRM region; 2000–2023. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2023.

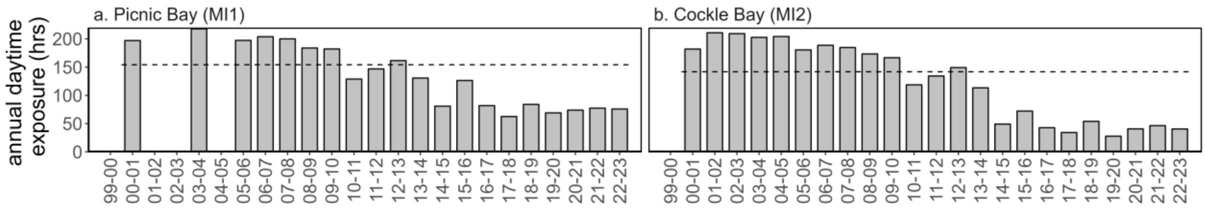

Figure 94. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of reef intertidal seagrass meadows in Burdekin NRM region; 2000–2023. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2023.

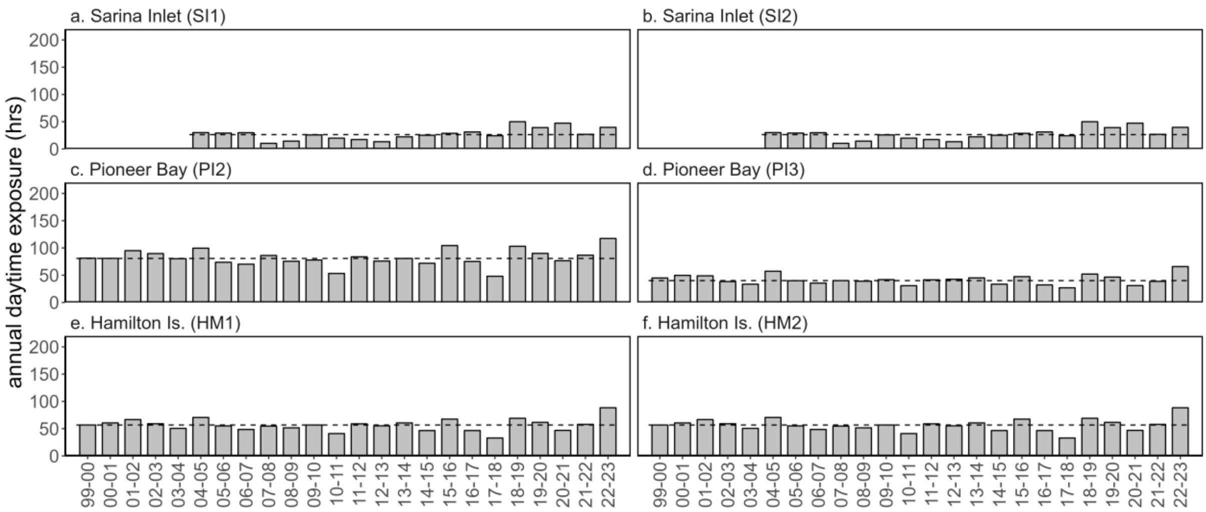

Figure 95. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of estuarine intertidal (a, b) coastal intertidal (c, d) and reef intertidal (e, f) seagrass meadows in Mackay–Whitsunday NRM region; 1999–2023. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2023.

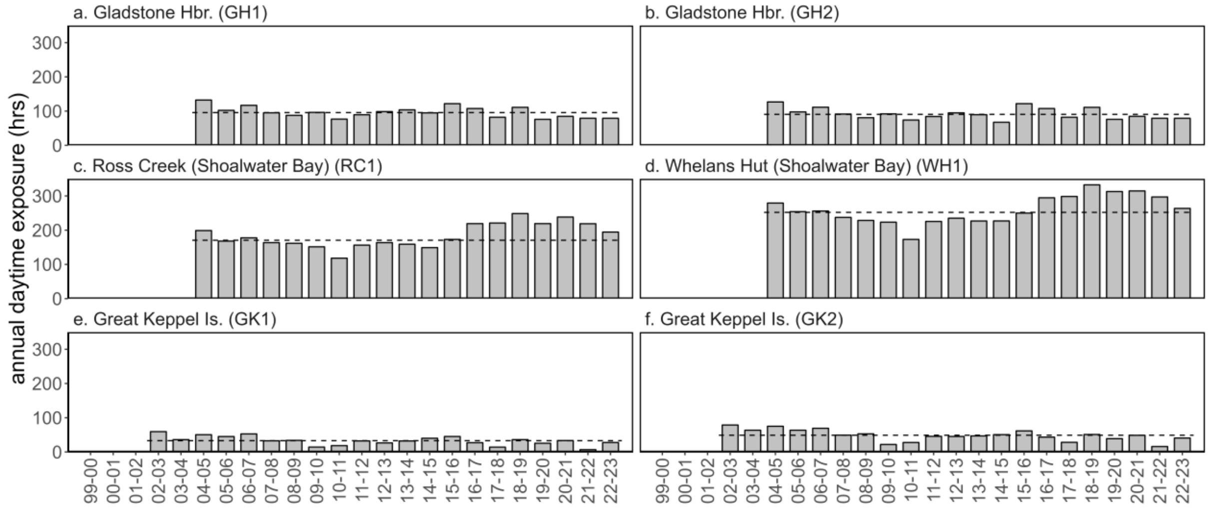

Figure 96. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of estuarine intertidal (a, b) coastal intertidal (c, d) and reef intertidal (e, f) seagrass meadows in the Fitzroy NRM region; 1999–2023. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2023.

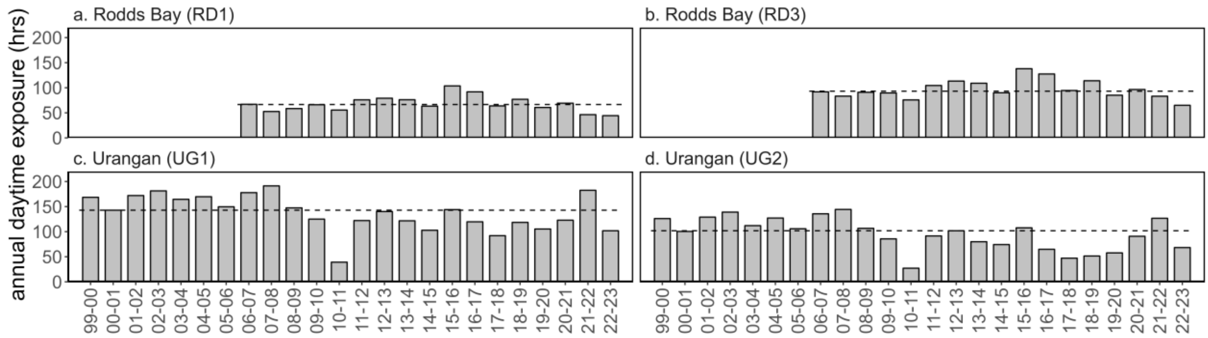

Figure 97. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of estuarine intertidal seagrass meadows in the Burnett–Mary NRM region; 1999–2023. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2023.

A2.1.2 Light at seagrass canopy

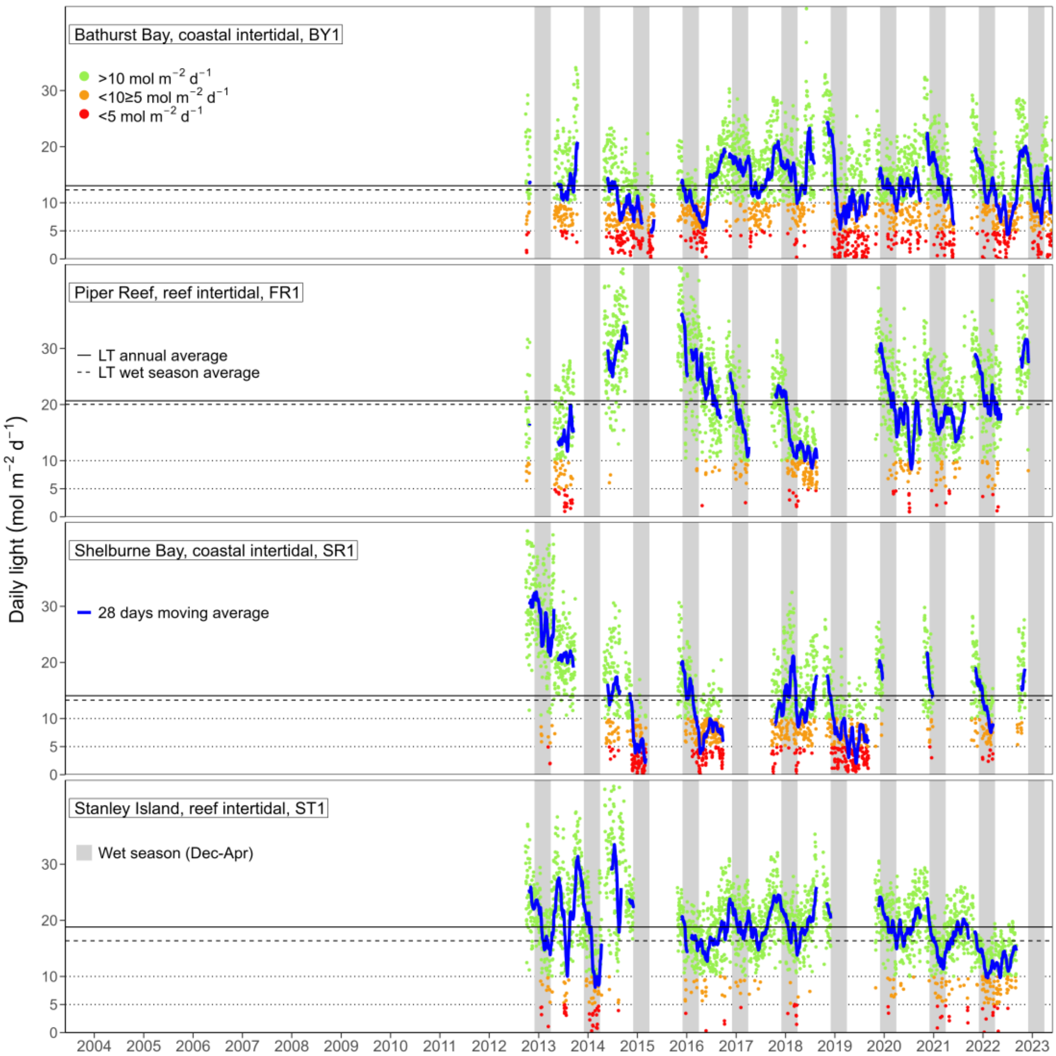

Figure 98. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in the Cape York NRM region.

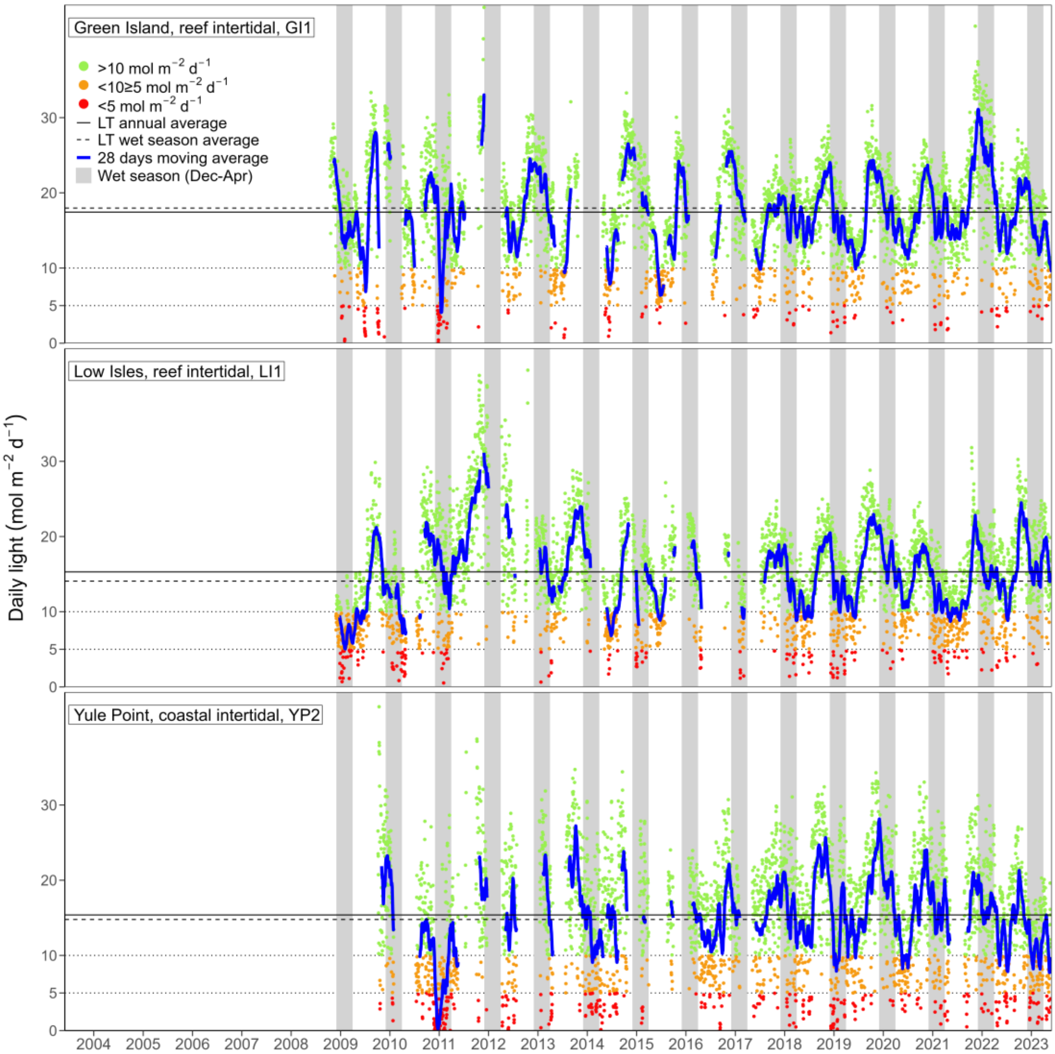

Figure 99. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in northern Wet Tropics region.

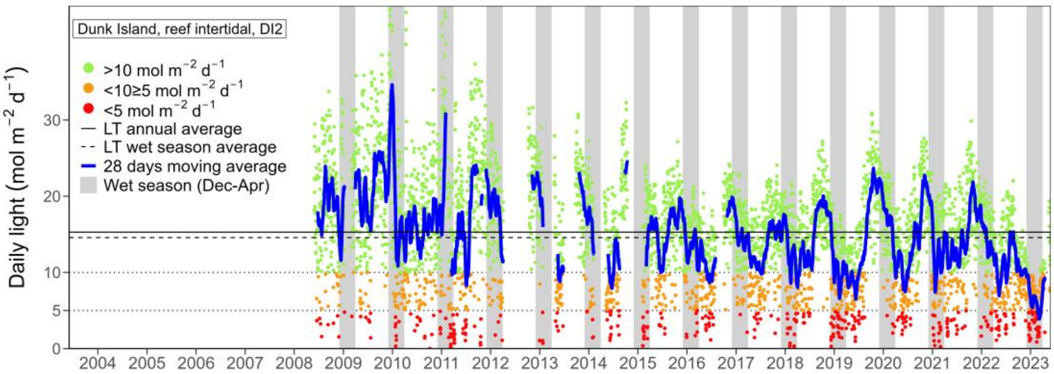

Figure 100. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in the southern Wet Tropics region.

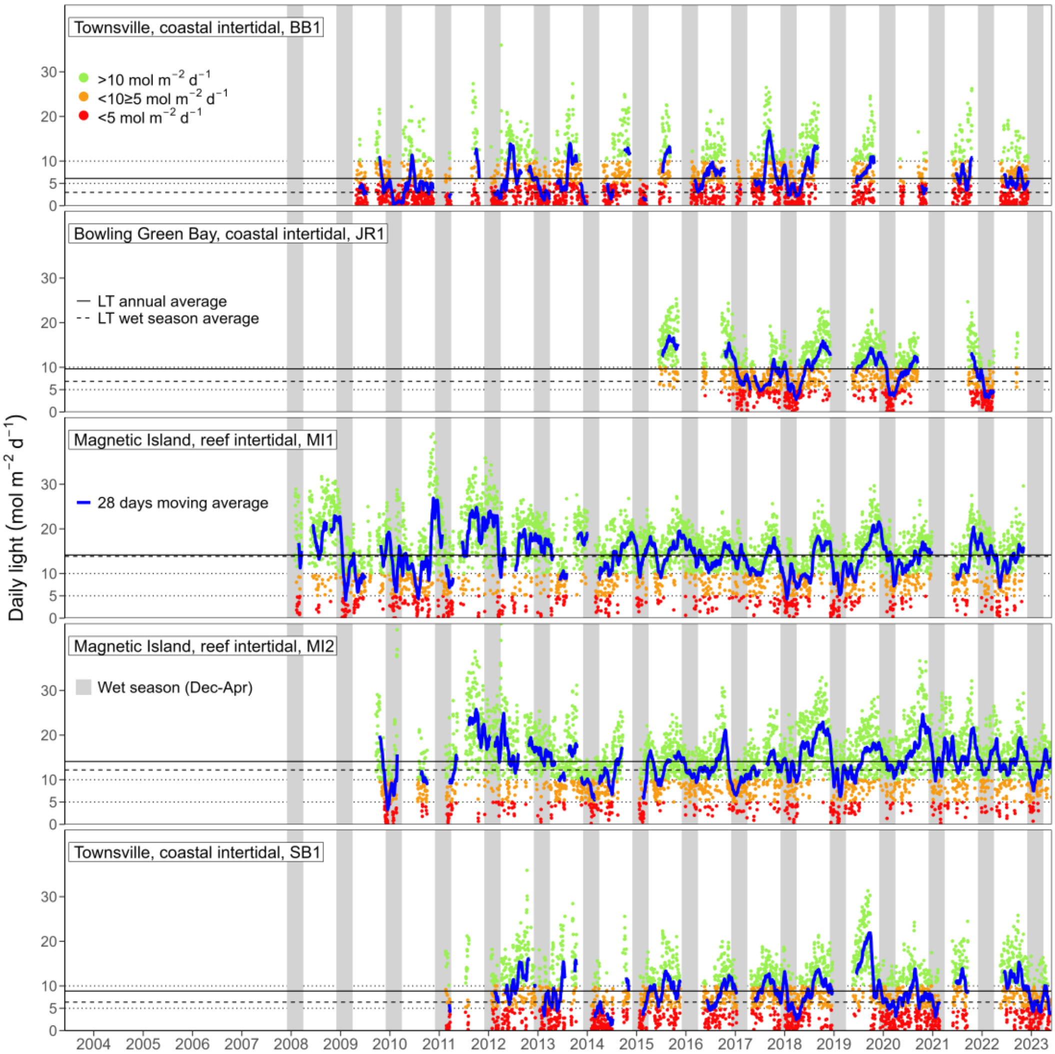

Figure 101. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in the Burdekin region.

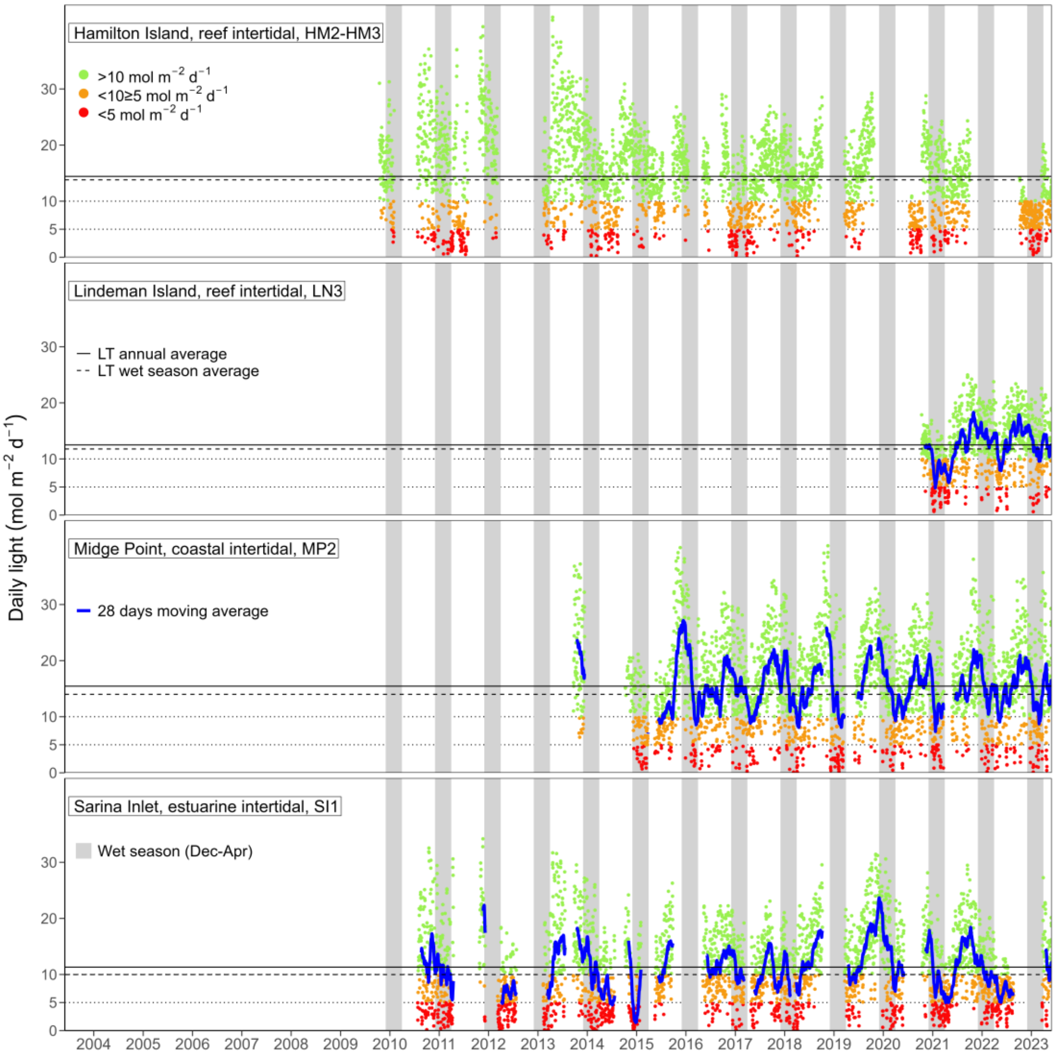
Hamilton Island, reef intertidal, HM2-HM3
>10 mol m⁻² d⁻¹
<10≥5 mol m⁻² d⁻¹
<5 mol m⁻² d⁻¹
Lindeman Island, reef intertidal, LN3
LT annual average
LT wet season average
Midge Point, coastal intertidal, MP2
28 days moving average
Sarina Inlet, estuarine intertidal, SI1
Wet season (Dec-Apr)
Daily light (mol m⁻² d⁻¹)
0
5
10
20
30
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023

Figure 102. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in the Mackay–Whitsunday NRM region.

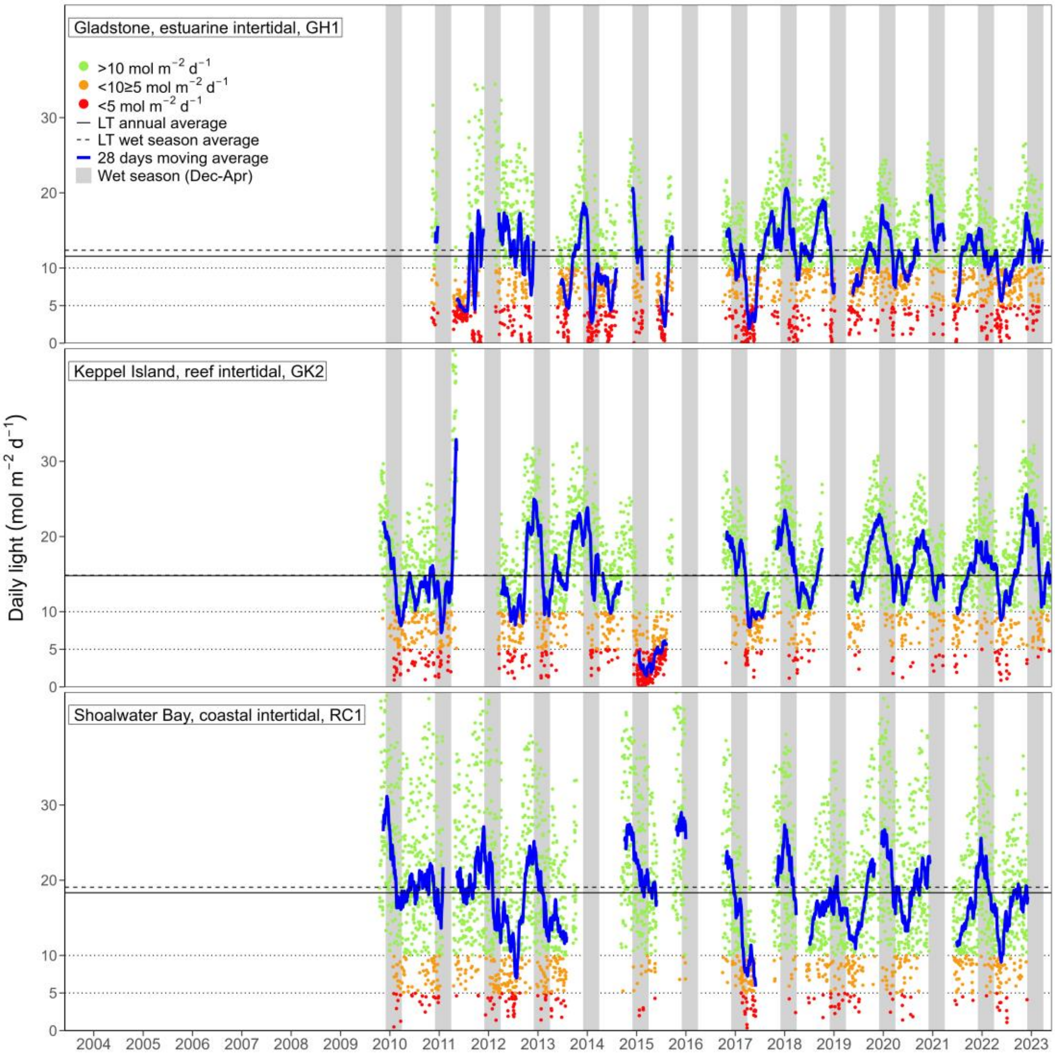

Figure 103. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in the Fitzroy NRM region.

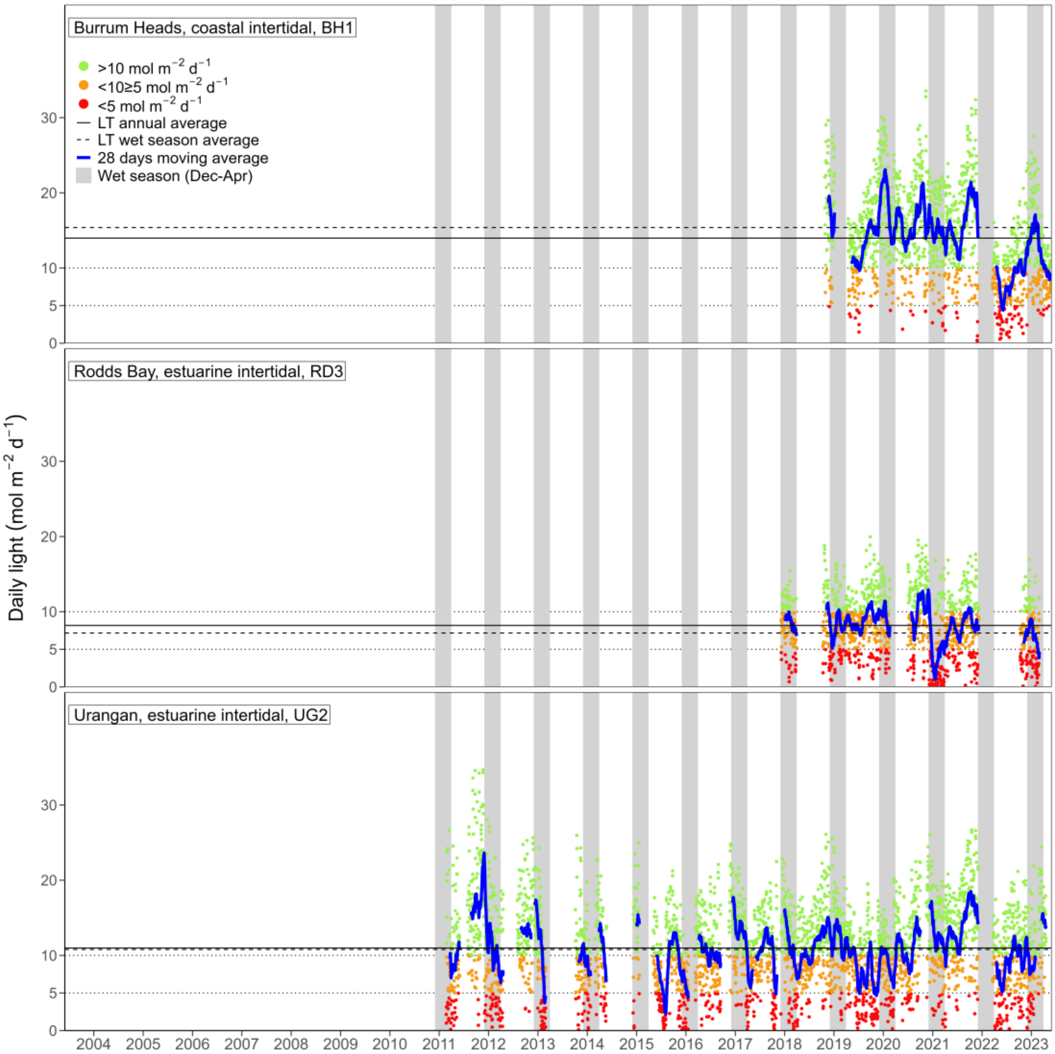

Figure 104. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in the Burnett–Mary NRM region.

A2.2 Seagrass habitat condition: Sediments composition

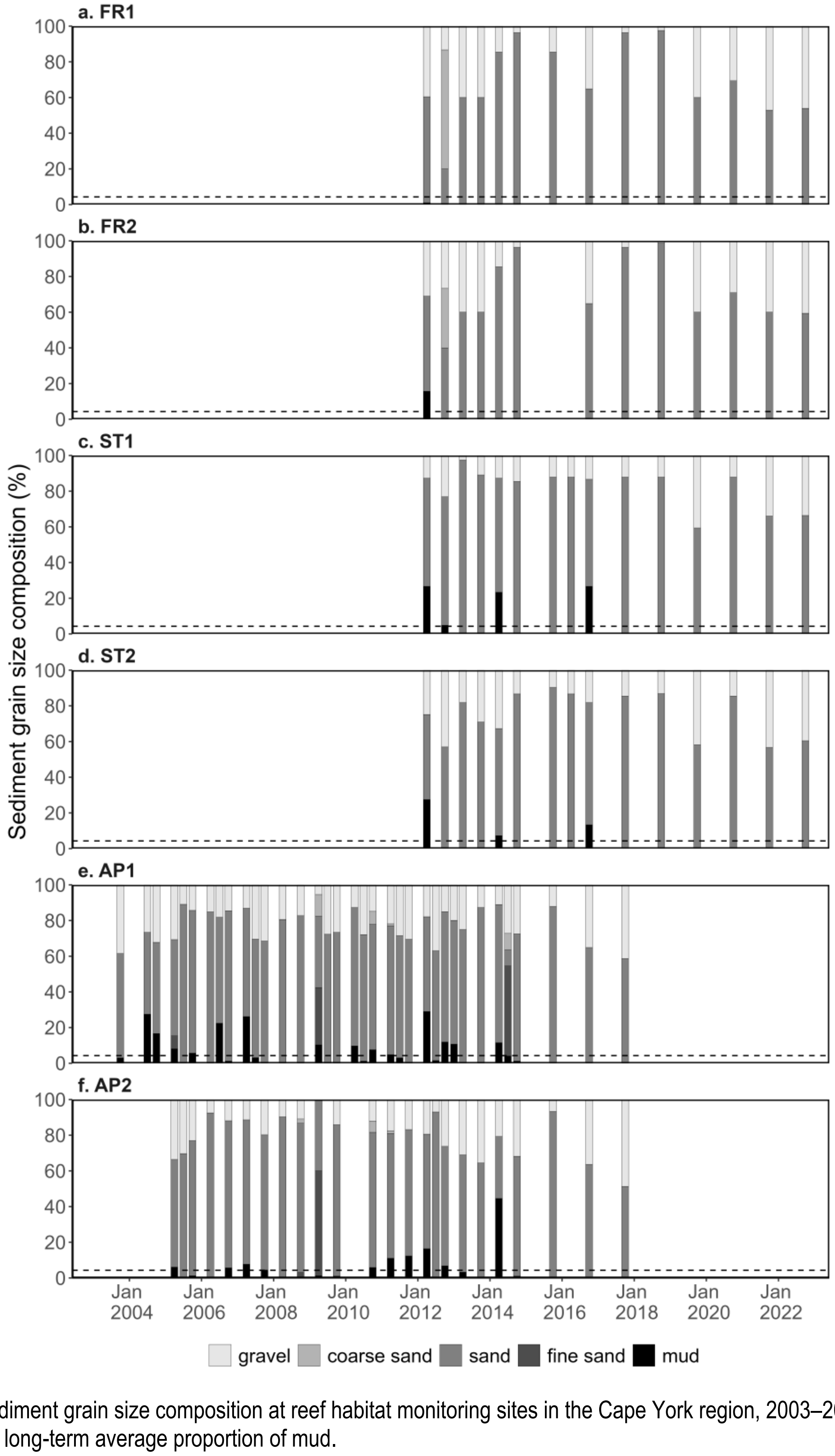

Figure 105. Sediment grain size composition at reef habitat monitoring sites in the Cape York region, 2003–2023. Dashed line is the Reef long-term average proportion of mud.

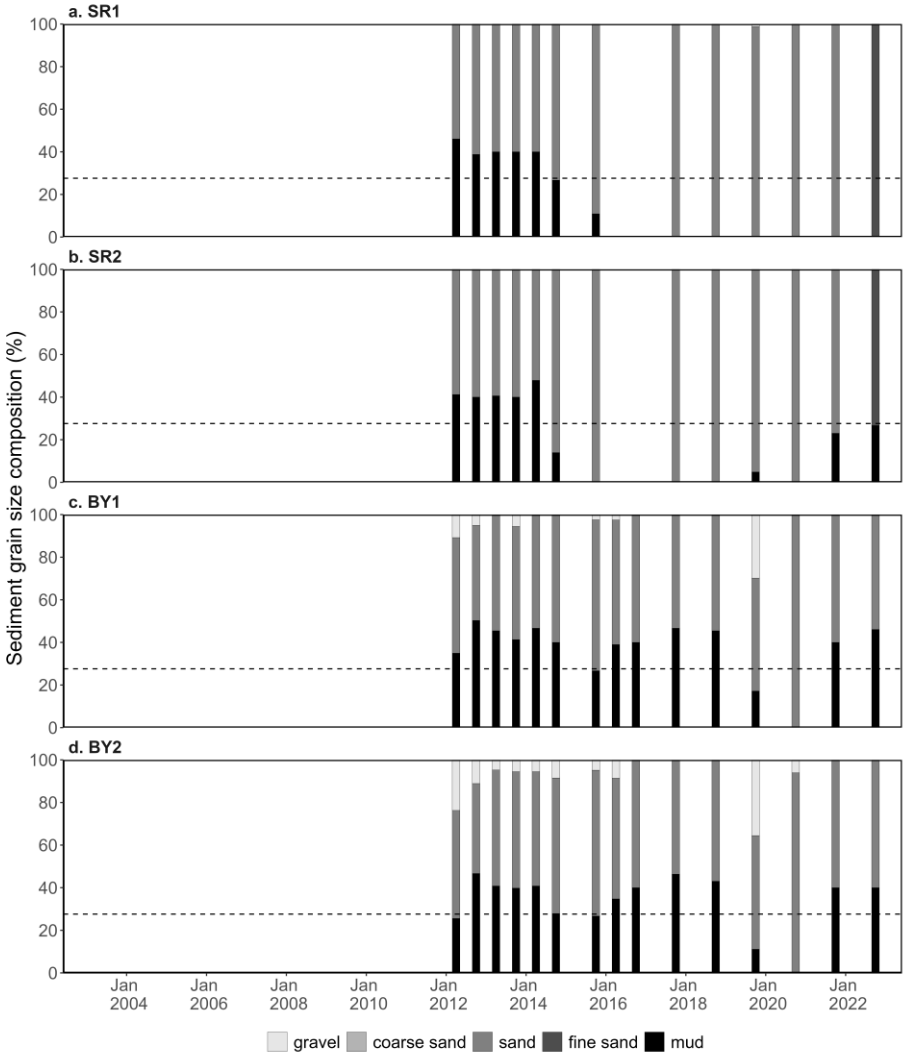

Figure 106. Sediment grain size composition at coastal habitat monitoring sites in the Cape York region, 2012–-2023. Dashed line is the Reef long-term average proportion of mud.

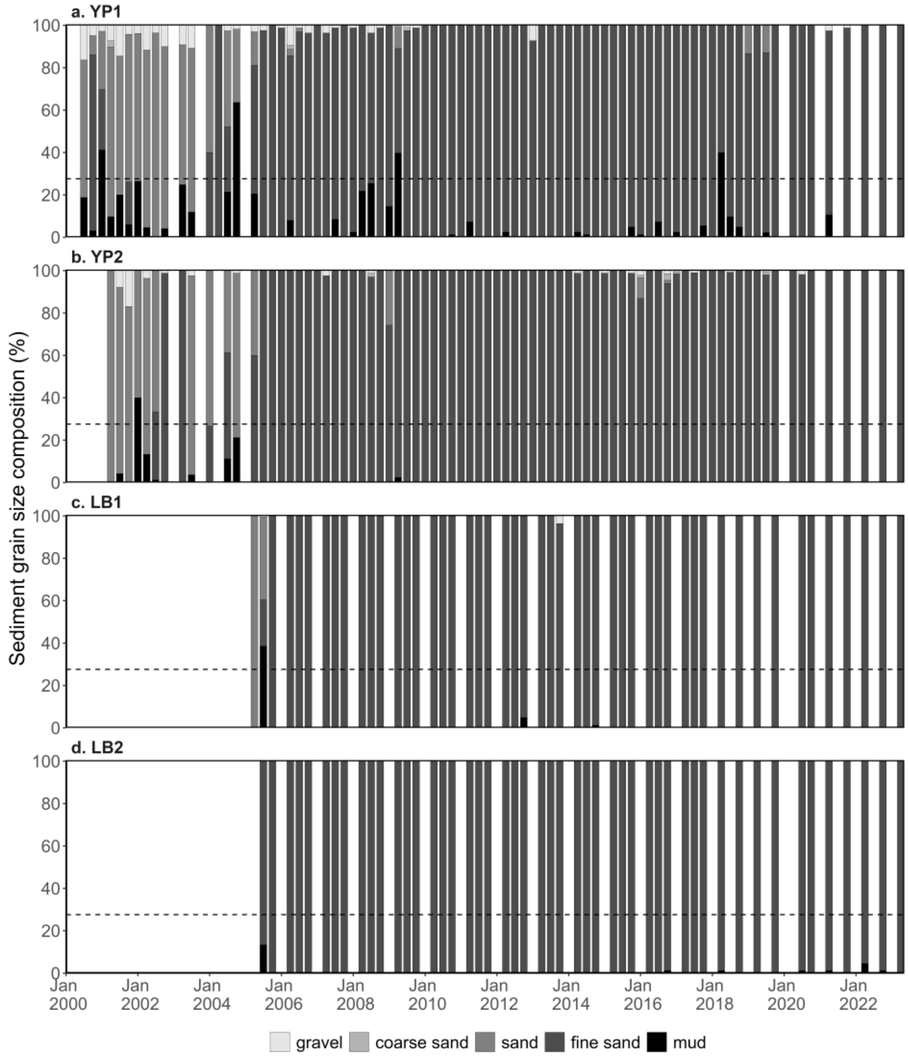

Figure 107. Sediment grain size composition at coastal intertidal habitat monitoring sites in the Wet Tropics region, 2001–2023. Dashed line is the Reef long-term average proportion of mud.

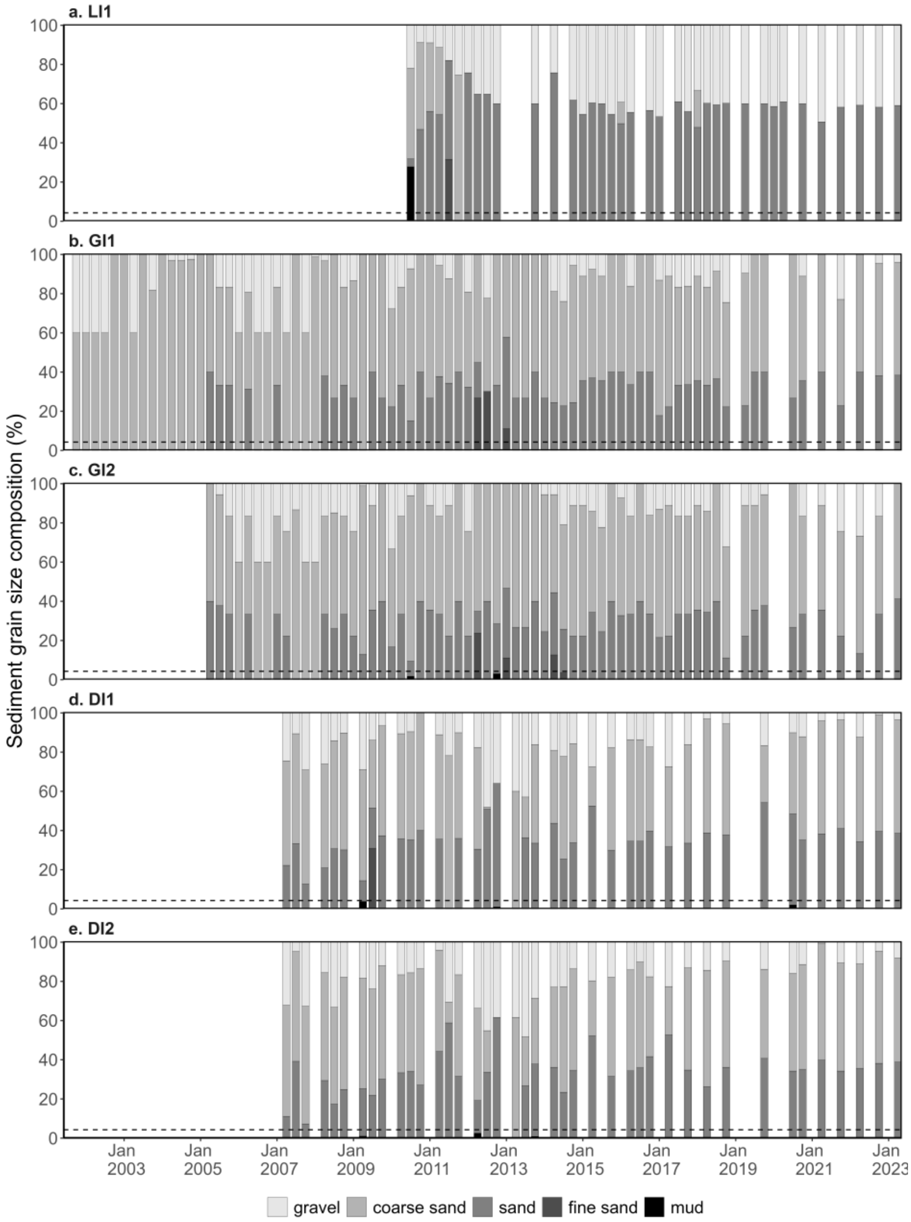

Figure 108. Sediment grain size composition at intertidal reef habitat monitoring sites in the Wet Tropics region, 2001–2023. Dashed line is the Reef long-term average proportion of mud.

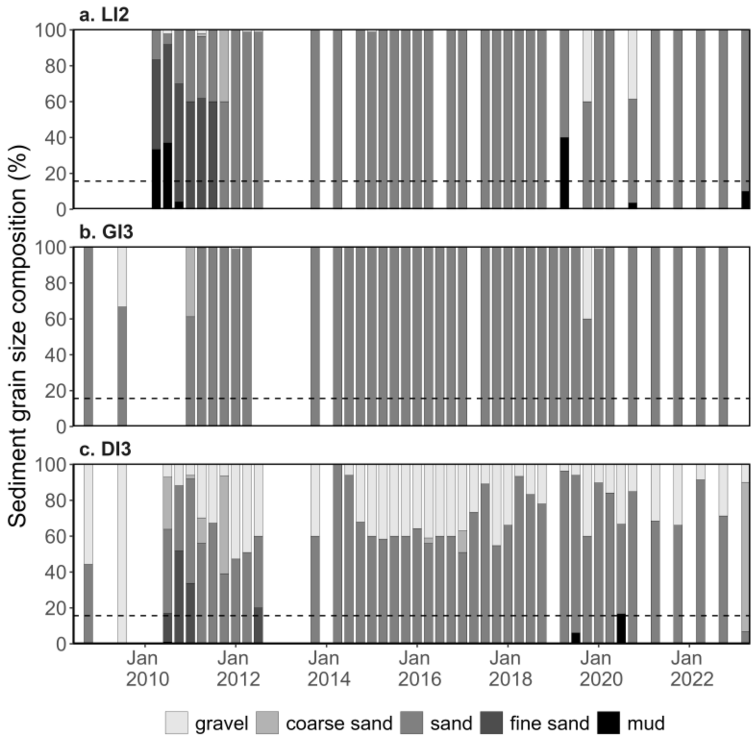

Figure 109. Sediment grain size composition at subtidal reef habitat monitoring sites in the Wet Tropics region, 2008–2023. Dashed line is the Reef long-term average proportion of mud.

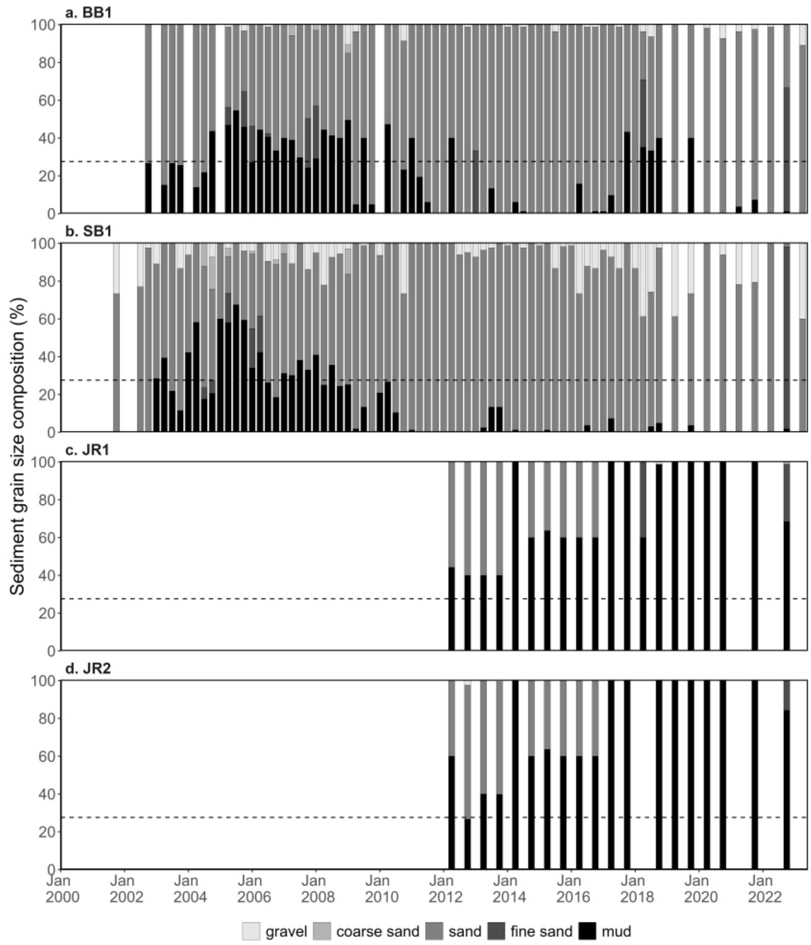

Figure 110. Sediment grain size composition at coastal intertidal habitat monitoring sites in the Burdekin region, 2001–2023. Dashed line is the Reef long-term average proportion of mud.

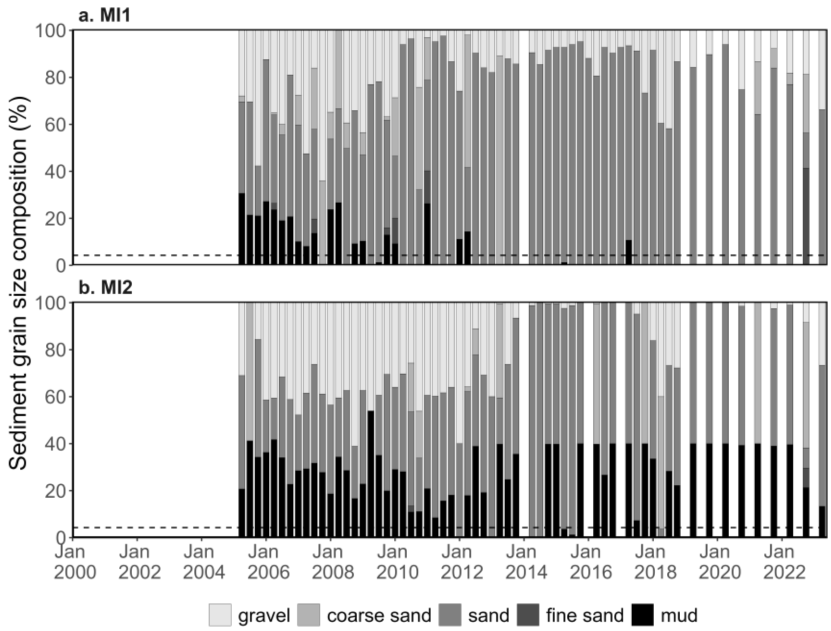

Figure 111. Sediment grain size composition at intertidal reef habitat monitoring sites in the Burdekin region, 2004–2023. Dashed line is the Reef long-term average proportion of mud.

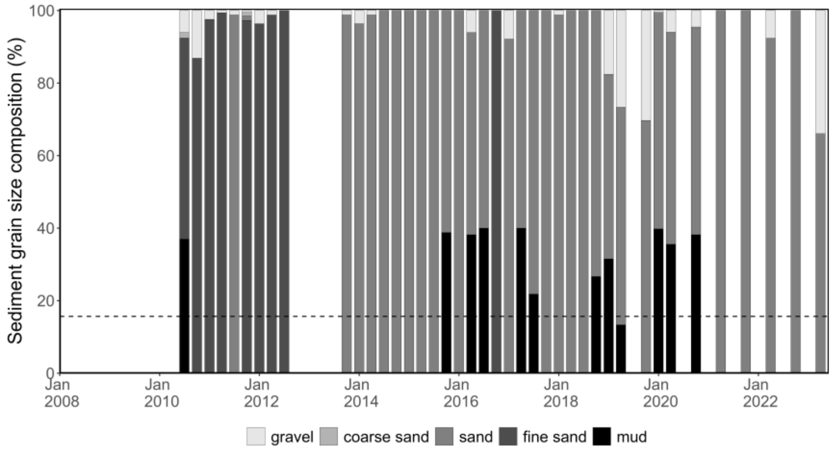

Figure 112. Sediment grain size composition at subtidal reef habitat monitoring sites in the Burdekin region, 2010–2023. Dashed line is the Reef long-term average proportion of mud.

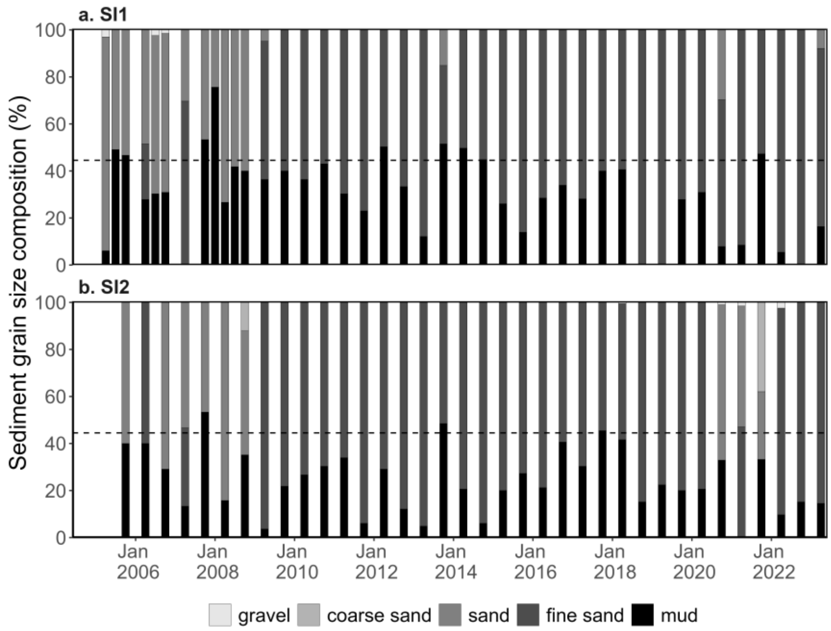

Figure 113. Sediment grain size composition at intertidal estuarine habitat monitoring sites in the Mackay–Whitsunday region, 2005–2023. Dashed line is the Reef long-term average proportion of mud.

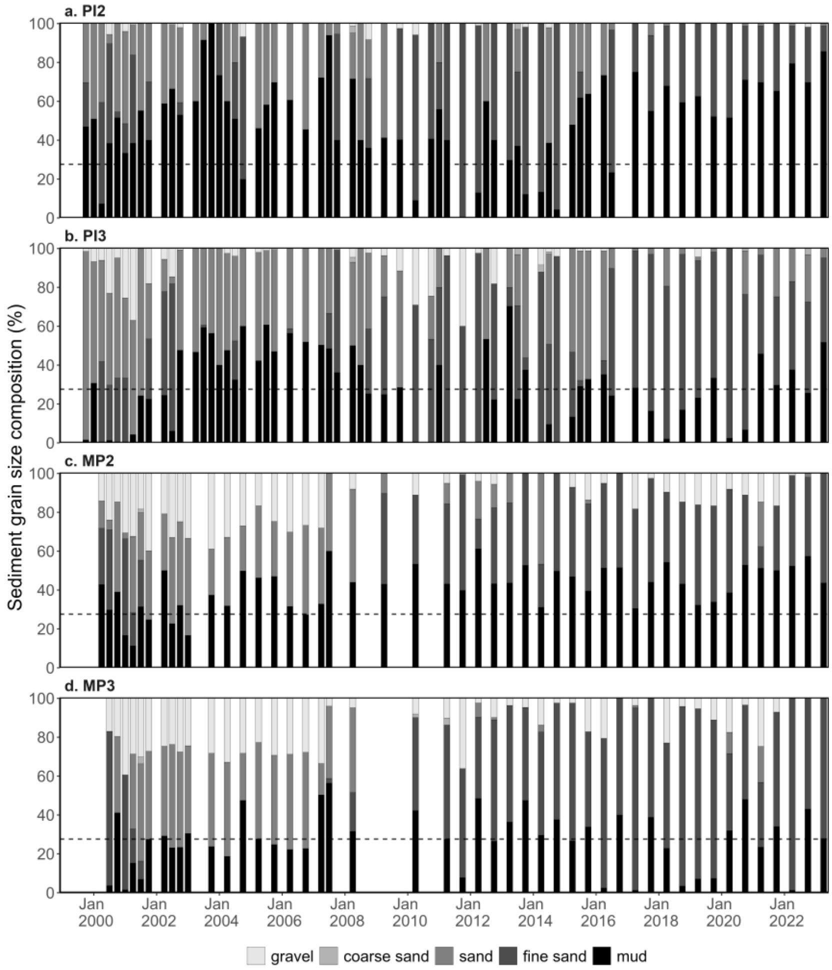

Figure 114. Sediment grain size composition at coastal intertidal habitat monitoring sites in the Mackay–Whitsunday region, 1999–2023. Dashed line is the Reef long-term average proportion of mud.

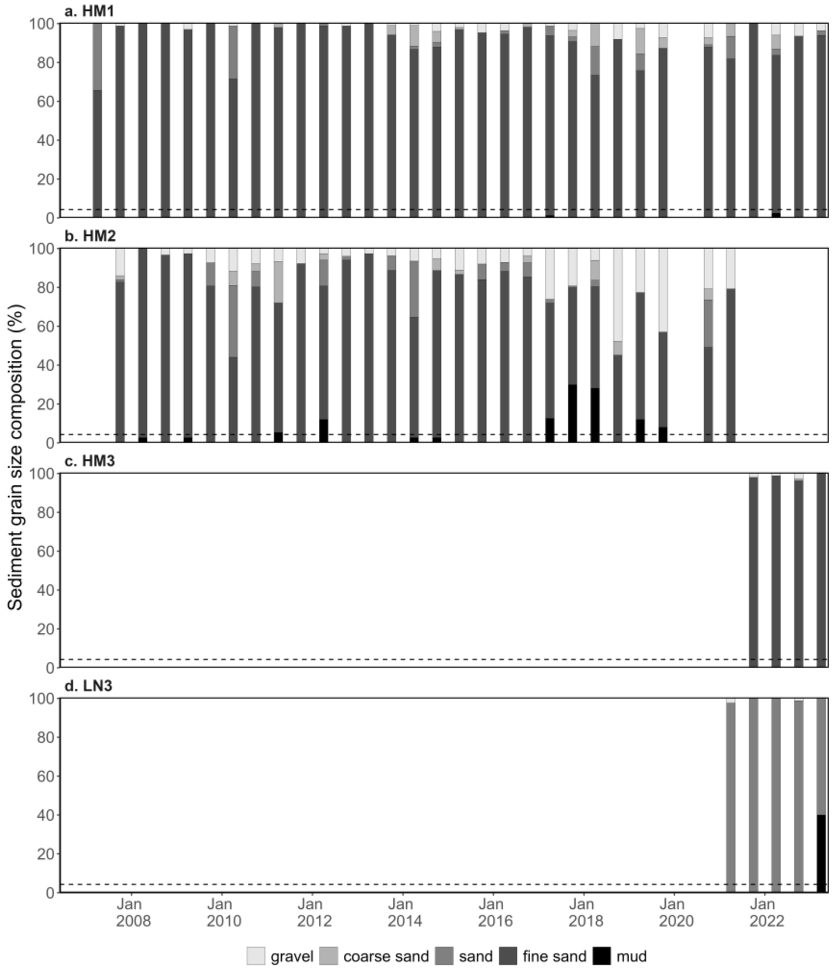

Figure 115. Sediment grain size composition at reef intertidal habitat monitoring sites in the Mackay–Whitsunday region, 2007–2023. Dashed line is the Reef long-term average proportion of mud.

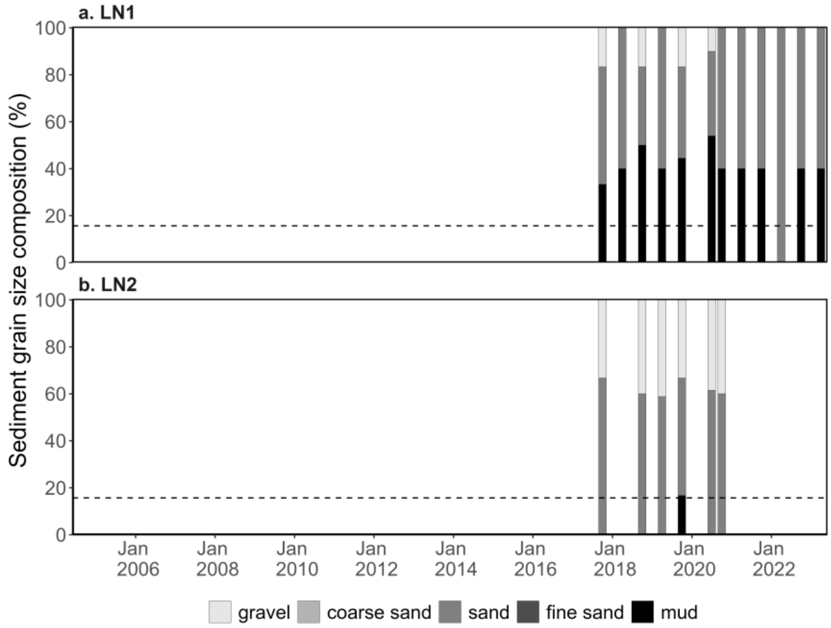

Figure 116. Sediment grain size composition at reef subtidal habitat monitoring sites in the Mackay–Whitsunday region, 2017–2023. Dashed line is the Reef long-term average proportion of mud.

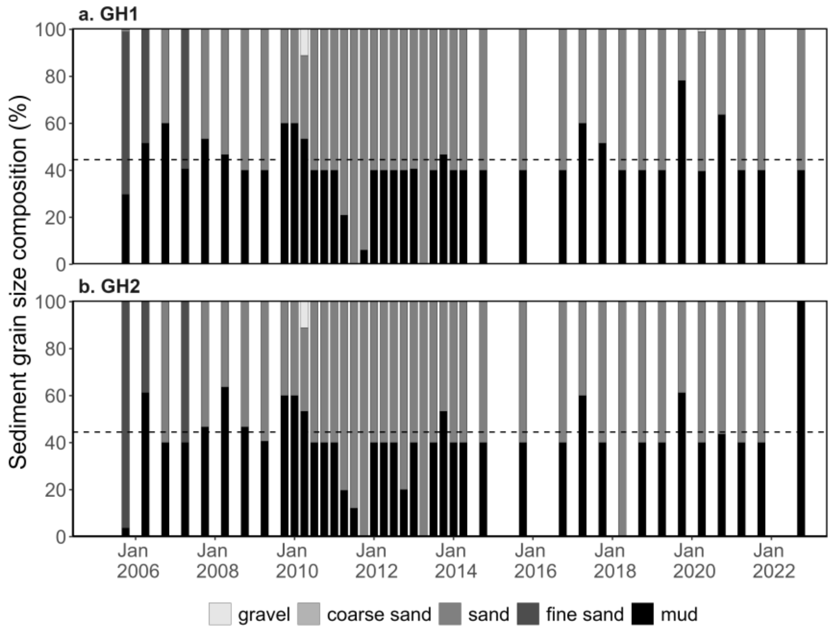

Figure 117. Sediment grain size composition at estuarine intertidal habitat monitoring sites in the Fitzroy region, 2005–2022. Dashed line is the Reef long-term average proportion of mud.

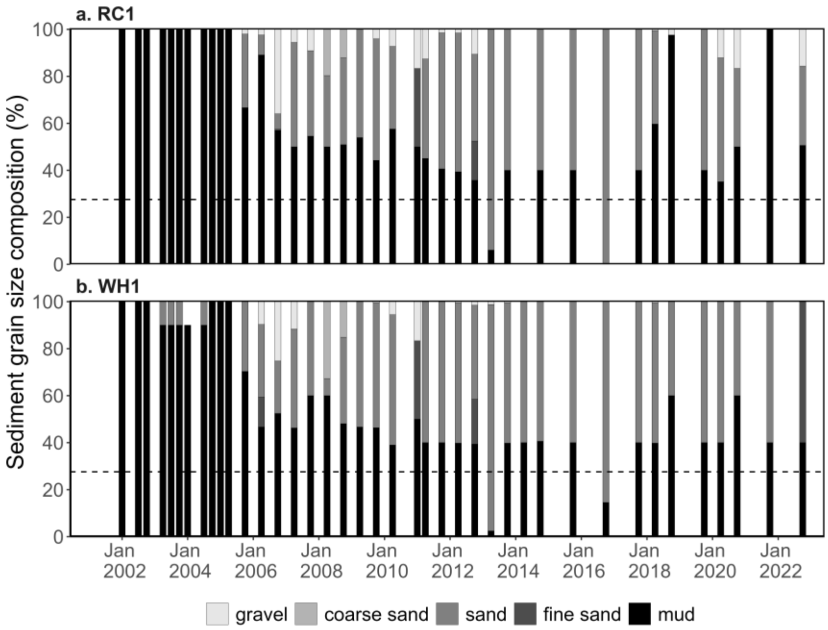

Figure 118. Sediment grain size composition at coastal intertidal habitat monitoring sites in the Fitzroy region, 2002–2023. Dashed line is the Reef long-term average proportion of mud.

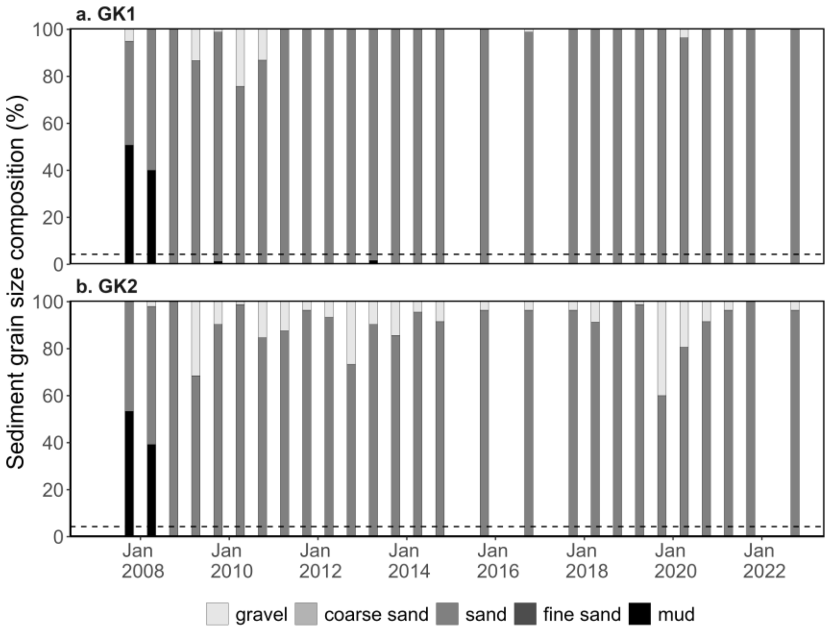

Figure 119. Sediment grain size composition at reef intertidal habitat monitoring sites in the Fitzroy region, 2007–2023. Dashed line is the Reef long-term average proportion of mud.

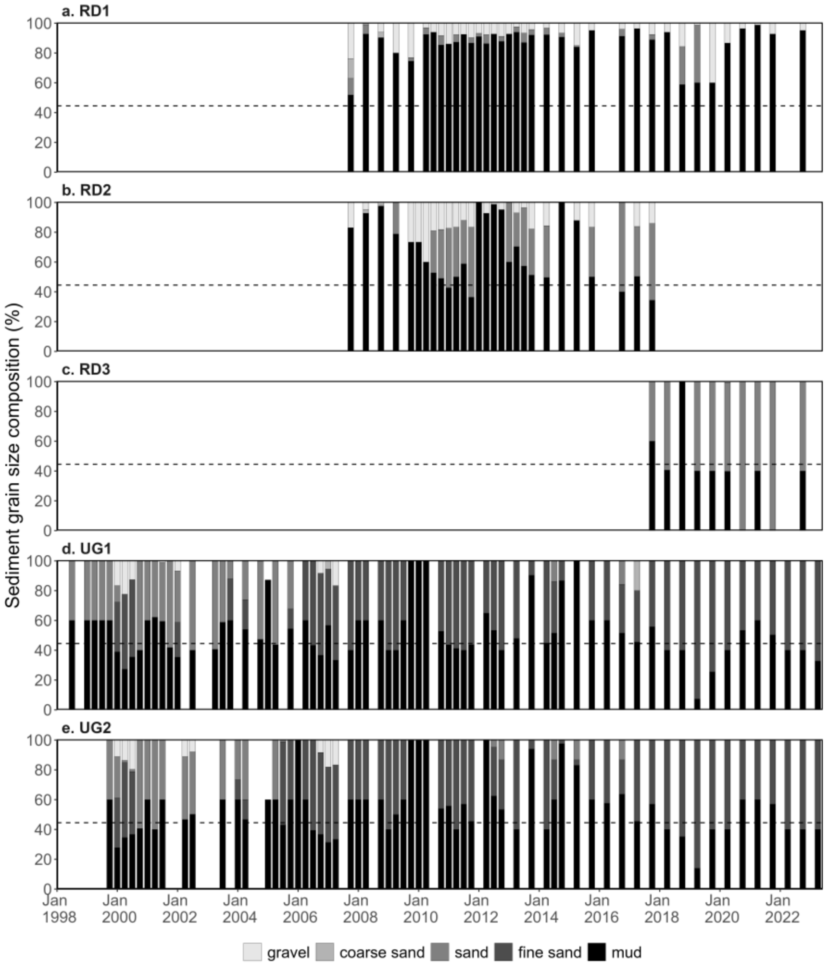

Figure 120. Sediment grain size composition at estuarine intertidal habitat monitoring sites in the Burnett–Mary region, 1999–2023. Dashed line is the Reef long-term average proportion of mud.

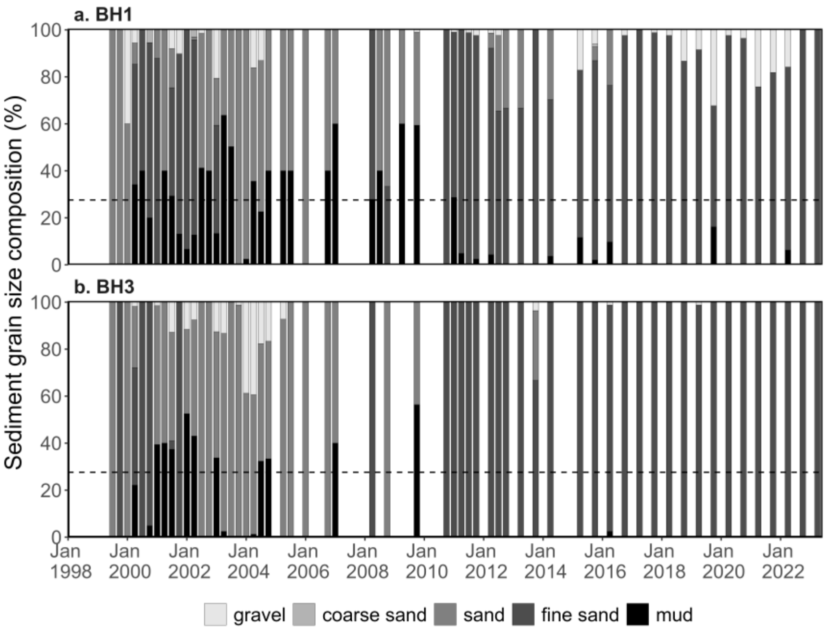

Figure 121. Sediment grain size composition at coastal intertidal habitat monitoring sites in the Burnett–Mary region, 1999–2023. Dashed line is the Reef long-term average proportion of mud.

Appendix 3 Results of statistical analysis

Table 22. Results of Mann-Kendall analysis to assess for a significant trend (decline or increase) over time in seagrass abundance (per cent cover).The reported output of the tests performed are Kendall's tau coefficient (Kendall-τ), two-sided p-value (significant at α = 0.05 in bold), the Sen's slope (showing sign and strength of trend –confidence intervals if significant) and the long-term trend.

NRM region	Habitat	Site	First Year	Last Year	*n*	*Kendall-τ*	*p* (2-sided)	Sen's slope (confidence interval)	trend
Cape York	coastal intertidal	BY1	2012	2022	15	-0.010	1.000	-0.028	no trend
		BY2	2012	2022	15	0.124	0.553	0.348	no trend
		SR1	2012	2022	13	-0.308	0.161	-0.423	no trend
		SR2	2012	2022	13	-0.013	1.000	-0.002	no trend
	coastal subtidal	BY3	2019	2021	3	1.000	0.296	5.658	no trend
		BY4	2017	2022	5	-0.400	0.462	-3.699	no trend
		LR1	2015	2022	7	0.238	0.548	1.125	no trend
		LR2	2015	2021	6	-0.200	0.707	-2.794	no trend
	reef intertidal	**AP1**	2003	2017	35	**-0.459**	**<0.001**	**-0.533** (-0.763 to -0.283)	**decrease**
		AP2	2005	2017	24	-0.022	0.901	-0.031	no trend
		FR1	2012	2022	14	-0.309	0.139	-0.246	no trend
		FR2	2012	2022	13	**-0.564**	**0.009**	**-1.286** (-1.909 to -0.655)	**decrease**
		ST1	2012	2022	15	**0.486**	**0.013**	**0.585** (0.165 to 0.951)	**Increase**
		ST2	2012	2022	15	**0.708**	**<0.001**	**0.697** (0.511 to 0.892)	**increase**
		YY1	2012	2014	3	0.333	1.000	1.045	no trend
	reef subtidal	FG1	2016	2022	7	-0.333	0.368	-1.945	no trend
		FG2	2016	2022	7	-0.333	0.368	-1.700	no trend
	pooled		2003	2022	41	**-0.366**	**0.001**	**-0.236** (-0.367 to -0.083)	**decrease**
Wet Tropics	coastal intertidal	**LB1**	**2005**	**2023**	**50**	**-0.370**	**<0.001**	**-0.020** (-0.067 to 0)	**decrease**
		LB2	**2005**	**2023**	**49**	**-0.229**	**0.027**	**-0.017** (-0.060 to 0)	**decrease**
		YP1	**2000**	**2023**	**83**	**0.205**	**0.006**	**0.133** (0.037 to 0.223)	**increase**
		YP2	**2001**	**2023**	**79**	**0.178**	**0.021**	**0.080** (0.012 to 0.144)	**increase**
	coastal subtidal	MS1	2017	2022	6	-0.333	0.452	-1.824	no trend
		MS2	2015	2022	7	0.333	0.368	1.889	no trend
	reef intertidal	DI1	2007	2023	41	0.095	0.387	0.044	no trend

NRM region	Habitat	Site	First Year	Last Year	*n*	*Kendall-τ*	*p* (2-sided)	Sen's slope (confidence interval)	trend
		DI2	2007	2023	41	0.109	0.323	0.083	no trend
		GI1	2001	2023	79	-0.071	0.358	-0.038	no trend
		GI2	2005	2023	65	0.027	0.756	0.018	no trend
		GO1	2008	2016	7	-0.429	0.230	-1.682	no trend
		LI1	2008	2023	47	-0.177	0.081	-0.067	no trend
	reef subtidal	DI3	2008	2023	53	0.030	0.759	0.002	no trend
		GI3	**2008**	**2022**	**49**	**-0.226**	**0.022**	**-0.321 (-0.567 to -0.058)**	**decrease**
		LI2	2008	2023	47	0.178	0.080	0.085	no trend
	pooled		2000	2023	92	-0.116	0.102	-0.049	no trend
Burdekin	coastal intertidal	BB1	2002	2023	70	-0.014	0.863	-0.011	no trend
		SB1	2001	2023	76	0.005	0.950	0.003	no trend
		SB2	2001	2023	74	-0.156	0.051	-0.129	no trend
		JR1	2012	2022	20	0.147	0.381	0.482	no trend
		JR2	2012	2022	19	0.287	0.093	0.928	no trend
		BW1	2019	2020	3	-1.000	0.296	-0.445	no trend
		BW2	2019	2023	8	0.000	1.000	-0.074	no trend
		BW3	2021	2023	5	0.000	1.000	-0.061	no trend
	reef intertidal	MI1	2005	2023	63	-0.059	0.495	-0.070	no trend
		MI2	**2005**	**2023**	**61**	**-0.258**	**0.003**	**-0.430 (-0.683 to -0.139)**	**decrease**
	reef subtidal	MI3	2008	2023	54	-0.050	0.602	-0.102	no trend
	pooled		2001	2023	83	-0.078	0.296	-0.057	no trend
Mackay Whitsunday	estuarine intertidal	SI1	2005	2023	41	-0.188	0.086	-0.151	no trend
		SI2	2005	2023	36	0.111	0.347	0.067	no trend
	coastal intertidal	**MP2**	**2000**	**2023**	**48**	**0.324**	**0.001**	**0.226** (0.101 to 0.337)	**increase**
		MP3	**2000**	**2023**	**46**	**0.204**	**0.047**	**0.135** (0.006 to 0.257)	**increase**
		PI2	**1999**	**2023**	**64**	**-0.337**	**<0.001**	**-0.272** (-0.404 to -0.157)	**decrease**
		PI3	1999	2023	64	-0.095	0.271	-0.060	no trend

NRM region	Habitat	Site	First Year	Last Year	*n*	*Kendall-τ*	*p* (2-sided)	Sen's slope (confidence interval)	trend
		CV1	2017	2023	12	0.212	0.373	0.196	no trend
		CV2	2017	2023	12	0.000	1.000	0.004	no trend
		SH1	2017	2023	13	0.487	0.024	1.968	no trend
		LL1	2022	2023	3	-0.333	1	-4.258	no trend
	coastal subtidal	NB1	2015	2022	8	-0.500	0.108	-5.124	no trend
		NB2	2015	2022	8	0.429	0.174	2.028	no trend
	reef intertidal	HB1	2000	2023	50	-0.091	0.358	-0.054	no trend
		HB2	2000	2023	49	0.060	0.552	0.032	no trend
		HM1	2007	2023	32	-0.363	0.004	**-0.153** (-0.312 to -0.065)	**decrease**
		HM2	2007	2021	27	-0.448	0.001	**-0.141** (-0.282 to-0.054)	**decrease**
		HM3	2021	2023	4	-0.333	0.734	-0.294	no trend
		LN3	2021	2023	5	-0.400	0.462	-0.876	no trend
	reef subtidal	TO1	2015	2022	8	0.071	0.902	0.879	no trend
		TO2	2015	2022	8	0.711	0.335	-3.549	no trend
		CH4	2000	2022	15	-0.581	0.003	**-2.812** (-4.167 to -1.019)	**decrease**
		WB1	1999	2022	3	-1.000	0.296	-12.107	no trend
		WB3	2000	2022	16	-0.192	0.321	-0.206	no trend
		LN1	2017	2023	12	-0.061	0.837	-0.202	no trend
		LN2	2017	2020	6	0.333	0.452	0.313	no trend
	pooled		1999	2023	78	**-0.277**	**<0.001**	**-0.105** (-0.162 to -0.053)	**decrease**
Fitzroy	estuarine intertidal	**GH1**	**2005**	**2022**	**41**	**-0.444**	**<0.001**	**-0.673** (-0.943 to 0.376)	**decrease**
		GH2	2005	2022	41	-0.179	0.101	-0.288	no trend
	coastal intertidal	RC1	2002	2022	40	-0.155	0.162	-0.219	no trend
		WH1	2002	2022	41	0.127	0.247	0.097	no trend
	reef intertidal	**GK1**	**2007**	**2022**	**27**	**-0.525**	**<0.001**	**-0.097** (-0.154 to -0.053)	**decrease**
		GK2	2007	2022	27	-0.131	0.348	-0.021	no trend
	pooled		2002	2022	53	**-0.406**	**<0.001**	**-0.235** (-0.331 to -0.140)	**decrease**

NRM region	Habitat	Site	First Year	Last Year	*n*	*Kendall-τ*	*p* (2-sided)	Sen's slope (confidence interval)	trend
Burnett Mary	estuarine intertidal	RD1	2007	2022	36	0.096	0.421	0.004	no trend
		RD2	**2007**	**2017**	**28**	**-0.409**	**0.003**	**-0.009** (-0.096 to -0.001)	**decrease**
		RD3	2017	2022	10	-0.378	0.152	-0.588	no trend
		UG1	1998	2023	69	0.034	0.689	0.000	no trend
		UG2	1999	2023	65	0.104	0.225	0.011	no trend
	coastal intertidal	BH1	1999	2023	60	0.016	0.863	0.012	no trend
		BH3	**1999**	**2023**	**58**	**0.284**	**0.002**	**0.126** (0.052 to 0.187)	**increase**
	pooled		1998	2023	83	-0.030	0.692	-0.012	no trend

Table 23. Resilience score and resilience score category for each site in 2022–23.

Cape York

MMP Site	Resilience score	Resilience score category	% Colonising species > 50%	% cover < low cover threshold	Reproduction structures present (all species)	Reproduction structures present (foundational species)	Reproduction history (last 3 years)	Persistent species present
BY1	65	2.1.2	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
BY2	36	2.1.1	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE
FR1	15	1.1	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE
FR2	15	1.2	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
SR1	30	2.1.1	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
SR2	7	1.1	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE
ST1	70	2.1.2	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
ST2	50	2.1.1	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE

Northern Wet Tropics

MMP Site	Resilience score	Resilience score category	% Colonising species > 50%	% cover < low cover threshold	Reproduction structures present (all species)	Reproduction structures present (foundational species)	Reproduction history (last 3 years)	Persistent species present
GI1	30	2.1.1	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE
GI2	100	2.2.2	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE
GI3	100	2.2.2	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE
LI1	6	1.2	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE
LI2	5	1.2	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
YP1	73	2.2.1	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE
YP2	78	2.2.1	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE

Southern Wet Tropics

MMP Site	Resilience score	Resilience score category	% Colonising species > 50%	% cover < low cover threshold	Reproduction structures present (all species)	Reproduction structures present (foundational species)	Reproduction history (last 3 years)	Persistent species present
DI1	100	2.2.2	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE
DI2	88	2.2.2	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE
DI3	30	2.1.1	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE

LB1	15	1.1	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
LB2	15	1.1	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE

Burdekin

MMP Site	Resilience score	Resilience score category	% Colonising species > 50%	% cover < low cover threshold	Reproduction structures present (all species)	Reproduction structures present (foundational species)	Reproduction history (last 3 years)	Persistent species present
BB1	50	2.1.2	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
JR1	50	2.1.2	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
JR2	74	2.2.1	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE
MI1	86	2.2.2	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE
MI2	5	1.2	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE
MI3	50	2.1.2	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE
SB1	50	2.1.2	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE

Mackay-Whitsunday

MMP Site	Resilience score	Resilience score category	% Colonising species > 50%	% cover < low cover threshold	Reproduction structures present (all species)	Reproduction structures present (foundational species)	Reproduction history (last 3 years)	Persistent species present
HM1	30	2.1.1	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
HM3	3	1.1	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE
LN1	70	2.2.1	FALSE	FALSE	TRUE	TRUE	TRUE	FALSE
LN3	14	1.1	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE
MP2	92	2.2.1	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE
MP3	87	2.2.1	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE
SI1	71	2.2.1	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE
SI2	90	2.2.1	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE

Fitzroy

MMP Site	Resilience score	Resilience score category	% Colonising species > 50%	% cover < low cover threshold	Reproduction structures present (all species)	Reproduction structures present (foundational species)	Reproduction history (last 3 years)	Persistent species present
GH1	71	2.2.1	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE
GH2	10	1.2	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE
GK1	0	1.1	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE
GK2	5	1.1	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE
RC1	30	1.2	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE
WH1	50	2.1.2	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE

Burnett-Mary

MMP Site	Resilience score	Resilience score category	% Colonising species > 50%	% cover < low cover threshold	Reproduction structures present (all species)	Reproduction structures present (foundational species)	Reproduction history (last 3 years)	Persistent species present
BH1	15	1.1	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
BH3	30	2.1.1	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
RD1	70	2.2.1	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE
RD3	15	1.1	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
UG1	0	1.1	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE
UG2	0	1.1	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE

Table 24 Results of Generalised additive models (GAMs) fitted to Reef-level abundance with habitat and NRM region as a fixed effect.

MODELS - REEF	N	EDF	CHI-SQ	*P*-VALUE	R-SQ (ADJ)	DEVIANCE EXPLAINED
% cover = s(date)	92	22.347	5478.072	<2e-16	0.559	0.731
% cover = s(date) + Habitat	334				0.502	0.807
Estuarine intertidal		22.467	1457.302	<2e-16		
Coastal intertidal		20.417	1007.170	<2e-16		
Coastal subtidal		2.438	14.006	0.002		
Reef intertidal		14.560	1013.783	<2e-16		
Reef subtidal		16.809	509.476	<2e-16		
% cover = s(date) + NRM	413				0.599	0.798
Cape York		6.488	60.301	<2e-16		
Wet Tropics		17.066	747.729	<2e-16		
Burdekin		19.371	1263.378	<2e-16		
Mackay Whitsunday		19.858	561.460	<2e-16		
Fitzroy		4.987	247.304	<2e-16		
Burnett Mary		22.387	1248.256	<2e-16		

Table 25 Results of Generalised additive models (GAMs) fitted to NRM region-level abundance with habitat, location or site as a fixed effect.

MODELS PER NRM REGIONS	N	EDF	CHI-SQ	*P*-VALUE	R-SQ (ADJ)	DEVIANCE EXPLAINED
Cape York						
% cover = s(date)	41	9.767	230.962	<2e-16	0.420	0.512
% cover = s(date) + Habitat	70				0.561	0.755
Coastal intertidal		3.452	15.251	0.003		
Coastal subtidal		2.232	34.269	0.000		
Reef intertidal		6.435	157.059	<2e-16		
Reef subtidal		2.874	85.839	<2e-16		
% cover = s(date) + Location	116				0.550	0.814
Coastal intertidal [BY]		3.106	6.301	0.123		
Coastal intertidal [SR]		1.023	0.092	0.815		
Coastal subtidal [BY]		1.784	28.714	<0.001		
Coastal subtidal [LR]		2.201	10.001	0.007		
Coastal subtidal [MA]		1.000	0.123	0.726		
Reef intertidal [AP]		5.840	67.073	<2e-16		
Reef intertidal [FR]		1.000	10.829	0.001		
Reef intertidal [ST]		1.975	9.170	0.008		
Reef intertidal [YY]		1.416	0.179	0.823		
Reef subtidal [FG]		2.741	50.287	<0.001		
% cover = s(date) + Site						
AP1	35	5.154	46.941	<2e-16	0.603	0.687
AP2	24	2.646	8.547	0.042	0.269	0.340
BY1	15	1.620	0.595	0.761	0.007	0.108
BY2	15	4.378	13.536	0.027	0.514	0.687
BY3						
BY4	5	2.673	11.113	0.012	-0.047	0.969
FG1	7	4.254	113.765	<2e-16	0.923	0.987
FG2	7	2.960	18.073	0.001	0.554	0.941
FR1	14	2.917	8.793	0.049	0.402	0.545
FR2	13	1.000	29.121	<2e-16	0.716	0.748
LR1	7	1.000	0.894	0.345	-0.092	0.130
LR2	6	2.753	8.877	0.036	-0.066	0.865
MA1						
MA2						
SR1	13	2.074	5.059	0.152	0.287	0.364
SR2	13	5.570	38.607	<0.001	0.771	0.857
ST1	15	3.437	32.337	<0.001	0.687	0.766
ST2	15	2.541	66.043	<2e-16	0.825	0.871
YY1						
Northern Wet Tropics						
% cover = s(date)	87	15.780	392.673	<2e-16	0.358	0.519
% cover = s(date) + Habitat	215				0.706	0.764
Coastal intertidal		13.071	224.313	<2e-16		
Reef intertidal		11.400	231.132	<2e-16		
Reef subtidal		10.325	50.983	0.000		
% cover = s(date) + Location	305				0.827	0.911
Coastal intertidal [YP]		12.466	194.996	<2e-16		
Reef intertidal [GI]		5.653	48.751	<2e-16		
Reef intertidal [LI1]		3.306	28.756	<0.001		
Reef subtidal [GI3]		5.023	63.645	<2e-16		
Reef subtidal [LI2]		7.335	137.939	<2e-16		

MODELS PER NRM REGIONS	N	EDF	CHI-SQ	*P*-VALUE	R-SQ (ADJ)	DEVIANCE EXPLAINED
% cover = s(date) + Site						
GI1	79	3.156	11.473	0.024	0.118	0.156
GI2	65	4.747	23.775	<0.001	0.281	0.337
GI3	49	4.584	53.024	<2e-16	0.520	0.587
LI1	47	4.011	41.280	<2e-16	0.475	0.512
LI2	47	5.317	61.902	<2e-16	0.339	0.643
YP1	83	10.429	100.832	<2e-16	0.552	0.704
YP2	79	8.404	47.256	<0.001	0.334	0.478
Southern Wet Tropics						
% cover = s(date)	64	15.353	1322.297	<2e-16	0.721	0.917
% cover = s(date) + Habitat	151				0.914	0.987
Coastal intertidal		14.008	1097.439	<2e-16		
Coastal subtidal		2.560	3.120	0.293		
Reef intertidal		12.424	699.118	<2e-16		
Reef subtidal		12.217	283.662	<2e-16		
% cover = s(date) + Location	158				0.920	0.988
Coastal intertidal [LB]		13.626	1112.693	<2e-16		
Coastal subtidal [MS]		2.571	3.118	0.291		
Reef intertidal [DI]		12.477	568.205	<2e-16		
Reef intertidal [GO]		5.492	176.754	<2e-16		
Reef subtidal [DI3]		12.614	285.241	<2e-16		
% cover = s(date) + Site						
DI1	41	10.087	252.520	<2e-16	0.892	0.963
DI2	41	9.880	238.125	<2e-16	0.827	0.962
DI3	53	11.758	263.662	<2e-16	0.735	0.964
GO1	7	2.941	42.018	<2e-16	0.923	0.905
LB1	50	9.960	494.863	<2e-16	0.902	0.979
LB2	49	8.927	264.139	<2e-16	0.772	0.950
MS1	6	1.000	1.230	0.267	0.014	0.223
MS2	7	1.000	1.712	0.191	-0.051	0.251
Burdekin						
% cover = s(date)	81	19.410	1717.822	<2e-16	0.770	0.907
% cover = s(date) + Habitat	196				0.778	0.908
Coastal intertidal		18.814	756.548	<2e-16		
Reef intertidal		13.686	446.864	<2e-16		
Reef subtidal		11.812	461.058	<2e-16		
% cover = s(date) + Location	224				0.743	0.892
Coastal intertidal [BW]		1.001	4.148	0.041		
Coastal intertidal [JR]		7.899	175.344	<2e-16		
Coastal intertidal [TSV]		18.139	509.824	<2e-16		
Reef intertidal [MI]		12.936	348.041	<2e-16		
Reef subtidal [MI3]		11.234	367.990	<2e-16		
% cover = s(date) + Site						
BB1	70	13.922	226.667	<2e-16	0.729	0.941
BW1						
BW2	8	1.684	2.170	0.336	0.155	0.355
BW3	5	1.941	15.805	<0.001	0.799	0.890
JR1	20	2.534	6.896	0.090	0.233	0.371
JR2	19	3.033	15.646	0.004	0.421	0.609
MI1	63	10.713	193.733	<2e-16	0.770	0.864
MI2	61	11.010	159.211	<2e-16	0.735	0.844
MI3	54	10.336	277.244	<2e-16	0.856	0.929

MODELS PER NRM REGIONS	N	EDF	CHI-SQ	*P*-VALUE	R-SQ (ADJ)	DEVIANCE EXPLAINED
SB1	76	16.418	222.287	<2e-16	0.730	0.918
SB2	73	12.778	114.284	<2e-16	0.584	0.797
Mackay Whitsunday						
% cover = s(date)	75	19.954	869.639	<2e-16	0.447	0.684
% cover = s(date) + Habitat	188				0.626	0.861
Estuarine intertidal		14.421	248.738	<2e-16		
Coastal intertidal		18.226	266.145	<2e-16		
Coastal subtidal		6.239	39.325	<0.001		
Reef intertidal		7.579	150.980	<2e-16		
Reef subtidal		4.285	16.569	0.004		
% cover = s(date) + Location	300				0.662	0.840
Estuarine intertidal [SI]		6.886	123.550	<2e-16		
Coastal intertidal [CV]		1.000	0.275	0.600		
Coastal intertidal [LL]		1.745	1.408	0.539		
Coastal intertidal [MP]		1.518	10.379	0.003		
Coastal intertidal [PI]		8.611	154.131	<2e-16		
Coastal intertidal [SH1]		2.798	15.151	0.001		
Coastal subtidal [NB]		2.576	22.229	0.001		
Reef intertidal [HB]		6.415	47.707	<2e-16		
Reef intertidal [HM]		1.629	22.791	<0.001		
Reef intertidal [LN3]		1.000	0.218	0.639		
Reef subtidal [CH]		1.000	0.002	0.962		
Reef subtidal [LN]		1.440	0.530	0.591		
Reef subtidal [TO]		3.017	5.518	0.074		
Reef subtidal [WB]		1.000	0.026	0.873		
% cover = s(date) + Site						
CH4						
CH5						
CV1	12	1.000	1.032	0.310	0.003	0.093
CV2	12	1.000	0.029	0.866	-0.099	0.003
HB1	50	6.748	57.238	<2e-16	0.519	0.671
HB2	49	9.597	96.794	<2e-16	0.687	0.778
HM1	32	1.795	15.900	0.001	0.336	0.346
HM2	27	4.514	56.540	<2e-16	0.413	0.838
HM3	4	1.000	0.350	0.554	-0.586	0.118
LL1						
LN1	12	1.576	0.959	0.635	-0.037	0.137
LN2	6	1.282	2.395	0.283	-0.051	0.421
LN3	5	1.528	2.375	0.377	0.213	0.515
MP2	48	1.377	10.181	0.003	0.213	0.212
MP3	46	1.323	2.334	0.159	0.055	0.075
NB1	8	1.000	11.646	0.001	0.571	0.699
NB2	8	3.196	6.135	0.140	-0.007	0.697
PI2	64	7.549	49.393	<0.001	0.371	0.585
PI3	64	11.701	73.889	<2e-16	0.500	0.707
SH1	13	3.204	18.937	0.001	0.622	0.721
SI1	41	9.478	59.025	<2e-16	0.439	0.780
SI2	36	4.111	8.203	0.172	0.033	0.334
TO1	8	3.426	11.003	0.027	-0.065	0.854
TO2	8	4.416	47.455	<2e-16	0.882	0.980
WB1						
WB3						

MODELS PER NRM REGIONS	N	EDF	CHI-SQ	*P*-VALUE	R-SQ (ADJ)	DEVIANCE EXPLAINED
Fitzroy						
% cover = s(date)	52	3.782	169.388	<2e-16	0.391	0.514
% cover = s(date) + Habitat	108				0.785	0.913
Estuarine intertidal		8.664	113.295	<2e-16		
Coastal intertidal		14.136	218.361	<2e-16		
Reef intertidal		1.000	8.181	0.004		
% cover = s(date) + Location	108				0.785	0.913
Estuarine intertidal [GH]		14.131	218.040	<2e-16		
Coastal intertidal [SWB]		8.663	113.299	<2e-16		
Reef intertidal [GK]		1.000	8.311	0.004		
% cover = s(date) + Site						
GH1	41	6.017	75.493	<2e-16	0.553	0.831
GH2	41	3.521	27.333	0.000	0.224	0.571
GK1	27	1.000	21.184	0.000	0.199	0.520
GK2	27	1.000	0.661	0.416	-0.003	0.025
RC1	39	8.094	89.241	<2e-16	0.711	0.786
WH1	40	8.156	93.878	<2e-16	0.711	0.784
Burnett Mary						
% cover = s(date)	77	21.323	649.583	<2e-16	0.500	0.730
% cover = s(date) + Habitat	133				0.522	0.871
Estuarine intertidal		6.870	50.820	<2e-16		
Coastal intertidal		20.094	715.809	<2e-16		
% cover = s(date) + Location	166				0.586	0.887
Estuarine intertidal [RD]		7.662	193.410	<2e-16		
Estuarine intertidal [UG]		19.451	681.908	<2e-16		
Coastal intertidal [BH]		6.686	47.585	<0.001		
% cover = s(date) + Site						
BH1	60	7.621	55.026	<2e-16	0.461	0.588
BH3	58	5.679	40.431	<0.001	0.385	0.502
RD1	36	1.000	0.599	0.439	-0.031	0.016
RD2	28	3.794	52.498	<2e-16	0.550	0.755
RD3	10	1.000	2.939	0.086	0.137	0.268
UG1	65	11.835	164.461	<2e-16	0.544	0.876
UG2	63	10.621	134.043	<2e-16	0.547	0.846

Table 26. Results of Generalised additive models (GAMs) fitted to habitat-level abundance with NRM region as a fixed effect

MODELS PER HABITAT	N	EDF	CHI-SQ	*P*-VALUE	R-SQ (ADJ)	DEVIANCE EXPLAINED
Estuarine Intertidal						
% cover = s(date) + NRM	155				0.444	0.799
Mackay Whitsunday		6.719	59.395	<2e-16		
Fitzroy		3.406	50.544	<2e-16		
Burnett Mary		8.759	429.332	<2e-16		
Coastal Intertidal						
% cover = s(date) + NRM	347				0.556	0.741
Cape York		3.407	6.343	0.140		
Wet Tropics		8.547	250.368	<2e-16		
Burdekin		8.316	520.513	<2e-16		
Mackay Whitsunday		8.659	135.588	<2e-16		
Fitzroy		6.778	76.765	<2e-16		
Burnett Mary		7.072	91.436	<2e-16		
Coastal Subtidal						
% cover = s(date) + NRM	22				0.166	0.699
Cape York		2.868	23.546	<0.001		
Wet Tropics		1.349	0.242	0.856		
Mackay Whitsunday		3.818	35.892	<0.001		
Reef Intertidal						
% cover = s(date) + NRM	267				0.763	0.854
Cape York		4.946	65.636	<2e-16		
Wet Tropics		7.314	575.734	<2e-16		
Burdekin		7.652	507.652	<2e-16		
Mackay Whitsunday		6.569	142.053	<2e-16		
Fitzroy		1.000	8.613	0.003		
Reef Subtidal						
% cover = s(date) + NRM	129				0.769	0.778
Cape York		8.304	332.887	<2e-16		
Wet Tropics		3.361	28.299	<0.001		
Burdekin		3.356	6.744	0.114		
Mackay Whitsunday		6.791	48.929	<2e-16		