Australian Government
Great Barrier Reef Marine Park Authority

Reef Authority

# GREAT BARRIER REEF MARINE MONITORING PROGRAM

## Inshore seagrass monitoring Annual Report 2023–24

JAMES COOK UNIVERSITY AUSTRALIA

TropWATER

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Front cover image: Researcher monitoring seagrass at Dunk Island (Wet Tropics). ©James Cook University. Photographer: Rudi Yoshida.

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:

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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 |
| GPS | Global Positioning System |
| ha | hectare |
| 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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# 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 were largely unchanged in overall condition in 2023–24, remained below the long-term average for the 5th consecutive year, with the Seagrass Index remaining **moderate** (Figure 1). Seagrass condition in the northern regions (Wet Tropics and Burdekin) declined to **poor**, whereas condition in the two southern most regions (Fitzroy and Burnett–Mary) improved to **moderate** and **poor**, respectively. Condition in the far northern (Cape York) and central (Mackay–Whitsunday) regions remained largely unchanged (with marginal declines in score) in at **moderate** state.

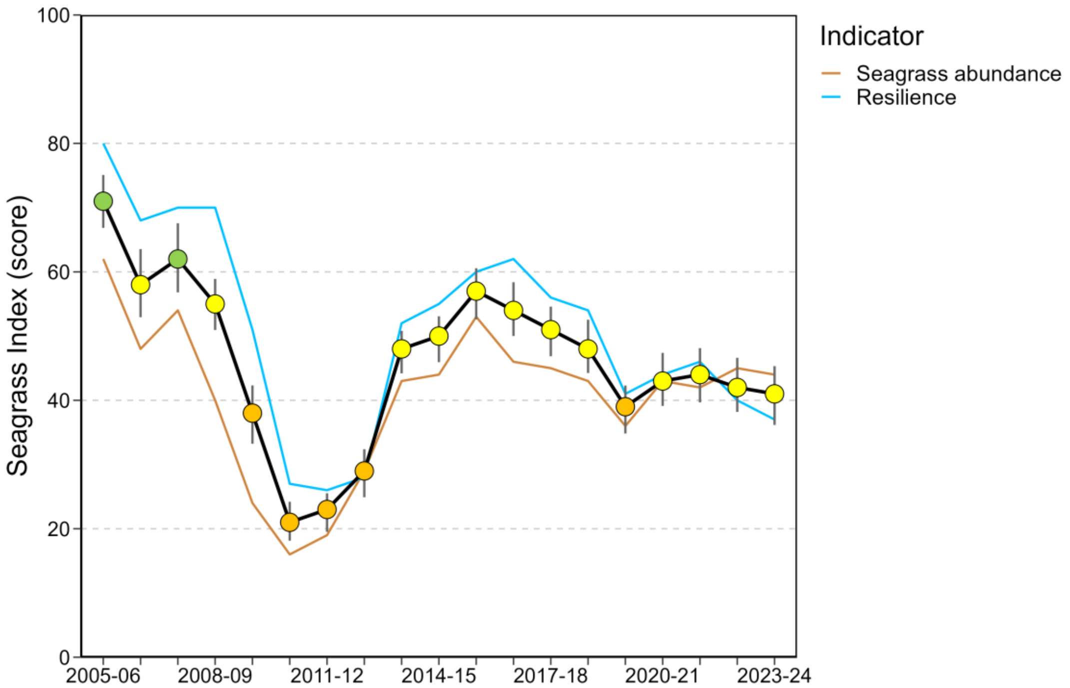



Figure 1. Overall inshore Reef Seagrass Index (±SE) with contributing indicator scores over the life of the MMP (Great Barrier Reef Marine Monitoring Program). The Index is derived from the aggregate of metric scores for indicators of seagrass condition: abundance and resilience. Index scores scaled 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 was largely unchanged in 2023–24, showing only a marginal decline in score after a slight improvement in the previous period. Abundances generally decreased in the northern regions, including Cape York, Wet Tropics, and Burdekin. Specifically, Cape York experienced a slight reduction (measured in the late dry season, before floods occurred), while in the Wet Tropics and Burdekin abundances declined from moderate to poor levels. Conversely, the Mackay–Whitsunday region recorded a slight increase in abundance, while the most notable improvements occurred in the southernmost regions of Fitzroy and Burnett–Mary.Reef-wide, around 70 per cent of the monitoring sites saw either improvement or stability in abundances in 2023–24. Over the long term, changes in Reef-wide seagrass abundance indicate periods of loss and recovery within specific regions. The decrease in seagrass abundance from 2015 to 2019 was largely attributed to losses in the Mackay–Whitsunday and Burdekin regions, while smaller declines were simultaneously observed in Cape York and the Wet Tropics. However, since 2019 and leading up to the present, the losses in the northernmost regions had 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, seagrass abundance continued to decline in all three southern regions during 2020–21. Although the declines abated in Mackay-Whitsunday, they persisted in the Fitzroy and Burnett-Mary regions up to the current period.

Resilience continued to decline in 2023–24, mirroring the overall Index, and reached its lowest score in a decade. 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. In 2023–24, resilience was moderate in the Mackay–Whitsunday and Wet Tropics regions, while all other regions were poor. The trends in the resilience score vary among regions, changing only slightly in Cape York and Mackay-Whitsunday regions, declining in the Wet Tropics and Burdekin regions and increasing in the Fitzroy and Burnett–Mary regions. Declines in overall resilience were mainly the result of deterioration in reef intertidal and subtidal habitats, which were greater than the slight improvements in estuarine and coastal habitats. Declines were the result of increasing prevalence of colonising seagrass species or abundances smaller than the threshold for resistance in Cape York, Mackay-Whitsunday, and Fitzroy regions. In the Wet Tropics, declines were the result of reduced presence of sexual reproductive structures. The largest decline was in the Burdekin region and lowest resilience score was in the Burnett–Mary region.

### Influencing pressures

Pressures affecting inshore Reef seagrass habitats varied across different regions and habitats during 2023–24. The northern Natural Resource Management (NRM) regions, including Cape York, Wet Tropics, and Burdekin, were all impacted by tropical cyclones that brought considerable rainfall, particularly in southern Cape York and the northern Wet Tropics, along with acute physical disturbance to the Burdekin. In the southern Mackay–Whitsunday region, river discharges surpassed the long-term median, while the Burnett–Mary NRM region also saw above-average rainfall resulting in river discharges that exceeded the long-term median in 2023–24.

During the 2023-24 wet season, the northern NRM regions (Cape York, Wet Tropics and parts of the Burdekin) experienced turbid coloured waters that extended further offshore than the long-term average. In contrast, other regions encountered similar or less turbid water exposure than the long-term average. The greater area of seagrass exposed to the turbid waters in the northern regions increased the risk of detrimental ecological effects.

Daily average benthic light availability during 2023-24 was below the long-term average (2008–2023) for inshore Reef seagrass meadows. Daily light was lower than average at most sites in the northern regions (Cape York, Wet Tropics and Burdekin). For the other regions, some sites had daily light levels that were above and others that were below their long-term averages, with the largest negative deviation at Rodds Bay in the south.

Within-canopy water temperatures are one of the most significant environmental pressures impacting inshore Reef seagrass meadows. In the 2023–24 period, within-canopy seawater temperature was slightly lower than the previous period, yet it remained above average for the third consecutive year, marking the seventh highest recorded temperature. Most regions had annual average temperatures that were around the long-term average, with the exception of the Burnett-Mary region, which was above average. The number of extreme heat days (days >40 °C) were the highest since monitoring was established in the Fitzroy region and second highest in the Mackay–Whitsunday. The hottest seawater temperature ever recorded since the MMP was established was 50.8 °C at Shoalwater Bay in the Fitzroy in October 2023, surpassing the previous record of 46.5 °C in the southern Mackay–

Whitsunday region in 2022–23. In contrast, the number of extreme temperature days in the Cape York, Burdekin, and Burnett-Mary regions was below average.

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 2023–24, remaining unchanged from the previous three monitoring periods. Inshore seagrass condition declined to **poor** grade in the northern NRM regions (Wet Tropics and Burdekin), whereas condition improved to **moderate** and **poor** in the two southern most regions (Fitzroy and Burnett–Mary, respectively). Condition in the far northern (Cape York) and central (Mackay–Whitsunday) regions remained largely unchanged (with marginal declines in score) in at **moderate** state.

Inshore seagrass condition scores across the regions reflect a system that is being impacted by elevated discharge from rivers, heatwaves, cyclones and local-scale disturbances. Regional differences in condition and indicator scores appear due to the legacy of significant environmental conditions. These include cyclone Debbie in Mackay–Whitsunday in 2016–17, with above-average riverine discharge throughout the southern and central Reef, and a marine heatwave in the northern and central Reef in 2018–19. There are also local-scale changes influencing regional scores, particularly in the Fitzroy region. In 2023–24, extreme elevated discharge and other associated pressures from cyclones (e.g. wind and waves) affected the northern regions (although Cape York was surveyed prior to these events). The Fitzroy and Mackay-Whitsunday regions were exposed to very high temperatures, however, the effects may not be evident in the Fitzroy until the next reporting period as it is only assessed annually, which was around the time of these temperature extremes.

Climate change is the most significant threat to the Reef’s long-term outlook, however, the 2024–24 wet season is expected to be around average, as the El Niño–Southern Oscillation (ENSO) outlook is neutral with weak signs of La Niña climatic phenomena. This may provide some relief and opportunity for buoyed seagrass recovery, particularly in the northern regions. However, chronic high local sea surface temperatures will strongly influence rainfall early in the wet season, 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 enhance the condition and resilience of these meadows. However, it is essential to explore additional strategies, such as enhancing seed banks or supplementing shoots, for strengthening resilience and restoring degraded meadows.

# 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). Comparatively, 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.

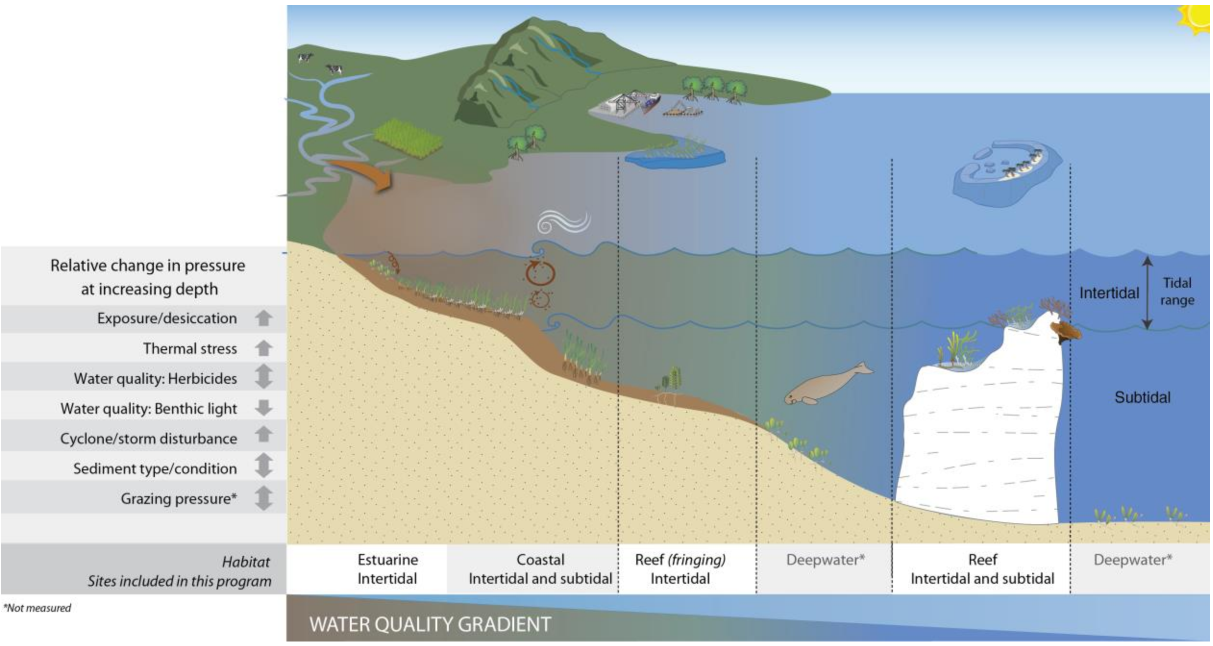



Figure 2. General conceptual model of seagrass habitats in north east Australia and the water quality impacts affecting the habitat (adapted from Carruthers *et al.* 2002, and Collier *et al.* 2014). Grey arrows indicate increase, decease or variable response with increasing depth.

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://shorturl.at/qRodx).

## 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 (Table 1).

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) (Table 1Table 1).

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.* 2016). 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 (Table 1). 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).

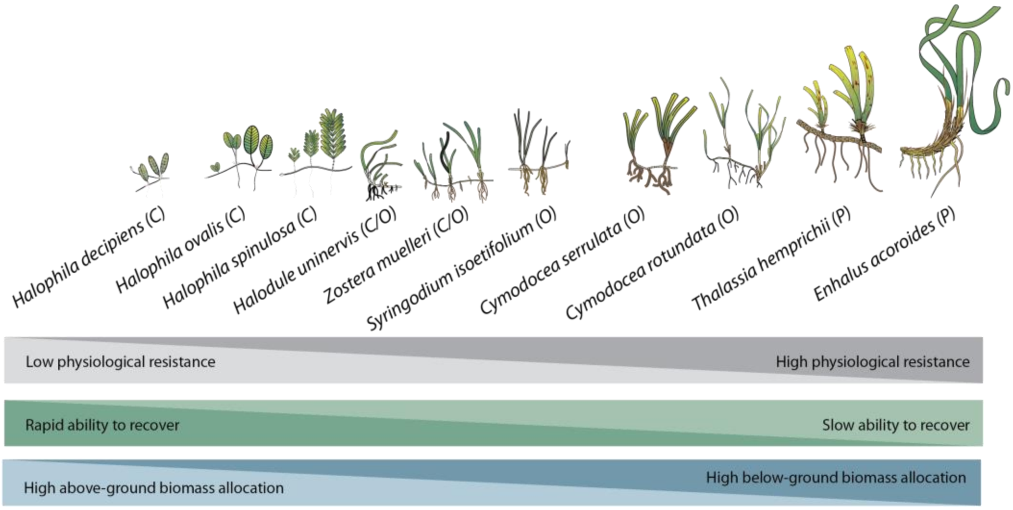



Figure 3. Dominant traits among the Reef seagrass species, with emphasis on their ability to either resist disturbances, or to recover following loss: colonising (C), opportunistic (O), or persistent (P). Adapted from Collier *et al*. (2021b) and Kilminster *et al*. (2015).

## 1.3 Structure of the Report

This report presents data from the fifteenth monitoring period for the inshore seagrass ecosystems of the Reef under the MMP (undertaken from June 2023 to May 2024; hereafter called 2023–24). 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 2023 and the late wet season (March to May) of 2024 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 2023–24, 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 Moran *et al*. (2025) 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 (Moran *et al.* 2025).

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 use 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 (Moran *et al.* 2025). 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 Moran *et al*. (2025). 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 Moran *et al.* 2025).

| 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 per cent 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 | 1968–2024 | remote sensing and observations at nearest weather station | yearly | No. $yr^{-1}$ | Bureau of Meteorology |
| Rainfall | 1889–2024* | rain gauges at nearest weather station | daily | mm $mo^{-1}$<br>mm $yr^{-1}$ | Bureau of Meteorology |
| Riverine discharge | 1970–2024 | water gauging stations at river mouth | | L $d^{-1}$<br>L $yr^{-1}$ | DES#, compiled by (from Moran *et al.* 2025) |
| Plume exposure | 2006–2024<br>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 Moran *et al.* 2025) |
| Tidal exposure | 1999–2024 | 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 | 2002–2024 | iBTag or HOBO® MX2201 | 15–90 min | °C, temperature anomalies, exceedance of thresholds | MMP Inshore Seagrass monitoring |
| Light | 2008–2024 | 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 | 1999–2024 | 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–six sites across 36 locations were assessed during the 2023–24 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 | 2023–24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |

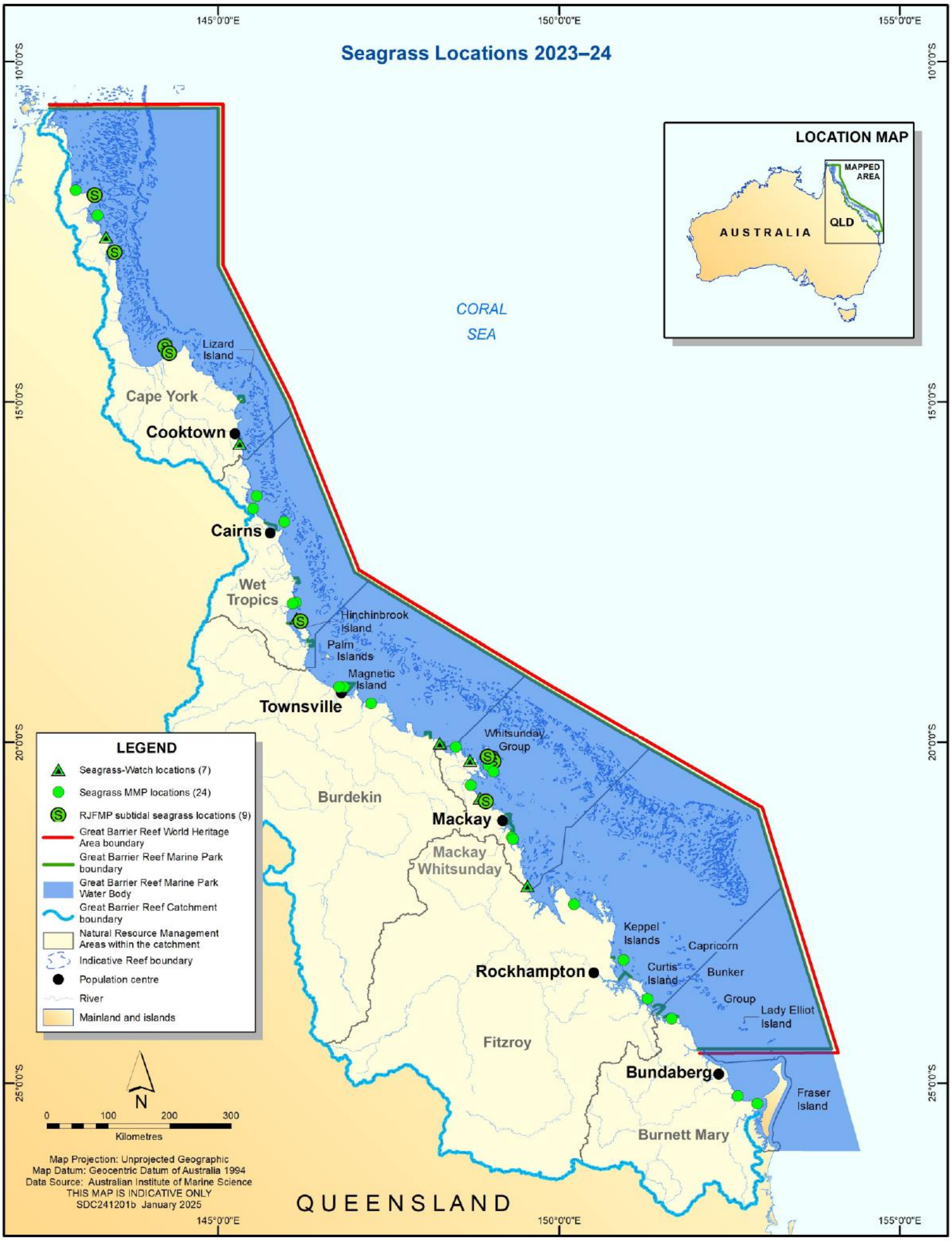



Figure 4. Inshore seagrass survey locations that exist as of 2023-24. However, not all locations were surveyed in 2023-24 (see Table 2).

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 3.42 m (Cairns) to 10.4 m (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. *Zostera, 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 *Zostera 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, Zostera, 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, an additional 15 sites from Seagrass-Watch and 18 sites from QPWS were established to improve the spatial resolution and representation of subtidal habitats (Table 6). In 2023–24, however, only 11 sites were assessed by Seagrass-Watch and 17 by QPWS (Table 20).

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 2023 and late wet 2024 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 ha area intertidally and 3.1 ha 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 2023) and late wet (March-May 2024) 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 = *Cymodocea serrulata*, EA = *Enhalus acoroides*, HD = *Halophila decipiens*, HO = *Halophila ovalis*, HS = *Halophila spinulosa*, HU = *Halodule uninervis*, SI = *Syringodium isoetifolium*, TH = *Thalassia hemprichii*, ZC = *Zostera 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 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 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 m (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.

Where permitted and when conditions were suitable (e.g., intertidal seagrass exposed with winds <20 kts and no rain), the meadows were mapped using a UAV (DJI Phantom 4 Pro V2) captured orthomosaic (McKenzie *et al.* 2022). The flight mission and image data capture was executed using the DroneDeploy app, with an altitude between 35 and 60 m and 80 % front and side overlap. The orthomosaic was produced using Pix4D or Agisoft Metashape. The resulting seagrass maps were mainly digitized in QGIS from visual interpretation of the orthomosaic. For the more complex or fragmented sites, only small representative parts were manually digitized to train a deep learning segmentation model (Unet) (McKenzie *et al.* 2022). The final maps were then obtained from the prediction from the model (probability>0.25).

### 2.2.3 Seagrass reproductive status

Seagrass reproductive state was assessed from samples collected in the late dry 2023 and late wet 2024 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 *Zostera 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 75$^{th}$ percentile
- *good*, median per cent cover at or above 50$^{th}$ percentile
- *moderate*, median per cent cover below 50$^{th}$ 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 20$^{th}$ or 10$^{th}$ percentile was used for the low guideline depended on the within-site variability; generally, the 20$^{th}$ percentile is used, unless within-site variability was low (e.g. CV<0.6), whereby the 10$^{th}$ 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 20$^{th}$ 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 = 10$^{th}$ or 20$^{th}$ 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 <20th 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 >20th percentile of site | Reproduction (foundational) not present last 3 years | Proportion of persistent species present (min <10th percentile, max 95th 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 >20th percentile of sites AND persistent species present | Reproduction (foundational) present | Reproductive structure count (min <10th percentile, max 95th 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). The R code is available on request from L.J.M. and L.A.L.

### 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-$\tau$), 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 2023–24

The following section provides detail on the overall climate and environmental pressures during the 2023–24 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

Environmental stressors for The Reef in 2023–24 were above the long-term average/median for rainfall and river discharge (Table 10), although there was significant variability across different regions. The northern NRM regions, including Cape York, Wet Tropics, and Burdekin, were all impacted by tropical cyclones that brought considerable rainfall, particularly in southern Cape York and the northern Wet Tropics, along with acute physical disturbance to the Burdekin. In the southern Mackay–Whitsunday region, river discharges surpassed the long-term median, while the Burnett–Mary NRM region also saw above-average rainfall leading to river discharges that exceeded the long-term median in 2023–24 (Moran et al. 2025).

The northern NRM regions, including Cape York, Wet Tropics, and Burdekin, experienced significant effects from tropical cyclones that caused extensive rainfall, especially in southern Cape York and the northern Wet Tropics, along with severe physical disturbances in the Burdekin area. In the southern Mackay–Whitsunday region, river discharges surpassed the long-term median, while the Burnett–Mary NRM region also saw above-average rainfall leading to river discharges that exceeded the long-term median in 2023–24.

Table 10. Summary of environmental conditions at monitoring sites across the Reef in 2023–24 compared to previous monitoring period and the long-term average (range indicated for each data set). *intertidal only.

| Environmental pressure | Long-term average | 2022–23 | 2023–24 |
|---|---|---|---|
| *Climate* | | | |
| Cyclones, number of events (1968–2023) | 4 | 0 | 2 |
| Wet season daily rainfall, mm $d^{-1}$ (1961–1990) | 4.0 | 4.1 | 4.8 |
| Riverine discharge, ML $yr^{-1}$ (1986–2016) | 51,812,207 | 83,283,163 | 104,086,500 |
| Wet season turbid water exposure, per cent (2003–2022) | 86 | 85 | 84 |
| *Within seagrass canopy* | | | |
| Temperature, °C (±) (max) (2003–2023)* | 25.7 ±0.4 (46.6) | 26.1 ±0.5 (46.5) | 25.9 ±0.3 (50.8) |
| Daily light, mol $m^{-2}$ $d^{-1}$ (2008–2023) annual average | 13.7 | 12.4 | 12.3 |
| (min site–max site) | (5.8–20.7) | (5.5–17.2) | (5.3–17.4) |
| Proportion mud, per cent | | | |
| *estuarine intertidal* (1999–2023) | 44.4 ±2.1 | 42.2 ±2.1 | 52.7 ±1.6 |
| *coastal intertidal* (1999–2023) | 27.4 ±2.1 | 22.6 ±1.7 | 30.8 ±1.7 |
| *coastal subtidal* (2015–2023) | 55.5 ±2.2 | 55.4 ±2.1 | 60.7 ±10.9 |
| *reef intertidal* (2001–2023) | 4.2 ±1.2 | 3.2 ±1.0 | 5.4 ±0.7 |
| *reef subtidal* (2008–2023) | 15.7 ±1.0 | 16.0 ±1.7 | 25.0 ±0.4 |

Long-term trends in the Water Quality Index indicate improvements in water quality in most regions examined in 2023–24 (Moran et al. 2025). The exceptions were the Cape York region where the Water Quality Index declined from ‘good’ to ‘moderate’ and the Fitzroy region which remained stable and ‘good’ (Moran et al. 2025).

Turbid coloured primary and secondary water (WT1 and WT2) dominated the water types in the wet season (December 2023–April 2024) as is characteristic of inshore conditions over the long-term. However, WT1 and WT2 extended further offshore than the long-term average in Cape York, the Wet Tropics and parts of the Burdekin regions but were narrower than average in other regions. The frequency in which the inshore seagrass monitoring sites were exposed to WT1 and WT2 was similar to the long-term average in all regions. The area of mapped seagrass exposed to water quality risk categories (II-IV) was 10 per cent higher in Cape York but unchanged for risk categories combined in other regions with some shifts in the exposure categories (Moran et al. 2025).

Daily light in 2023–24 was below the long-term Reef average. This is based on 16 of the 23 sites where light is monitored while the other 7 sites had insufficient data for inclusion in the averages. Daily light was lower than average at most sites in the northern regions (Cape York, Wet Tropics and Burdekin) except at Low Isles. For the other regions, some sites had daily light levels that were above and others that were below their long-term averages, with the largest negative deviation at Rodds Bay.

Within canopy seawater temperature in 2023–24 was the third consecutive year of above-average temperature and seventh highest on record. Most regions had annual average temperatures that were around the long-term average except for the Burnett-Mary which was above average. The number of extreme heat days (days >40 °C) were the highest since monitoring was established in the Fitzroy region and second highest in the Mackay–Whitsunday. The hottest seawater temperature ever recorded since the MMP was established was 50.8 °C at Shoalwater Bay in the Fitzroy in October 2023, which followed the previous record high of 46.5 °C in the southern Mackay–Whitsunday region in 2022–23 (Figure 11). The number of extreme temperature days was lower than average in Cape York, the Burdekin and Burnett-Mary regions.

There were two active cyclones in the 2023–24 wet season to affected Reef waters (Moran et al. 2025).

## 3.2 Cyclones

Two cyclones affected the Reef in 2023–24: Tropical Cyclones Jasper and Kirrily. Tropical Cyclone Jasper entered the Reef as a Category 2 system on 13 December 2023, resulting in intense winds, high rainfall, and flooding in coastal communities between Innisfail and Cooktown (Prasad 2024). After crossing the coast near Wujal Wujal (between Mossman and Cooktown), the cyclone quickly weakened to a tropical depression, stalling over Cape York for several days bringing major flooding for the rivers of southern Cape York and northern Wet Tropics: the Daintree River peaked at 14.85 m (previous record 12.6 m in January 2019) and the Barron River surpassed the March 1977 record of 3.8 metres, making the event the worst flooding event since records began in 1915. Overall, it was the wettest tropical cyclone, including the highest 24-hour rainfall total ever reliably measured, in Australian history (Prasad 2024).

Tropical Cyclone Kirrily entered the Reef on 25 January 2024 when it reached a peak intensity of category 3, before rapidly weakening and crossing the coast just north of Townsville as a Category 1 system later that evening (Wedd *et al.* 2024). While crossing the Reef, wind speeds reached an estimated 65 knots (120 km/h), and extended as far south as the Whitsunday Islands (Wedd *et al.* 2024). Several hours prior to landfall, the Jason-3 satellite detected altimeter Significant Wave Heights (the average of the highest 1/3rd of the wave distribution) up to 6.2 m off the coast of Townsville (Bachmeier 2024). Tide gauges along the coast between Lucinda and Mackay recorded surge values between 0.4-0.7 m, with a higher surge of around 1.1 m recorded at Cape Ferguson (Bachmeier 2024). After making landfall, Kirrily weakened rapidly, leading to heavy rainfall, as well as widespread flooding for western Queensland (Bachmeier 2024).

## 3.3 Rainfall

Rainfall across the Reef regions in the 2023–24 wet season was above the 30-year long-term average (1961 to 1990) in the far northern NRM regions (Cape York and Wet Tropics) and southern most region (Burnett-Mary). Rainfall in the Burdekin and Fitzroy regions was similar to the long-term average, and below average for the Mackay–Whitsunday region (Figure 5, Figure 6) (Moran et al. 2025).

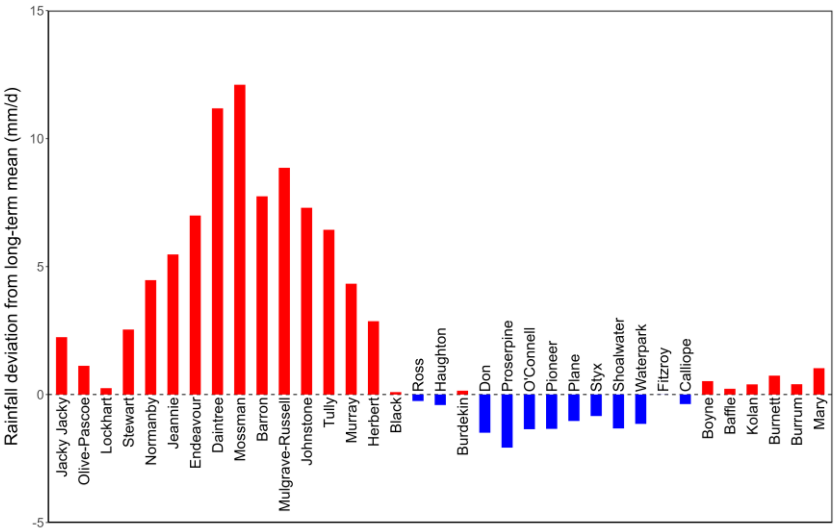



Figure 5. Per basin difference between annual average daily wet season rainfall (December 2023–April 2024) and the long-term average (1961–1990). Red and blue bars denote basins with rainfall above and below the long-term average, respectively. Note that the basins are ordered from north to south (left to right). Basins have been grouped into NRM regions as indicated by shaded panels. Compiled by Moran *et al.* 2025.

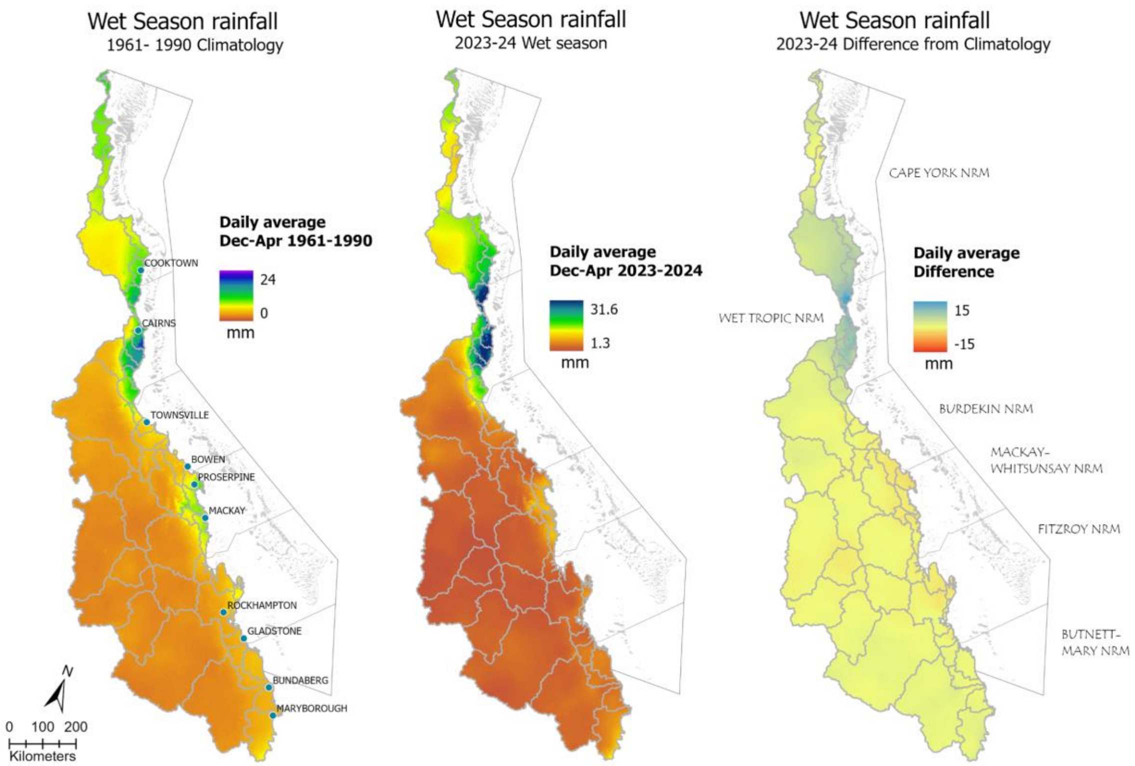



Figure 6. Average daily rainfall (mm day$^{-1}$) in the Reef catchment: (left) long-term annual average (1961–1990; time period produced by BOM), (centre) 2023–24 and (right) the difference between the long-term annual average and 2023–24 rainfall patterns where negative values indicate less rain. From Moran *et al.* 2025.

## 3.4 River discharge

The discharge of rivers into the inshore Reef is closely linked to rainfall during the wet season, significantly impacting the quality of coastal waters (Waterhouse *et al.* 2024). Annual river discharge for the Reef was above the long-term median in 2023–24, following three consecutive wet years and was the wettest since 2010–11 (Table 11). Discharges from the majority of basins entering Cape York were above the long-term median, reaching more than three times above it in the Normanby, Jeannie and Endeavour Rivers. River discharge was also similarly three times above the long-term median in the Daintree and Barron Rivers in the northern Wet Tropics, and slightly lower in the southern Wet Tropics. The Burrum River Basin (Burnett-Mary NRM) recorded discharge levels that were three times higher than the long-term median. The Waterpark Creek Basin (Fitzroy NRM region) and both the Burnett and Mary Basins (Burnett-Mary region) recorded discharges 2 to 3 times their respective long-term medians. Meanwhile, the Styx and Shoalwater Creek Basins (Fitzroy NRM) saw discharge levels ranging from 1.5 to 2.0 times the long-term medians. In contrast, all basins within the Mackay-Whitsunday region had discharge rates below their long-term medians (Moran *et al.* 2025).

Table 11. Annual water year discharge (ML) of the main Reef rivers (1 October 2023 to 30 September 2024, inclusive) compared to the previous three wet seasons and long-term (LT) median discharge (1986–87 to 2022–23). 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.* 2025.

| Region | Basin | LT median | 2020 - 2021 | 2021 - 2022 | 2022 - 2023 | 2023 - 2024 |
|---|---|---|---|---|---|---|
| Cape York | Jacky Jacky Creek | 2,471,267 | 3,607,722 | 2,365,731 | 4,611,721 | 3,487,440 |
| | Olive Pascoe River | 3,180,267 | 5,540,683 | 4,879,388 | 6,053,581 | 6,050,915 |
| | Lockhart River | 1,538,839 | 2,680,976 | 2,360,994 | 2,929,152 | 2,927,862 |
| | Stewart River | 758,172 | 1,419,942 | 569,738 | 1,366,633 | 1,100,668 |
| | Normanby River | 3,864,344 | 6,149,878 | 3,562,637 | 11,791,399 | 16,300,347 |
| | Jeannie River | 1,428,920 | 1,342,490 | 1,566,621 | 2,093,623 | 4,440,165 |
| | Endeavour River | 1,583,881 | 1,489,348 | 1,734,492 | 2,310,900 | 4,877,431 |
| Wet Tropics | Daintree River | 1,918,174 | 1,834,774 | 2,519,318 | 4,685,640 | 9,176,968 |
| | Mossman River | 604,711 | 654,566 | 800,754 | 815,267 | 1,745,893 |
| | Barron River | 622,447 | 667,265 | 692,908 | 1,217,590 | 3,603,793 |
| | Mulgrave-Russell River | 4,222,711 | 4,771,460 | 4,091,750 | 4,291,804 | 6,786,526 |
| | Johnstone River | 4,797,163 | 5,324,040 | 4,712,174 | 5,385,426 | 8,157,637 |
| | Tully River | 3,393,025 | 4,123,338 | 3,175,489 | 3,660,701 | 5,563,920 |
| | Murray River | 1,484,246 | 1,947,050 | 1,269,280 | 1,526,232 | 2,595,878 |
| | Herbert River | 3,879,683 | 6,842,168 | 3,283,590 | 4,919,143 | 8,516,360 |
| Burdekin | Black River | 293,525 | 429,282 | 273,677 | 353,756 | 526,432 |
| | Ross River | 279,376 | 232,975 | 202,811 | 209,681 | 285,424 |
| | Haughton River | 558,735 | 595,709 | 735,754 | 1,219,825 | 583,152 |
| | Burdekin River | 4,406,780 | 8,560,072 | 5,442,976 | 9,702,259 | 5,745,479 |
| | Don River | 496,485 | 510,906 | 383,927 | 999,723 | 372,511 |
| Mackay-Whitsunday | Proserpine River | 859,348 | 537,613 | 446,839 | 1,869,821 | 618,392 |
| | O'Connell River | 835,478 | 522,680 | 434,427 | 1,817,882 | 601,214 |
| | Pioneer River | 616,216 | 235,359 | 277,610 | 761,905 | 589,249 |
| | Plane Creek | 1,058,985 | 600,958 | 489,222 | 1,440,350 | 632,961 |
| Fitzroy | Styx River | 629,037 | 927,219 | 1,080,829 | 849,506 | 1,030,316 |
| | Shoalwater Creek | 727,306 | 1,072,570 | 1,250,433 | 982,586 | 1,191,945 |
| | Water Park Creek | 392,614 | 675,102 | 820,627 | 601,479 | 772,773 |
| | Fitzroy River | 2,875,792 | 436,730 | 4,505,289 | 3,078,896 | 2,100,507 |
| | Calliope River | 257,050 | 123,050 | 250,551 | 135,396 | 172,394 |
| | Boyne River | 179,108 | 31,002 | 171,925 | 44,649 | 85,541 |
| Burnett-Mary | Baffle Creek | 347,271 | 112,323 | 1,000,587 | 170,693 | 424,436 |
| | Kolan River | 115,841 | 19,211 | 818,716 | 83,734 | 139,893 |
| | Burnett River | 264,307 | 118,241 | 3,894,616 | 358,852 | 598,898 |
| | Burrum River | 130,835 | 44,691 | 1,612,683 | 270,059 | 476,512 |
| | Mary River | 908,873 | 420,909 | 10,139,380 | 673,298 | 1,806,668 |
| | **Sum of basins** | **60,746,947** | **64,602,302** | **71,817,742** | **83,283,163** | **104,086,501** |

## 3.5 Water quality index

The Great Barrier Reef Marine Monitoring Program's water quality component assesses the annual and long-term condition of inshore water quality across the Reef, based on 19 years of monitoring data (Moran *et al.* 2025). Inshore water quality is evaluated using an index derived from five key indicators: water clarity, nitrate/nitrite, particulate nitrogen, particulate phosphorus, and chlorophyll *a*. This data is reported annually for the Cape York, Wet Tropics, Burdekin, Mackay-Whitsunday, and Fitzroy regions (Moran *et al.* 2025). Satellite imagery and remote sensing are integrated with on-site monitoring data to estimate inshore areas' exposure to river end-of-catchment loads across all Reef catchment regions.

The annual Water Quality condition Index for 2023–24 (1 October 2023 to 30 September 2024) as reported by Moran *et al.* (2025) was:

- **'moderate'** in the Cape York region, representing deterioration compared with the previous year's 'good' score;
- **'good'** in the Wet Tropics and Burdekin regions, which was an improvement in comparison to the previous several years;
- **'moderate'** in the Mackay-Whitsunday region and continuing to improve since 2018; and
- **'good'** in the Fitzroy region, similar to the previous three years.

## 3.6 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.

Turbid coloured primary and secondary water (WT1 and WT2) dominated the water types in the wet season (December 2023–April 2024) as is characteristic of inshore conditions over the long-term (2003–2019, Figure 7, panel 1). WT1 and WT2 extended further off shore in 2023–24 than the long-term average in the northern half of the Reef including in Cape York, the Wet Tropics and parts of the Burdekin (Figure 7, panel 2). WT1 and WT2 did not extend as far offshore in 2023–24 for the central and southern Reef including remainder of the Burdekin, the Mackay-Whitsundays, Fitzroy and Burnett–Mary NRM regions.

The frequency the seagrass sites were exposed to WT1 and WT2 combined in the wet season was around multiannual conditions in all but the Mackay–Whitsunday NRM region where the level of exposure was below average (Figure 8). This is because the monitoring sites are inshore and are frequently exposed to WT1 and WT2 waters. There were also many gaps in the data for these regions in 2023–24 due to clouds, so the actual frequency of exposure may be higher. In the Mackay-Whitsunday region there was also a decrease in 2023–24 in the area of mapped seagrass exposed to water quality risk categories (Moran et al 2025). By contrast, there was a 10 % increase in mapped Cape York seagrass that was exposed to water quality risk compared to the long-term average (Moran et al 2025). In the Wet Tropics there was a decrease in risk of exposure to the high-risk category and an increase in the low-risk category leading to no change in total seagrass area exposed (Moran et al 2025). In the Burdekin region there was a decrease in area of mapped seagrass exposed to the low-risk category and an increase in the moderate risk category resulting in no overall change in area exposed (Moran et al 2025).

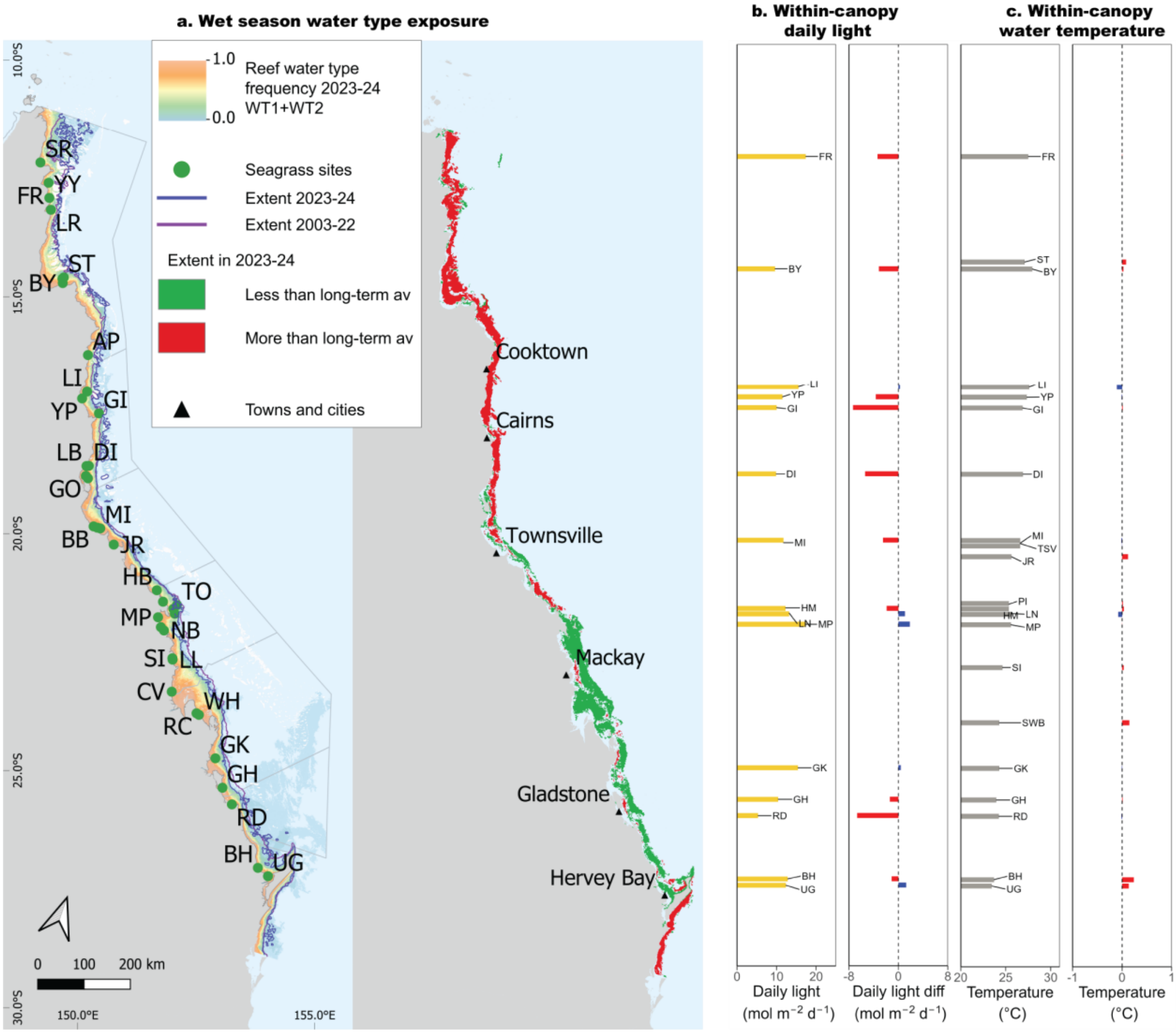



Figure 7. Environmental pressures in the Reef during 2023–24 and relative to long-term: a. Frequency of turbid water (WT1 and WT2) exposure shown in the left-hand panel in the Reef from December 2023 to April 2024 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed), and right-hand panel the distribution of WT1 and WT2 (10 per cent boundary) in 2023–24 relative to the long-term average, with red showing that that these water types extended further in 2023–24 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 Moran *et al.* 2025.

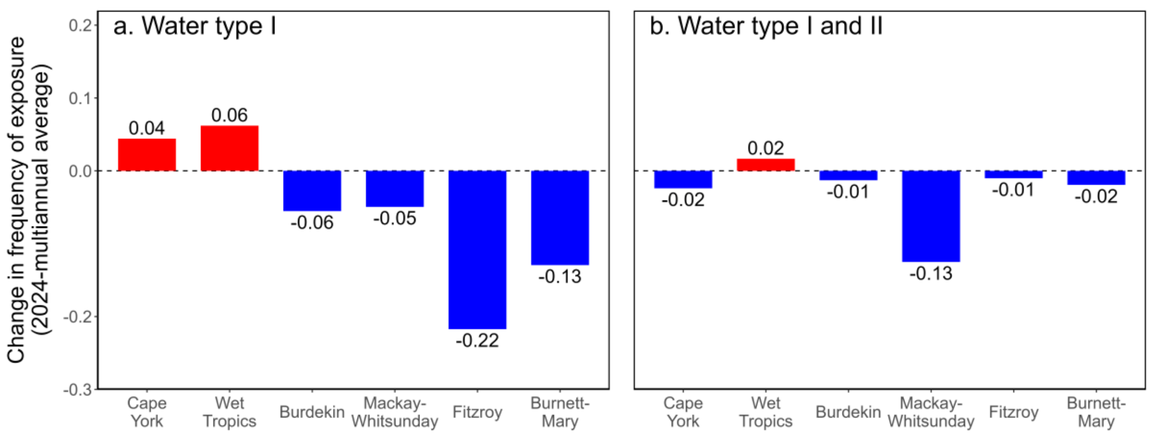



Figure 8. Difference in the frequency of exposure to primary (WT1, left) and primary and secondary optical water types (WT1 and WT2, right) at seagrass monitoring sites during the wet season (December 2023–April 2024) compared to the long-term multiannual exposure (2003–2022).

## 3.7 Daily light

Daily light reaching the top of the seagrass canopy in the Reef in 2023–24 was 12.3 mol $m^{-2}$ $d^{-1}$ when averaged for all sites (Table 10), compared to a long-term average of 13.7 mol $m^{-2}$ $d^{-1}$.

Daily light in habitats is influenced by depth of the site, cloud cover and water quality which is affected by river discharge and resuspension caused by wind and currents. (Anthony *et al.* 2004; Fabricius *et al.* 2012). Tidal changes in water depth affect the frequency and duration of full sunlight exposure at low tide, particularly in intertidal sites, which are the focus of light monitoring in this program. Therefore, variations in daily light among the seagrass sites presented here primarily reflect site-specific differences in water quality and cloud cover, since all sites are intertidal. Regional averages in daily light are also influenced by the data available as some sites (16 out of 23 of the locations where light is monitored) had considerable logger failure in 2023–24 and they were not included. For example, in the Burdekin region in 2023–24, only reef sites (MI1 and MI2) had sufficient data and the generally more turbid coastal sites did not, leading to an apparent increase in light for region. The data for each site are presented in the appendices (Figures 98–104).

Daily light in the regions in 2023–24 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 (12.3 mol $m^{-2}$ $d^{-1}$) ↓
- southern Wet Tropics (9.9 mol $m^{-2}$ $d^{-1}$) ↓
- Burdekin (11.7 mol $m^{-2}$ $d^{-1}$) ↑
- Mackay–Whitsunday (14.3 mol $m^{-2}$ $d^{-1}$) ↑
- Fitzroy (12.9 mol $m^{-2}$ $d^{-1}$) ↓
- Burnett–Mary (10.1 mol $m^{-2}$ $d^{-1}$) ↓

Daily light in the habitats in 2023–24 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 (13.0 mol $m^{-2}$ $d^{-1}$) ↓
- coastal intertidal, n = 4 (12.8 mol $m^{-2}$ $d^{-1}$) ↑
- estuarine, n = 3 (9.3 mol $m^{-2}$ $d^{-1}$) ↓

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 most of the sites in the northern half of the Reef where light was recorded except for Low Isles (Figure 7).The decline in light was the largest at Green Island due to lower than average light levels in the dry and wet season (Figure 99) as was also the case at Magnetic Island (MI2) (Figure 99). Piper Reef and Bathurst Bay had lower than usual light levels in the dry season which may have been a legacy of precious year's discharges and dry season wind causing wind-induced resuspension and elevated turbidity (this would not show in water type exposure which is only assessed for the wet season).  Most of the other sites including a large decline at Dunk Island, Yule Point and Rodds Bay were low during the wet season, however the latter two were also missing some dry season data when light levels are generally higher.

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 but was elevated in 2023–24 dry season and reached a maximum in November 2023. Tidal 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. This contributes to light levels decreasing through the wet season (Figure 9). Daily light was lower than average in the late wet season and post-wet season. In 2023–24, daily light quickly decreased with the onset of the wet season and continued to decline through to end of the 2023-24 reporting period.

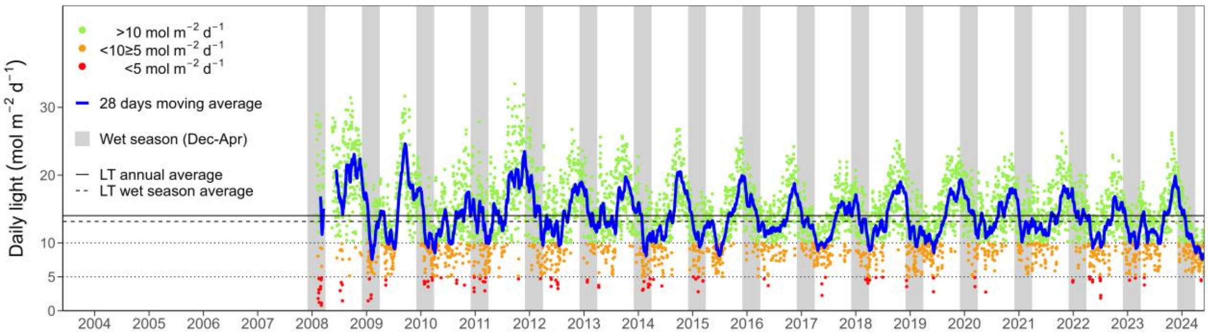



Figure 9. Daily light (coloured points) and 28-days moving average (blue, bold line) for all sites combined from 2008 to 2024. In 2008–2009, light data is from the Burdekin and Wet Tropics regions only. Other regions were included from 2009–2010, with Cape York added post 2012–2013 reporting period. 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.* 2016).

## 3.8 Within-canopy seawater temperature

Daily within-canopy seawater temperature across the inshore Reef in 2023–24 was slightly lower than the previous reporting period (Figure 10). Since 2013, the frequency of weekly warm water deviations appears to have generally increased, relative to cooler occurrences (Figure 10). The 2023–24 average temperature (25.9 ± 0.3 °C) was the third consecutive year of above average temperatures and the seventh highest since the MMP was established (2016-17 was the highest) (Table 10). However, there were regional and habitat differences relative to the long-term (Figure 7).

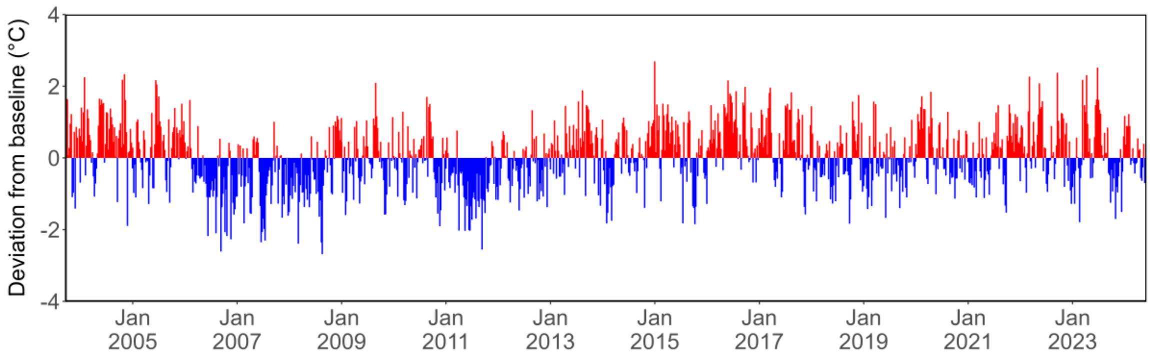



Figure 10. Inshore intertidal sea temperature deviations from baseline for Reef seagrass habitats from 2003 to 2024. Data presented are deviations from 19-year mean weekly temperature records (based on records from September 2003 to June 2023). Weeks above the long-term average are represented as red 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 2023–24 (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 = 27.4°C, max = 37.6°C, days$_{>35\leq40°C}$ = 28) ↕
- northern Wet Tropics (avg = 27.0°C, max = 46.5°C, days$_{>35\leq40°C}$ = 53, days$_{>40°C}$ = 4) ↕
- southern Wet Tropics (avg = 26.9°C, max = 37.2°C, days$_{>35\leq40°C}$ = 3) ↕
- Burdekin (avg = 26.3°C, max = 37.8°C, days$_{>35\leq40°C}$ = 19) ↕
- Mackay–Whitsunday (avg = 25.6°C, max = 46.3°C, days$_{>35\leq40°C}$ = 79, days$_{>40°C}$ = 10) ↕
- Fitzroy (avg = 24.2°C, max = 50.8°C, days$_{>35\leq40°C}$ = 83, days$_{>40°C}$ = 15) ↕
- Burnett–Mary (avg = 23.9°C, max = 37.8°C, days$_{>35°C}$ = 9) ↑

Daily within-canopy seawater temperatures in each habitat in 2023–24 relative to respective long-term average (↑ = above, ↓ = below, ↕ = similar to long-term, difference = greater than 0.3°C) were:

- estuarine habitat (avg = 26.3°C, max = 50.8°C)↑
- coastal intertidal habitat (avg = 26.7°C, max = 40.5°C)↕
- reef intertidal habitat (avg = 26.3°C, max = 46.5°C)↕

The hottest seawater temperature recorded at inshore seagrass sites along the Reef during 2023–24 was 50.8°C at Shoalwater Bay (25Oct23 at 12:20pm) in the Fitzroy region. This was the hottest temperature ever recorded since the MMP was established (hottest was 46.6 ºC, at Shelley Beach, 3pm on 10Jan08). In 2023-24, the NRM region with the highest number of days of extreme temperatures (>40°C) was Fitzroy, which was also the highest for the region 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.

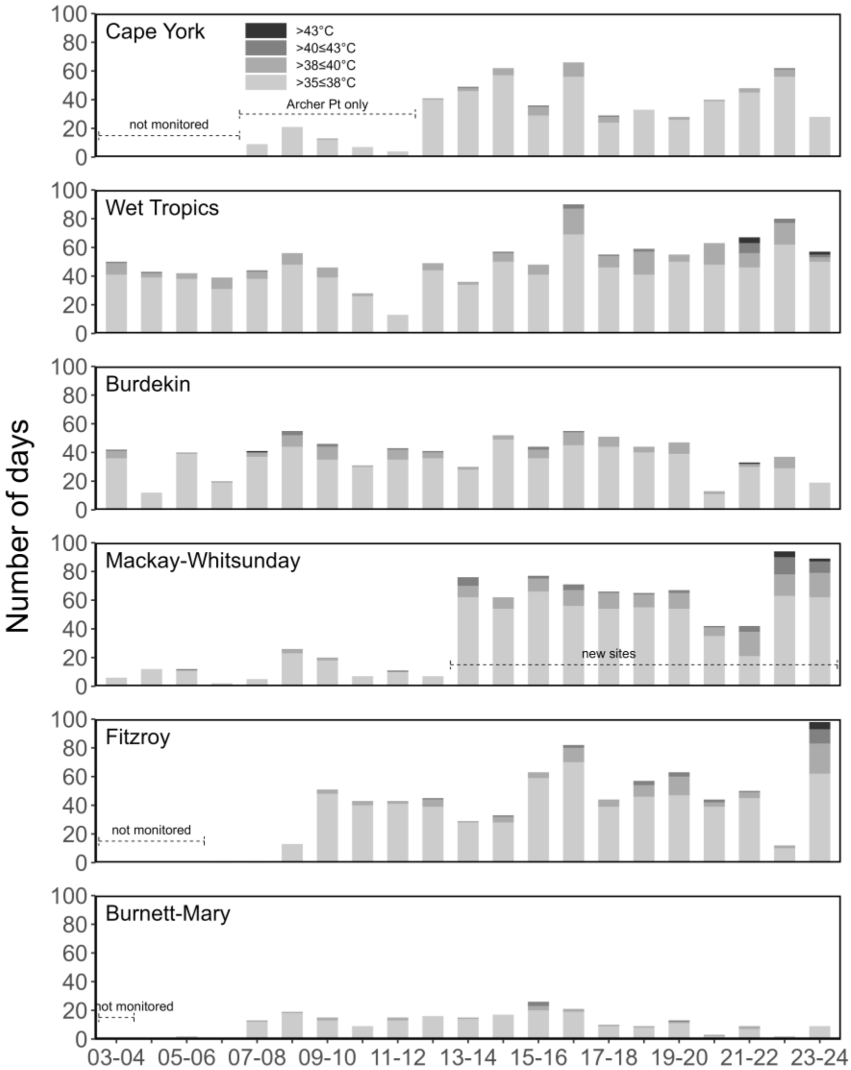



Figure 11. Number of days when inshore intertidal sea temperature exceeded 35°C, 38°C, 40°C and 43°C in each monitoring period in each NRM region. Thresholds adapted from Campbell *et al*. 2006; Collier *et al*. 2012a.

## 3.9 Seagrass meadow sediments

Estuarine and coastal subtidal 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 (1999–2023). *only 7 years of data.

| Habitat | Mud | Fine sand | Sand | Coarse sand | Gravel |
|---|---|---|---|---|---|
| estuarine intertidal | 44.4 ±2.1 | 23.9 ±2.1 | 29.7 ±1.8 | 0.2 ±0.5 | 1.8 ±0.9 |
| coastal intertidal | 27.4 ±2.1 | 32.7 ±2.4 | 35.6 ±2.5 | 0.5 ±0.7 | 3.8 ±1.2 |
| coastal subtidal* | 55.4 ±2.2 | 9.5 ±1.5 | 17.0 ±.2.3 | 5.2 ±0.8 | 13.0 ±1.3 |
| reef intertidal | 4.2 ±1.2 | 7.0 ±1.8 | 53.4 ±2.8 | 14.8 ±1.9 | 20.5 ±2.3 |
| reef subtidal | 15.7 ±1.0 | 13.6 ±1.0 | 58.3 ±5.1 | 1.5 ±0.9 | 10.9 ±5.1 |

Throughout the 2023–24 monitoring period, the contribution of mud to sediment type increased in all seagrass habitats compared to the previous year, with proportions in each habitat surpassing the long-term average for the Reef (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 seagrass 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. *Zostera*) are able to persist, providing sufficient light for photosynthesis is available (Ferguson *et al.* 2016).

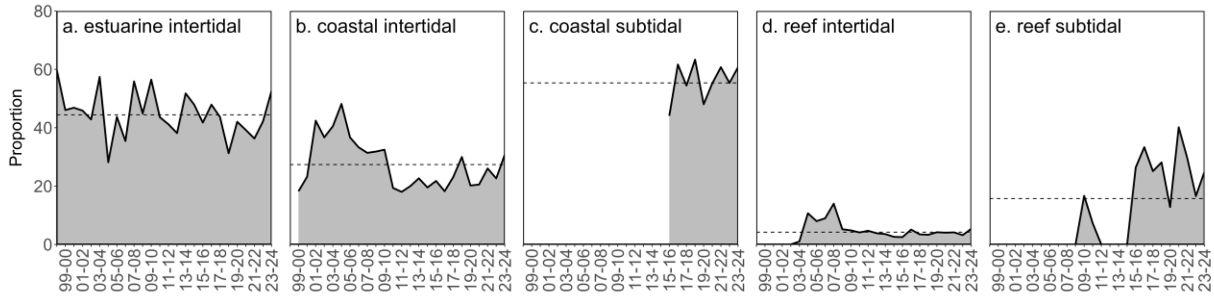



Figure 12. Proportion of sediment composed of mud (grain size <63 µm) at inshore Reef seagrass monitoring habitats from 1999–2024. Dashed line illustrates the Reef long-term average for each habitat type.

# 4 Seagrass condition and trend

The following results section provides detail on the overall seagrass responses for the 2023–24 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 2023–24, with the condition grade remaining **moderate** (Figure 13). Cape York and the Fitzroy regions are surveyed in the late dry only, which was prior to the flood events that affected the northern regions.

In summary, the seagrass abundance indicator remained relatively stable but the resilience indicator decreased:

- The seagrass abundance indicator has been on a gradually improving trajectory since 2019–20 however, it remained **moderate** and stagnated in 2023–24 based on the average score against the seagrass guidelines (determined at the site level), (Figure 13). 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 was in a moderate condition.

- The resilience indicator declined in 2023–24 to **poor** (Figure 13) which was the lowest level since 2012–13 when it was recovering from extreme weather events. 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. Resilience has been on a declining trend since 2016–17, though with a two-year reprieve when it rose slightly.

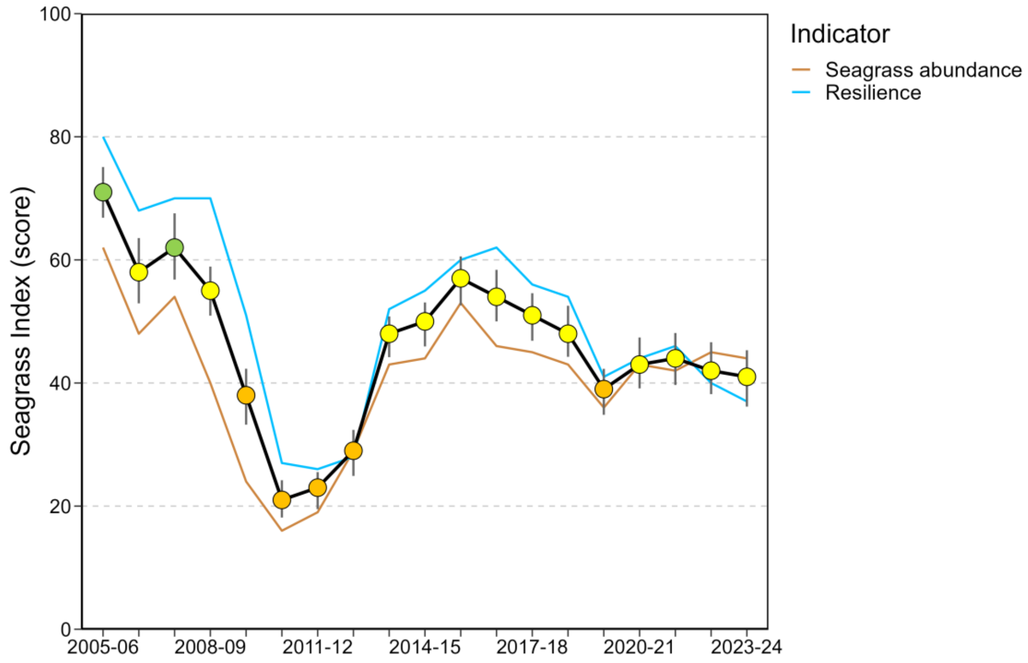



Figure 13. Overall inshore Reef Seagrass Index (± SE) with contributing indicator scores over the life of the MMP. The Index is derived from the aggregate of metric scores for indicators of seagrass condition: abundance and resilience. Index scores scaled from 0–100 and graded: ● = very good (81–100), ● = 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 2023–24 the Index improved in two regions, declined in two and remained relatively stable in two (Figure 14). The seagrass Index was moderate and stable in Cape York and Mackay–Whitsunday regions (Figure 14). The Index declined from moderate to poor in the Wet Tropics and Burdekin regions. It was the first time the Index in the Burdekin was poor since 2012–13. There were substantial increases in the Index in the southern regions with the Fitzroy region remaining poor and the Burnett–Mary recovering from very poor to poor and on the cusp of reaching moderate (Figure 14). Over the long-term, the abundance and resilience 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:

- The abundance score in 2023–24 generally followed the same trends as the overall Index. Abundance decreased slightly in Cape York (measured in the late dry, before floods) and increased slightly in the Mackay–Whitsunday regions. There were substantial declines in abundance from moderate to poor in the Wet Tropics and Burdekin regions and increases in the Fitzroy and Burnett–Mary regions.

- The seagrass resilience score in 2023–24 was moderate in the Mackay–Whitsunday and Wet Tropics regions and poor in all other regions. In 2023–24, the resilience score trends also paralleled the overall Index. Resilience was only slightly changed in Cape York and Mackay-Whitsundays, declined in the Wet Tropics and Burdekin regions and increased in the Fitzroy and Burnett–Mary regions.

Inshore seagrass condition scores across the regions reflect a system that is being impacted by elevated discharge from rivers, heatwaves, cyclones and local-scale disturbances. Regional differences in condition and indicator scores appear due to the legacy of significant environmental conditions. These include in 2016–17 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. In 2023–24, extreme elevated discharge and other associated pressures from the cyclones (e.g. wind and waves) affected the northern regions but Cape York was surveyed prior to these events. The Fitzroy and Mackay-Whitsundays were exposed to very high temperatures, however, the Fitzroy was surveyed once and around the time of these temperature extremes, and the effects of them may not be evident until the next reporting period.

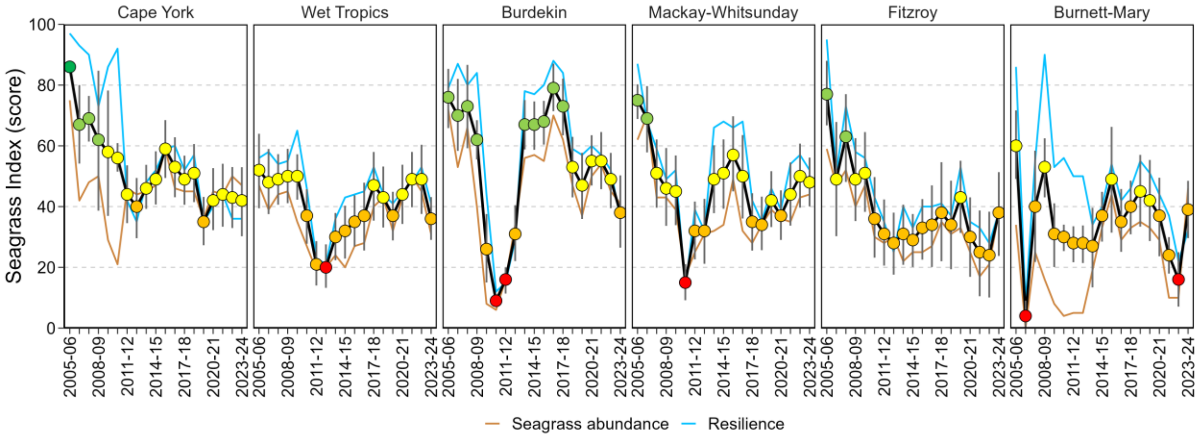



Figure 14. Seagrass Index (± SE) with contributing indicator scores for each NRM region over the life of the MMP. The Index is derived from the aggregate of metric scores for indicators of seagrass condition: abundance and resilience. Values are indexed scores scaled from 0–100 and graded: ● = very good (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 for all regions has been relatively stable since 2018–19 only increasing slightly in 2023–24. The resilience indicator score has similarly declined to its lowest levels in the 2010–11 through 2012–13 monitoring periods. The resilience score has been on a declining trajectory since 2016–17 and influenced heavily by large changes in the Burdekin region, and smaller fluctuations in other regions.

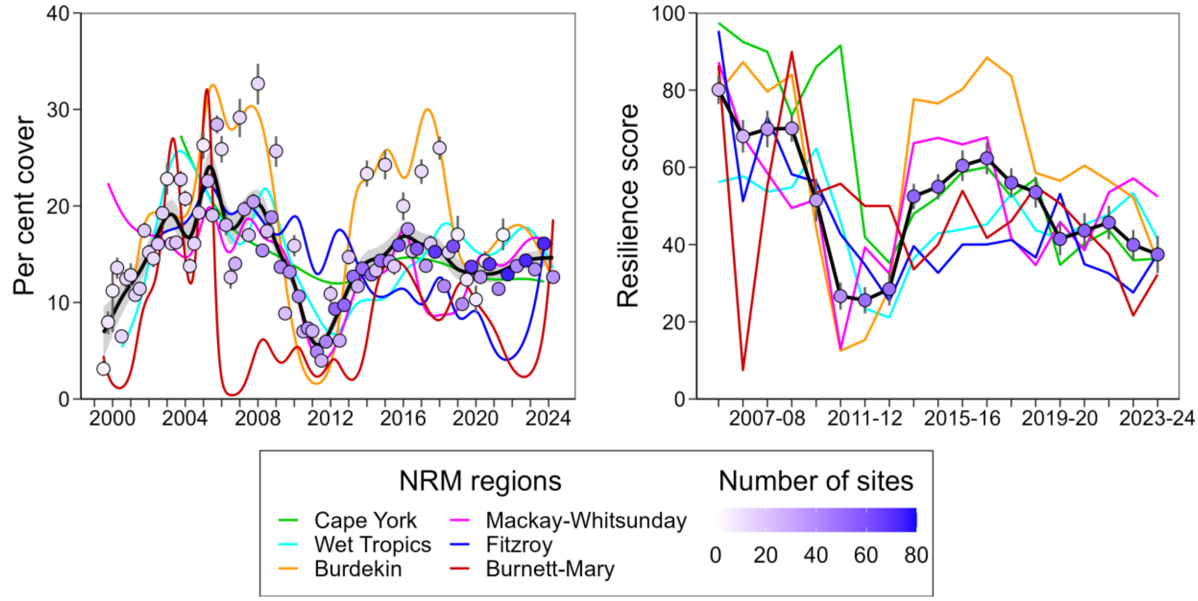



Figure 15. Trends in the seagrass indicators used to calculate the Seagrass Index including trends in Reef seagrass abundance (per cent cover, ± SE) represented by a GAM plot (black line with shaded areas defining 95 per cent confidence interval), and coloured lines representing NRM trends (left), and 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 varied since monitoring began. A review of long-term data from inshore Reef sites shows no significant overall trend, with:

- no significant trends at 75 per cent of long-term monitoring sites assessed, although 8 per cent of sites significantly increased in abundance and 17 per cent decreased (Appendix 3, Table 22),
- the rate of change in abundance was lower for sites that were increasing (0.4 ±0.2 per cent, sampling event$^{-1}$) compared to those decreasing (-0.6 ±0.2 per cent sampling event$^{-1}$) (Appendix 3, Table 22).

Since 1999, the median percentage cover values for the Reef were mostly below 25 per cent cover, and depending on habitat, the 75$^{th}$ 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.

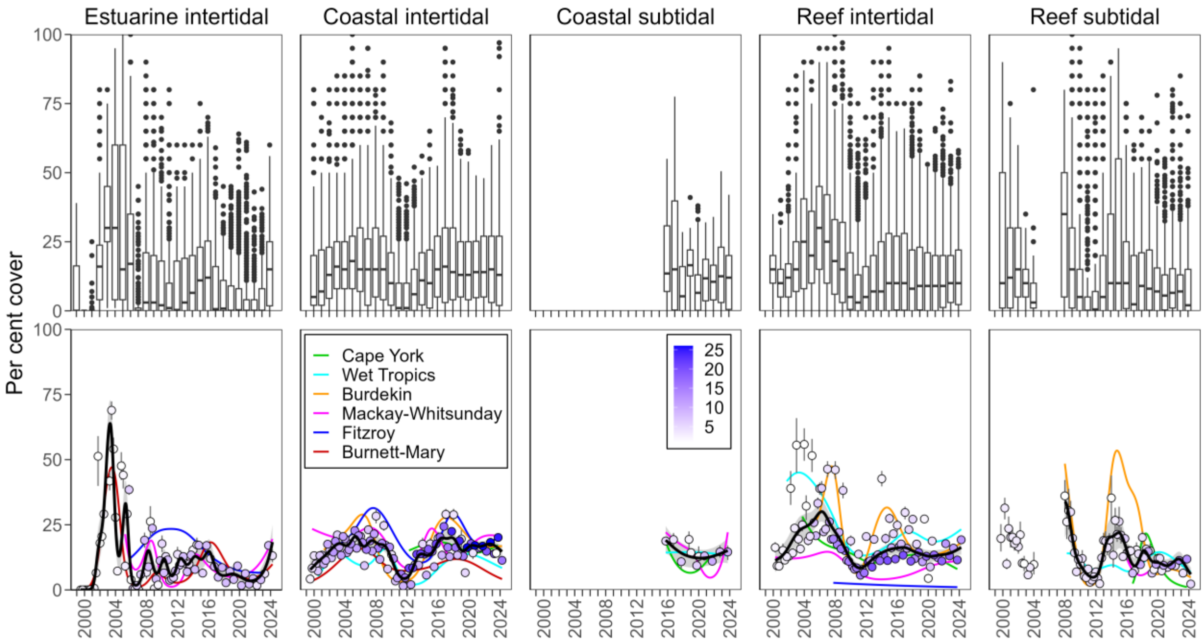



Figure 16. Seagrass per cent cover measures per quadrat from habitats monitored from June 1999 to May 2024 (sites pooled). In the whisker plots (top), the box represents the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box 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 2023–24, coastal habitats maintained the highest average seagrass abundance among all habitat types, while estuarine habitats had the lowest (Figure 16). Over the past decade, trends in seagrass abundance have been similar between intertidal sites in coastal and reef habitats. Abundance gradually increased following the extreme weather events of early 2011 (e.g., Cyclone Yasi), declined between 2017 and 2019 due to Cyclone Debbie, and began improving again from 2020 onward (Figure 16). In 2023–24, average abundance was similar to 2022–23 in coastal and reef intertidal habitats and coastal subtidal habitats. Abundance declined in reef subtidal habitats in 2023–24 and to the second lowest on record.

Estuarine habitats, monitored exclusively in the southern NRM regions (Mackay–Whitsunday, Fitzroy, and Burnett–Mary), recorded peak percent cover levels prior to the establishment of the MMP (2004–05). 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 2023–24, seagrass abundance at estuarine habitats continued to increase to the highest level since 2006–07 due to recovery in the Burnett–Mary and Fitzroy regions.

In 2023–24, the overall relative spatial extent of inshore Reef seagrass meadows continued to increase compared to the previous year, with late dry season extents reaching the highest levels on record (Figure 17). However, following the wet season, relative spatial extent declined. Since the establishment of the MMP in 2005, the overall trend was at first relatively stable but showed a gradual decline in seagrass meadow extent from 2008–09 to early 2011, a recovery within 3–4 years, followed by another decline from late 2016 to early 2019, before starting to recover again (Figure 17). As with seagrass abundance, these declines in relative extent are primarily linked to extreme weather events, associated flooding, and location-specific climatic factors such as the frequency of strong wind days.

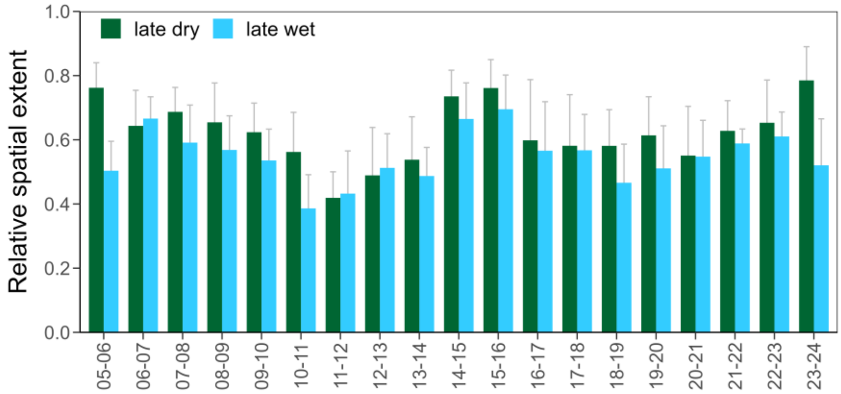



Figure 17. Average relative spatial extent of seagrass distribution at monitoring sites across inshore Reef (locations, habitats and NRM regions pooled, + SE). Green bars represent late dry and Blue bars late wet.

Following a series of consecutive above-average wet seasons from 2009, culminating in the extreme weather events of 2011, there were widespread declines in seagrass extent (Figure 17) and abundance. This was accompanied by an increased proliferation of colonising species (i.e. *Halophila spp)* at coastal and reef sites (Figure 18). Between 2012–13 and 2015–16, the proportion of species exhibiting colonising traits gradually declined, but this trend reversed in 2016–17 when they proliferated again. Since then, the proportion has fluctuated across habitats. During the 2023–24 monitoring period, the proportion of species displaying colonising traits decreased slightly in estuarine, coastal intertidal, and subtidal habitats, while increasing slightly in reef intertidal and subtidal habitats. Despite these variations, the proportion remained above the inshore Reef average for each respective habitat type. This may suggest rising environmental pressures impacting seagrass growth requirements.

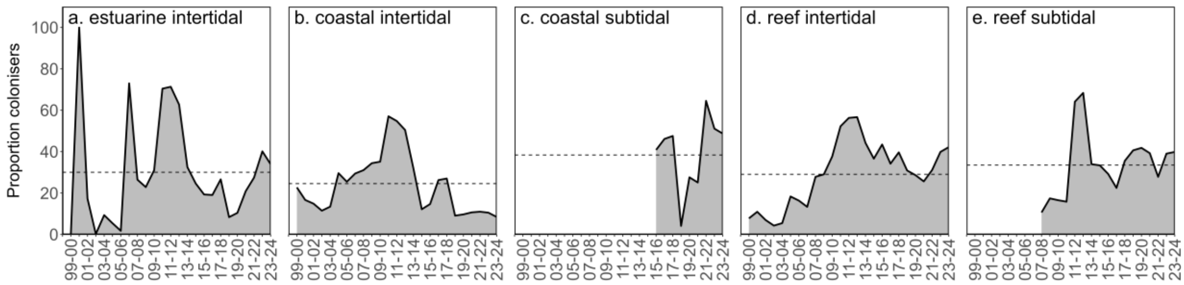



Figure 18. Proportion of total seagrass abundance composed of species displaying colonising traits (e.g. *Halophila ovalis*) in: a) estuarine intertidal, b) coastal intertidal, c) coastal subtidal, d) reef intertidal and e) reef subtidal habitats (sites pooled) of the Reef (regions pooled) for each monitoring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

### 4.3.2 Seagrass reproductive status

Reproductive effort, defined as the number of sexual reproductive structures per unit area, along with seed banks, which represent the number of intact seeds per unit area, reflect the reproductive status of the Reef's inshore seagrass.

Reproductive effort reduced in 2023–24 in the late dry on average in intertidal habitats across the inshore Reef compared to 2022–23. Reproductive effort was also lower than the long-term average and seed density was well below the long-term average. Maximum reproductive effort and the inter-annual variability follows a different pattern among 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 because seeds can persist in the sediment for years (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 reduced in 2023–24 compared to the previous year, but was similar to the long-term average (Figure 19) as was seed density (Figure 20). This trend in reproductive effort was driven by decreases the Mackay–Whitsunday and Fitzroy region estuarine habitats offset to a small degree by increases in the Burnett–Mary. Foundational species were flowering at most of the estuarine sites. Seeds declined in both the Burnett–Mary and Fitzroy regions, and there were no seeds in the Mackay–Whitsunday region estuarine sites for the second year in a row (Figure 20).

In coastal habitats, reproductive effort and seed density was more variable inter-annually than in other habitats. From 2017 to 2019, coastal habitats exhibited historically high reproductive effort, driven by a record number of reproductive structures in the northern Wet Tropics (Yule Point) and Burdekin (Bushland Beach and Jerona). However, since 2019, reproductive effort in inshore Reef coastal habitats has remained low, with levels in 2023–24 being lower than 2022–23 (Figure 19). There were small increases in reproductive effort in Cape York, Burdekin and Fitzroy NRM regions, with others remaining similar to previous years and low. Seed bank densities also reduced considerably at coastal sites in 2023–24 and were one of the lowest levels on record (Figure 20). This was driven primarily by large reductions at Burdekin and northern Wet Tropics coastal habitats while there were small increases in Cape York and the Fitzroy NRM regions.

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 such as *Thalassia hemprichii* which do not produce a seed bank in the majority of reef habitats. However, foundational species such as *Halodule uninervis, Cymodocea rotundata* and *Cymodocea serrulata* also have low rates of reproduction at reef sites. In 2023–24, reproductive effort increased across reef intertidal habitats to the highest level since 2018–19. The increases occurred in the northern Wet Tropics, Burdekin and Mackay–Whitsunday NRM regions and were almost entirely from flowering of colonising species (*Halophila ovalis*). The seeds produced by colonising species are not assessed because of their size. Seed densities of reef intertidal sites increased to the highest level since 2017–18 but remained slightly lower than the long-term average. There were no seeds at Cape York, northern Wet Tropics and Fitzroy reef intertidal habitats (see 2.2.3).

At reef subtidal habitats, reproductive effort increased to the fourth highest level on record. The rise was driven by increases in the Burdekin and Mackay–Whitsunday NRM regions and were exclusively of colonising species. Seeds are not assessed at subtidal habitats.

Overall, reproductive structures were absent at 19 of the 47 of the sites assessed in 2023–24. The greatest losses compared to 2022–23 occurred in the Fitzroy, while the largest improvement was in the Burnett–Mary region (Figure 19). Reef intertidal and subtidal sites had the most substantial increases in reproduction but they were almost exclusively of colonising species. Seed densities in seed banks remained absent at 18 of 41 sites in 2023–24. The greatest loss was in the Wet Tropics and Burdekin regions and there were gains in Cape York and the Fitzroy regions. 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.

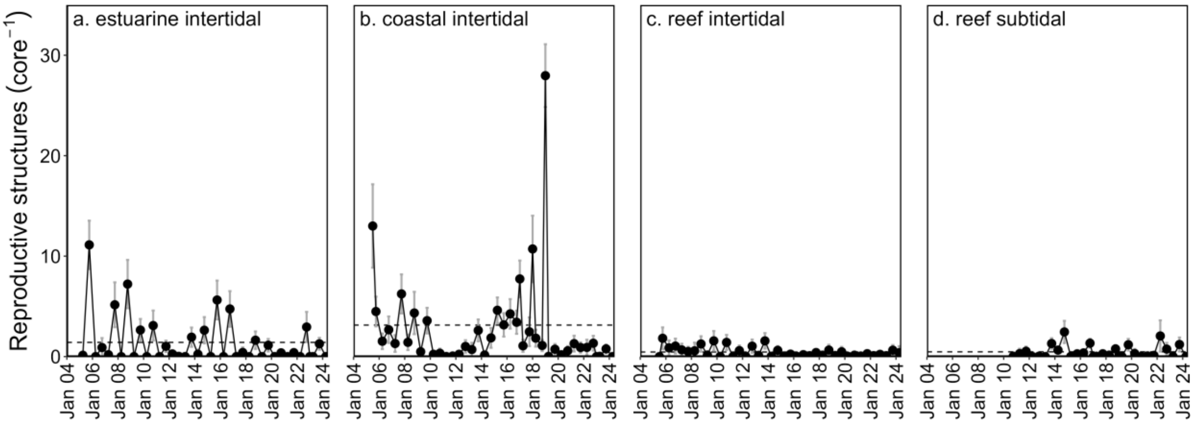



Figure 19. Seagrass reproductive effort (number of reproductive structures produced by all seagrass species, ± SE) in Reef seagrass habitats for a) estuarine intertidal; b) coastal intertidal; c) reef intertidal; d) reef subtidal. Dashed line illustrates Reef long-term average reproductive effort in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

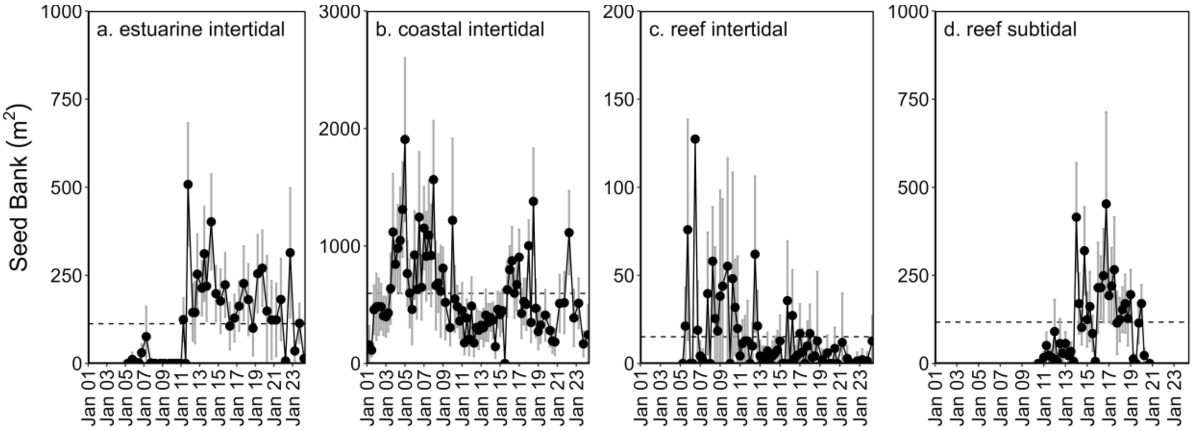



Figure 20. Average seeds banks (seeds per square metre of sediment surface, all sites and species pooled, ± SE) in Reef seagrass habitats: a) estuarine intertidal; b) coastal intertidal; c) reef intertidal; d) reef subtidal.

### 4.3.3 Resilience

The resilience score was moderate and improved slightly in estuarine and coastal habitats but declined and was poor in reef intertidal and subtidal habitats (Figure 21,Table 23). However, the trend for the habitat types varied among regions.

Resilience of estuarine sites improved in the Burnett–Mary and Fitzroy, but not declined slightly in the Mackay–Whitsunday NRM region. There are no estuarine sites in the other NRM regions (Figure 21,Table 23).

Resilience improved in coastal habitats in the majority of NRM regions. The score declined in the Mackay–Whitsunday, Burdekin and northern Wet Tropics NRM region, which were driven by small declines in reproductive effort (Figure 21,Table 23).

Resilience declined in reef intertidal habitats in most NRM regions driven by declines in abundance or the proportion of foundation species in Cape York, Mackay–Whitsundays and Fitzroy NRM regions and declines in reproductive effort in the Wet Tropics subregions. The score was stable for coastal habitats in the Burdekin NRM region (Figure 21,Table 23).

Resilience also declined in reef subtidal habitats driven by declines in per cent cover to below the resistance threshold in the Burdekin, and due to declines in reproductive effort in the Mackay–Whitsundays and northern Wet Tropics. The resilience improved slightly in the southern Wet tropics due to the proportion of persistent species but there was no reproductive effort (Figure 21,Table 23).

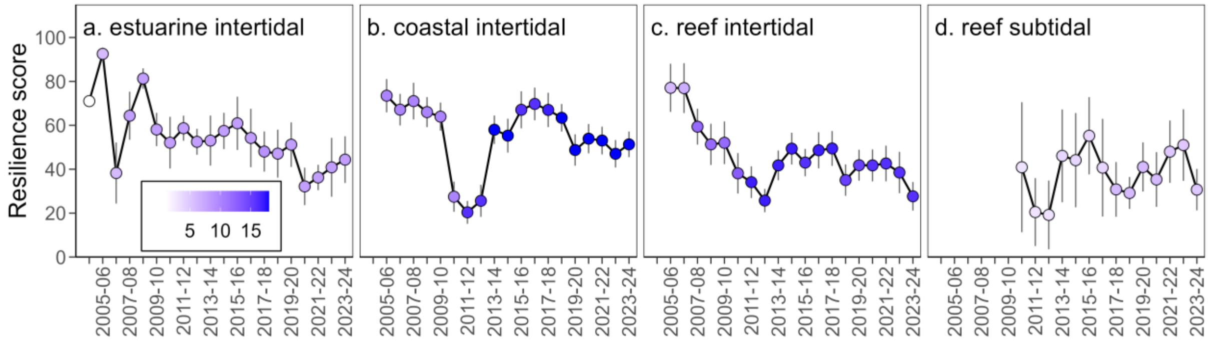



Figure 21. Trends in resilience score summarised for each habitat type of the Reef. Blue shading of points indicates the number of sites contributing to the score. Vertical error bars represent standard error.

Resilience in 2023–24 was moderate but declined a little in Cape York, the Mackay–Whitsundays, and northern and southern Wet Tropics. The resilience score was poor in all other regions but the trend varied. The resilience score was poor but improved in the Burnett–Mary and Fitzroy NRM regions, was poor and stable in Cape York and poor and declined in the Burdekin NRM regions.

### 4.3.4 Epiphytes and macroalgae

Epiphyte cover on seagrass leaves has fluctuated and often varied seasonally. For example, in 2023–24, epiphytes in estuarine habitats declined in the late dry 2023 and increased above the long-term average in the late wet season. Conversely, epiphyte cover in coastal intertidal habitats are less seasonal and often below the GBR-wide average potentially due to exposure (drying at low tide and waves) and in 2023–24 epiphytes were below average in both seasons (Figure 22). Epiphyte cover at reef intertidal sites was slightly above the average in both seasons, and substantially above average in reef subtidal habitats (Figure 22).

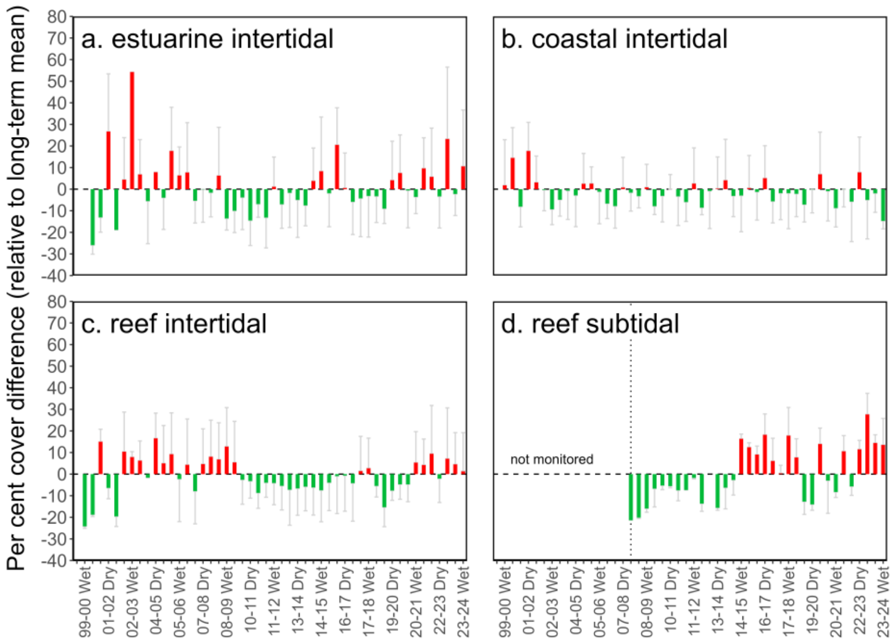



Figure 22. Epiphyte abundance (per cent cover) relative to the long-term average (the zero axis) for each Reef seagrass habitat (sites pooled, ± SE). Reef long-term average (1999 to 2023); estuarine = 25.9 ±5.1 per cent, coastal intertidal = 17.5 ±4.2 per cent, reef intertidal = 22.4 ±4.7 per cent, reef subtidal = 21.8 ±4.7 per cent.

Macroalgae abundance in 2023–24 followed the general trends of the previous 10 years in all habitats, remaining around or below the overall inshore Reef long-term average for each of the habitats (Figure 23).

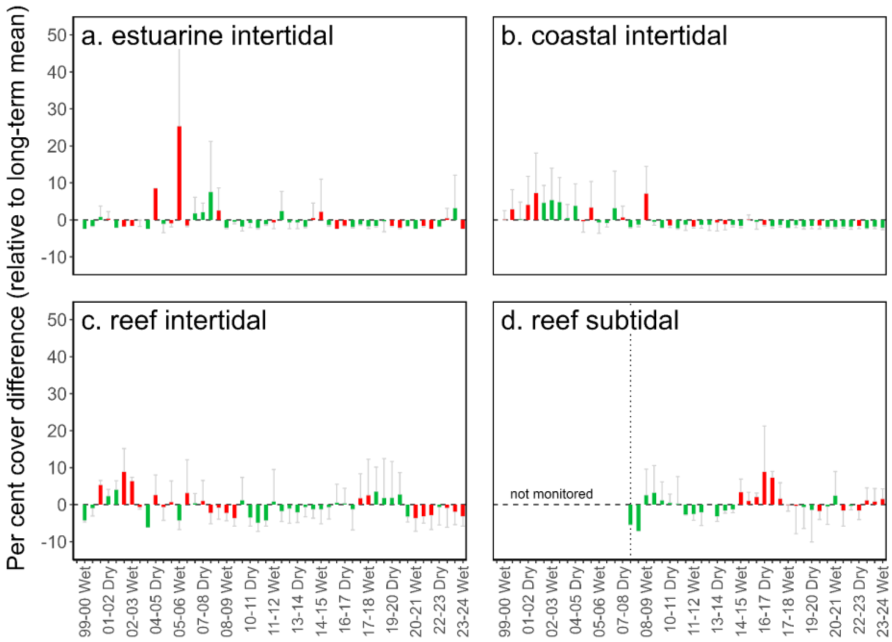



Figure 23. Macroalgae abundance (per cent cover) relative to the long-term average for each inshore Reef seagrass habitat. (sites pooled, ± SE). Reef long-term average (1999-2024); estuarine = 1.9 ±1.4 per cent, coastal intertidal = 2.1 ±1.5 per cent, reef intertidal = 6.9 ±2.6 per cent, reef subtidal = 6.7 ±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 2023–24 Summary

Wet season rainfall was above average and annual river discharges were above the long-term medians, particularly in the most southern Cape York basins. Exposure of the seagrass sites to turbid water types 1 and 2 was also above-average, which resulted in below-average daily light throughout the region. Within-canopy water temperatures remained above average for the fourth consecutive year in the last decade, but were cooler than the previous three years.

Seagrass condition was assessed only in the late dry in Cape York, which precedes the summer when the highest rainfall, river discharge and temperatures occurred. Seagrass meadow condition across the Cape York NRM region in 2023–24 was marginally lower than 2022–23 and remained **moderate**. The decrease was due to the abundance score slightly deteriorating while resilience remained steady. For the indicators:

- abundance score was moderate
- resilience score was poor.

Seagrass abundance (per cent cover) in 2023–24 declined from the previous period overall, to the lowest levels since monitoring commenced. This decline in seagrass abundance was driven by deterioration at all habitats, but the greatest in reef intertidal and subtidal sites, particularly in the south of the region. Coastal intertidal abundances declined after four years of consecutive increase, and coastal subtidal abundances similarly declined, with sites in the south remaining devoid of seagrass for the second year in a row.

Overall, the resilience score remained poor. The score increased at coastal sites overall due to large increases in the score at one site in each of Bathurst Bay and Shelburne Bay where abundance increased, and both reproductive structures and persistent species were present. At reef sites, the score was the lowest on record. At all reef sites, abundance was below the low resistance threshold and there were no reproductive structures present so they were all in the lowest resilience score category. Seeds were present at Bathurst Bay but there were none at other coastal and reef sites.

The number of monitored sites, their establishment dates, and the duration of monitoring at each location all play a role in shaping the long-term trends for the region. Prior to 2011–12, only one location was monitored, while the trends following this period incorporated multiple sites and various habitat types. Elevated discharge levels in 2010–11 and 2018–19 resulted in a decline in seagrass condition. Coastal and reef subtidal habitats displayed significant variability in seagrass abundance and were adversely affected by elevated discharge after 2018–19. Post-flood assessments were conducted in the subsequent growing season, revealing that the health score had deteriorated to poor once again. The resilience of coastal habitats was further compromised by extreme weather, and while seagrass habitats across the region were recovering, resilience diminished in 2022–23, a legacy from impacts of the previous wet season.

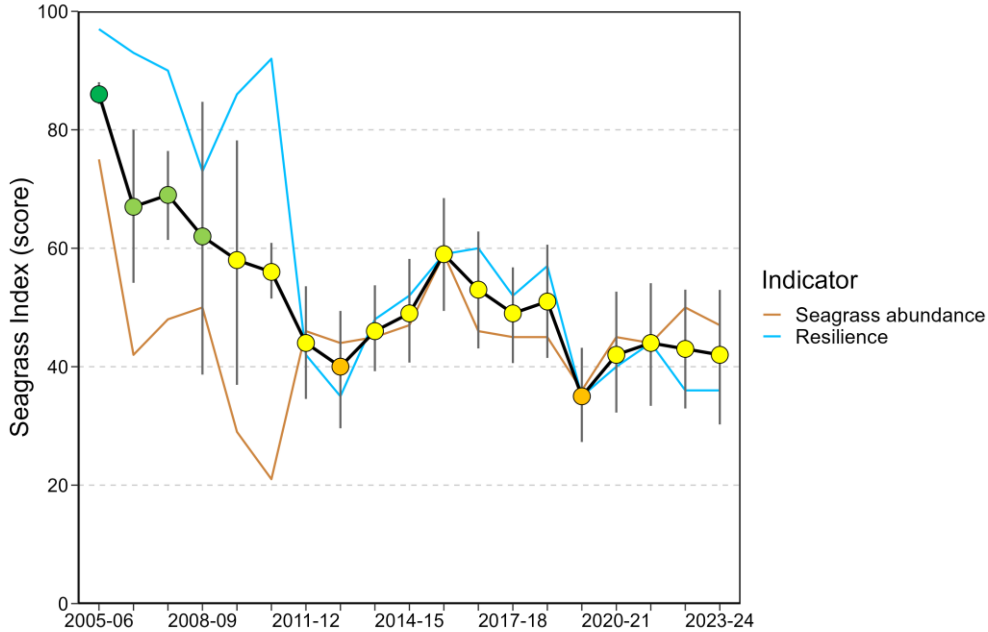



Figure 24. Temporal trend in the Seagrass Index (± SE) with contributing indicator scores for the Cape York NRM region (averaged across habitats and sites). Index scores scaled from 0–100 and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40), ● = very poor (0–20).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

### 5.1.2 Climate and environmental pressures

In 2023-24, seagrass habitats in the northern Wet Tropics were predominantly affected by above-average rainfall, above-median river discharge, above-average exposure to turbid waters and below-average daily light.

One tropical Cyclone (Jasper) formed offshore reaching a category 5 tropical cyclone on the 7th December 2024, but as it approached the shore it weakened then re-intensified making landfall as a category 2 cyclone at Wujal Wujal on the 13th December 2024. Jasper then weakened into a low and moved overland until the 18th December 2024. There was moderate to intense rainfall associated with the system particularly in the days after it made land fall.

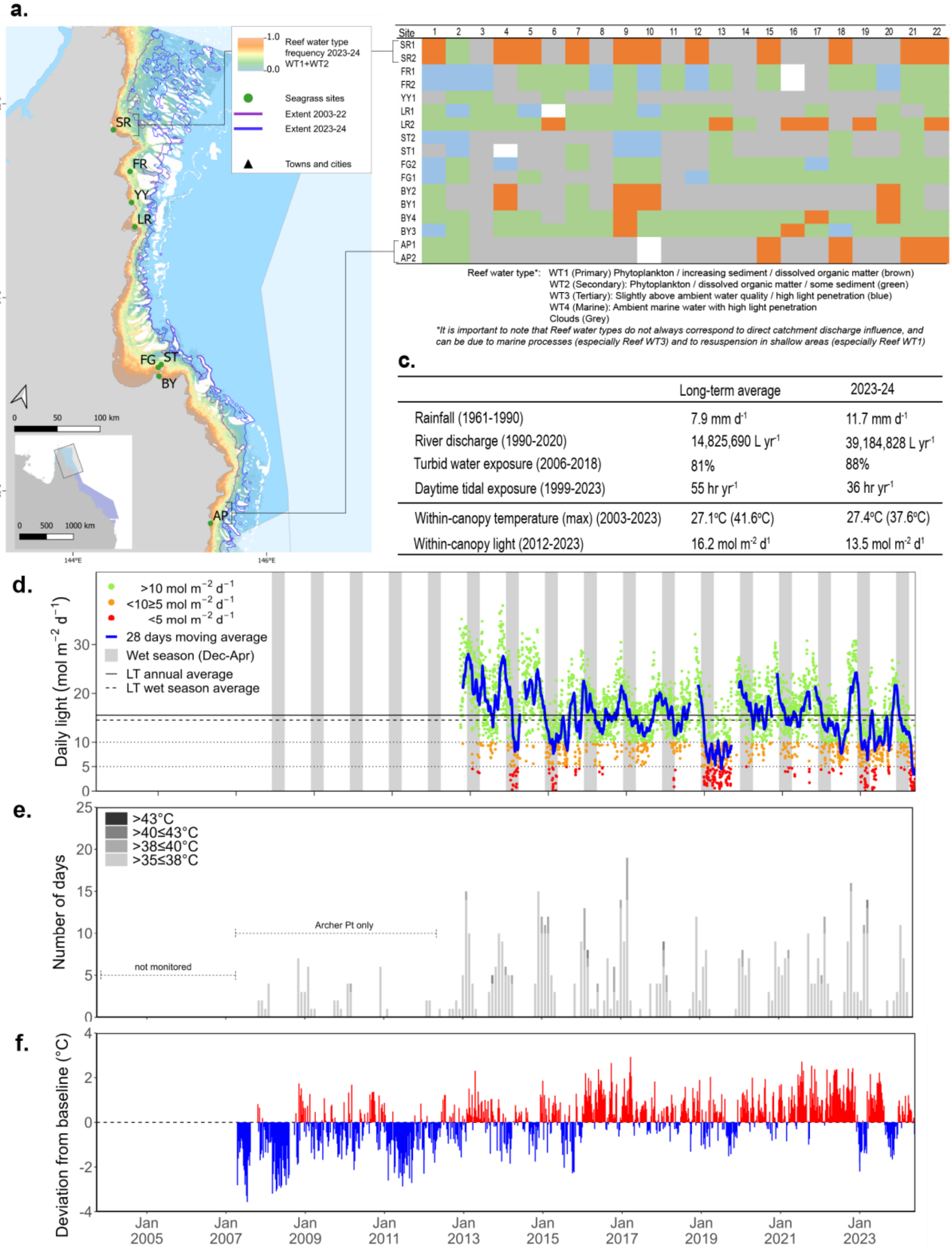
Wet season (December to April) rainfall in 2023–24 was above the 30-year long-term average (1961 to 1990) in the Cape York NRM region (Figure 25). Specifically, the Jeannie and Endeavour basins in the southern part of the region experienced wet season rainfall that 1.5 times the long-term average (Figure 5).

Annual discharge was at least 1.5 to 2 times above median from all basins in Cape York, with the exception of Jacky Jacky Creek in the far north, which was only slightly above median (Table 11). River basins in the south had the highest discharges relative to the long-term median (Table 11). Annual discharge was more than 3 times the long-term median from the Endeavour and Jeannie Rivers and more than 4 times the average from the Normanby River. Discharge from the Lockhart River was above median despite the low rainfall across the basin.

Exposure to water types 1 (WT1) and 2 (WT2) was slightly greater than the long-term average in Cape York but the calculation of this from satellite imagery was hampered by a frequent presence of clouds when the water types could not be determined (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). 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.

The risk of exposure of mapped seagrass to the water types are assessed in the water quality report (Moran et al 2025). In Cape York, 10% more of the mapped seagrass in Cape York was exposed to water quality risk (predominantly moderate risk category) in 2023–24 compared to the long-term average area of exposure.

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 2023–24, 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 Shelburne Bay and Stanley Island (Figure 98). Therefore, daily light at Bathurst Bay and Piper reef were the only contributors to the regional average through the wet season. Bathurst Bay has the lowest daily light of all Cape York sites on average and it was also lower in 2023–24 than usual particularly during the wet season. 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.




| | Long-term average | 2023-24 |
|---|---|---|
| Rainfall (1961-1990) | 7.9 mm d⁻¹ | 11.7 mm d⁻¹ |
| River discharge (1990-2020) | 14,825,690 L yr⁻¹ | 39,184,828 L yr⁻¹ |
| Turbid water exposure (2006-2018) | 81% | 88% |
| Daytime tidal exposure (1999-2023) | 55 hr yr⁻¹ | 36 hr yr⁻¹ |
| Within-canopy temperature (max) (2003-2023) | 27.1°C (41.6°C) | 27.4°C (37.6°C) |
| Within-canopy light (2012-2023) | 16.2 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 2023 to April 2024 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 Moran *et al* 2025), b. wet season water type at each site; c. average conditions and max temperature over the long-term and in 2023–24; 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.

2023–24 was cooler than the previous three years and the seventh warmest year on record 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 28 days (in total among all sites where temperature is monitored) during 2023–24 (Figure 25e), which was lower than 2023–23. The highest temperature recorded at 37.6°C (Bathurst Bay, 8Feb24). Daytime tidal exposure (hours water has drained from the intertidal meadow) was below the Cape York long-term median (Figure 25c, Figure 90).

In the Cape York NRM region, there was minimal alteration in the sediments of reef habitats, which continued to be primarily composed of sands and coarser grains (Appendix 2, Figure 105). During 2023–24, coastal habitats maintained their dominance of fine sand, while the rising mud levels in Bathurst Bay slightly fell below the long-term average at one location (BY2) (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 2023–24, 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 2023–24, 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 2023–24 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). This change was the result of a marginal decline in the abundance indicator, while the resilience indicator remained stable.

The abundance indicator slightly declined in 2023–24, losing some of the gains reported in the previous period (Figure 26). The declines were primarily driven by abundance scores deteriorating in the coastal intertidal habitat in Shelburne Bay (good to moderate) and the subtidal habitats in Margaret Bay (very good to good) and Bathurst Bay (poor to very poor), in the north and south of the region, respectively. The remaining coastal habitats either remained stable or slightly increased in intertidal and subtidal meadows, respectively. Additionally, reef intertidal habitats were stable in both the north and south, while the reef subtidal habitats monitored throughout the region continued to remain very poor.

The resilience score varied between coastal intertidal sites, showing increases at certain sites (SR2 in Shelburne Bay and BY1 in Bathurst Bay) while other sites experienced losses or remained stable. Overall, resilience increased at coastal intertidal habitats (Figure 26). Conversely, resilience declined at reef intertidal habitats, with a drop from moderate to poor at Stanley Island in the south, while remaining stable at Piper Reef in the north (Figure 26). Losses appear a consequence of reduced reproductive effort and diminished seed banks. It's important to note that resilience is only assessed for intertidal habitats in Cape York.

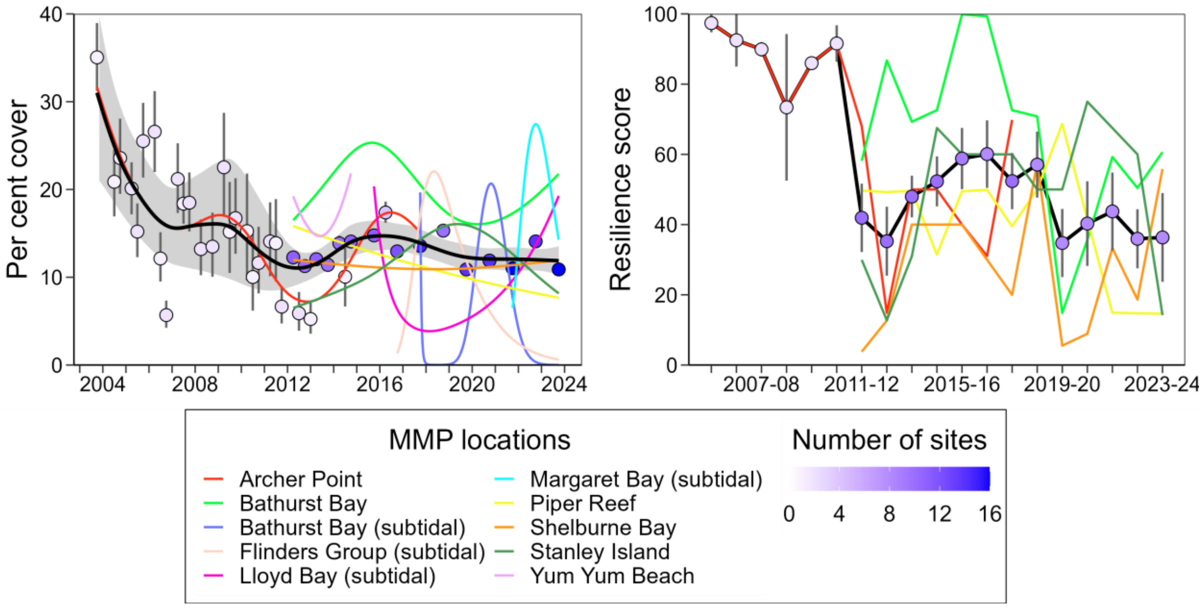



Figure 26. Temporal trends in the Cape York seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area defining 95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

A careful interpretation is necessary when examining the long-term trends in abundance across the Cape York NRM region, as new sites added in 2012–13 are linked to consistently lower abundance compared to the peak levels previously recorded for the region (Figure 26). Additionally, Archer Point, the sole location monitored before 2012–13, has 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 Cape York NRM regions average seagrass abundance slightly declined in 2023–24 to its lowest level (8.4 ± 1.4 per cent) since monitoring commenced. This decline was a consequence of deteriorating per cent cover in all habitats in 2023–24. The greatest decline was in both reef intertidal and subtidal habitats which deteriorated well below their respective long term averages to the lowest average (and near lowest median) abundances since monitoring began (Figure 27). While there was a marginal improvement in abundance at reef intertidal sites in the north (Piper Reef), these gains were offset by continued decline at Stanley Island (ST1 and ST2) in the south for the fifth year. Reef subtidal habitats at the Flinders Group (FG1 and FG2) have remained very low and have continued to decline since 2018-19, with abundances in 2023-24 the lowest since monitoring was established. (Figure 27). Coastal intertidal habitat abundances declined below their long-term average, following four years of consecutive increase, with levels in 2023–24 around the fifth lowest recorded. These losses were driven by sites (SR1 and SR2) located in Shelburne Bay in the north and one of the sites (BY2) in Bathurst Bay in the south. Coastal subtidal abundances in the north declined due to losses in Margaret Bay (MA1 and MA2), and replicate sites in Bathurst Bay in the south remain devoid of seagrass for the second year in a row (Figure 27). Nevertheless, coastal subtidal abundances overall remained above the long-term average for the region.

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 2023–24 wet season, the declines in subtidal and reef intertidal abundances are likely the legacy of flooding event in early February 2022 and above-average rainfall and discharges more than three times above the long-term median in the 2022–23 wet season.

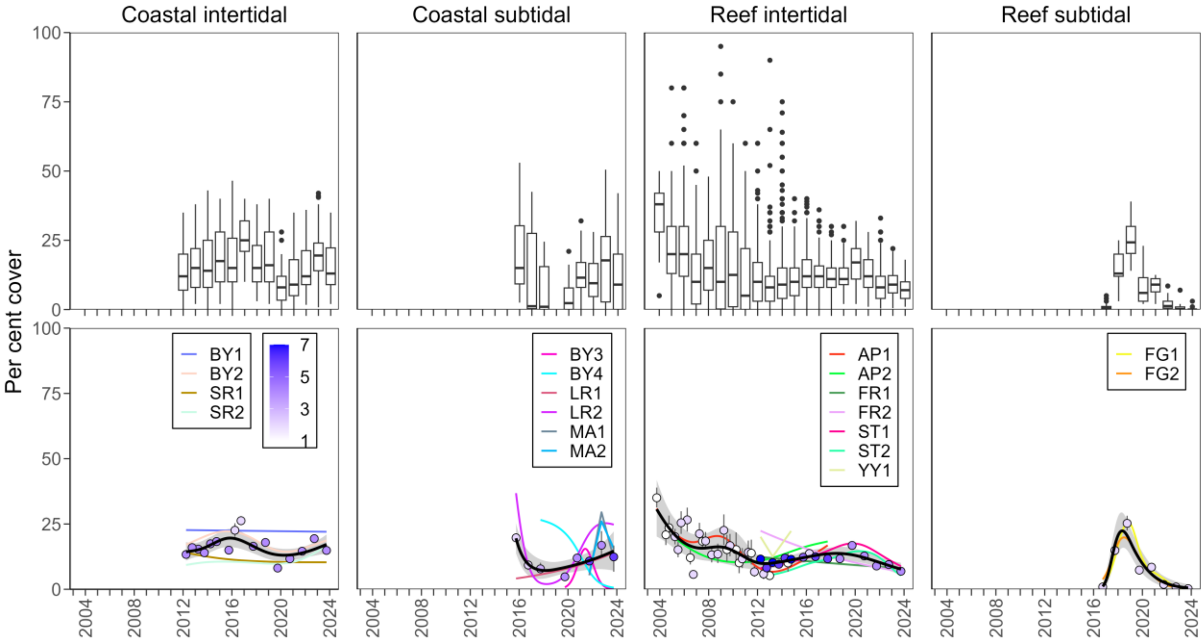



Figure 27. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends for each habitat monitored in the Cape York region from June 2005 to May 2024. Whisker plots (top) show the box representing the interquartile range of values, where the boundary of the box closest to zero indicates 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 throughout Cape York from 2003 to 2012. Following this period, there was a modest recovery, particularly at Stanley Island (e.g., ST2), however, 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 2023–24, the proportion of species displaying colonising species traits (*Halophila ovalis*) were lower than the previous reporting year in all Cape York habitats, except reef subtidal which remained unchanged. The proportions of colonising species in both coastal and reef subtidal habitats remained above the Reef long-term average, however, at coastal intertidal habitats it dipped below the Reef long-term average for the first time in seven years (Figure 28).

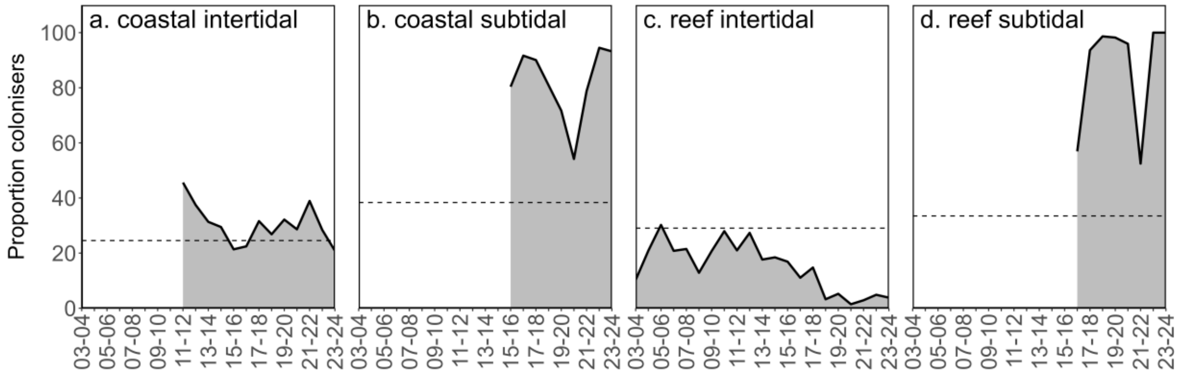



Figure 28. Proportion of seagrass abundance composed of colonising species at inshore intertidal habitats in the Cape York region, 2004 to 2024. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

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.

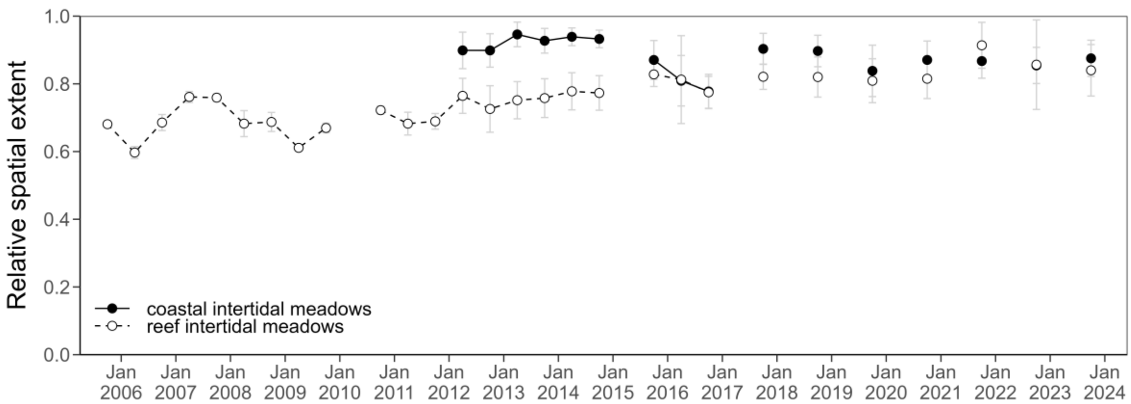



Figure 29. Change in relative spatial extent (± SE) of seagrass meadows within monitoring sites for each intertidal coastal and reef habitat and monitoring period across the eastern Cape York NRM region, 2005–2024.

### 5.1.3.3 Seagrass reproductive status

Reproductive effort increased at coastal habitats in 2023–24 but were well below the peak in 2016 (Figure 30). There were reproductive structures at both coastal locations at Shelburne Bay and Bathurst Bay. There were reproductive structures of both foundational and colonising species, though at Bathurst Bay the flowers were predominantly colonising species (*Halophila ovalis*). 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, which is typical of reef habitats throughout the Reef. In 2023–24 there was no reproductive effort at reef intertidal meadows. 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 and it will affect genetic diversity (i.e. low resilience).

Seed banks 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. Seeds were present at Bathurst Bay in 2023–24 but there were no seeds at Shelburne Bay resulting in a low seed density or coastal sites overall (Figure 30). Seeds are typically low in density or absent in reef intertidal habitats, and in 2023–24 none were recorded (Table 5).

Reproductive effort and seeds are only monitored at intertidal meadows in Cape York.

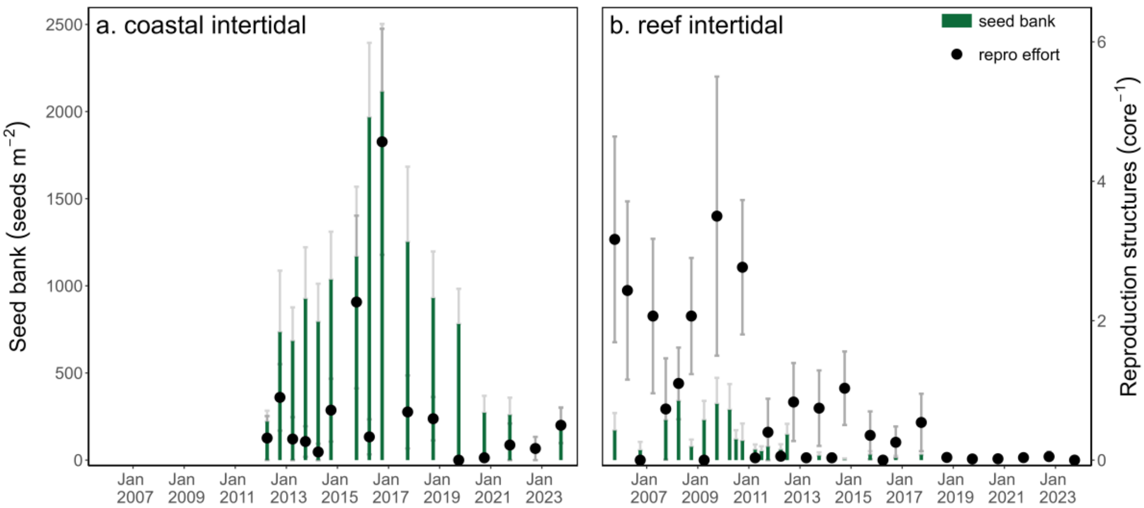



Figure 30. Seed banks and reproductive effort at inshore intertidal coastal (a) and reef (b) habitats in the Cape York region, for late dry season, 2005–24(species and sites pooled). Seed banks (green bars, ± SE) presented as the total number of seeds per m$^2$ sediment surface. Reproductive effort (dots, ± 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 2023–24, the resilience score was low overall and the fourth lowest on record remaining unchanged from 2022–23.

At coastal sites, the score increased in 2023–24 to the fourth highest score on record. At BY1, abundance was stable and there was persistent species and reproductive structures present (albeit a low count) and therefore in the highest category. At BY2 abundance increased and there were persistent species, but there have been no reproductive structures present for more than three years and so the score was in category 2.1.1. In Shelburne Bay, at site SR1, total abundance was below the low resistance threshold and there were no reproductive structures, but foundational species dominated. By contrast at SR2, the resilience score increased substantially with foundational species dominating, persistent species present and a high count of reproductive structures in 2023–24 leading to a score of 100.

Resilience declined at reef intertidal sites leading to the lowest reef score since monitoring began. Cover was below the resistance thresholds at all reef sites, and there were no reproductive structures present, so they were all in category 1.1 but being dominated by foundational species had high scores in this category (14–15).

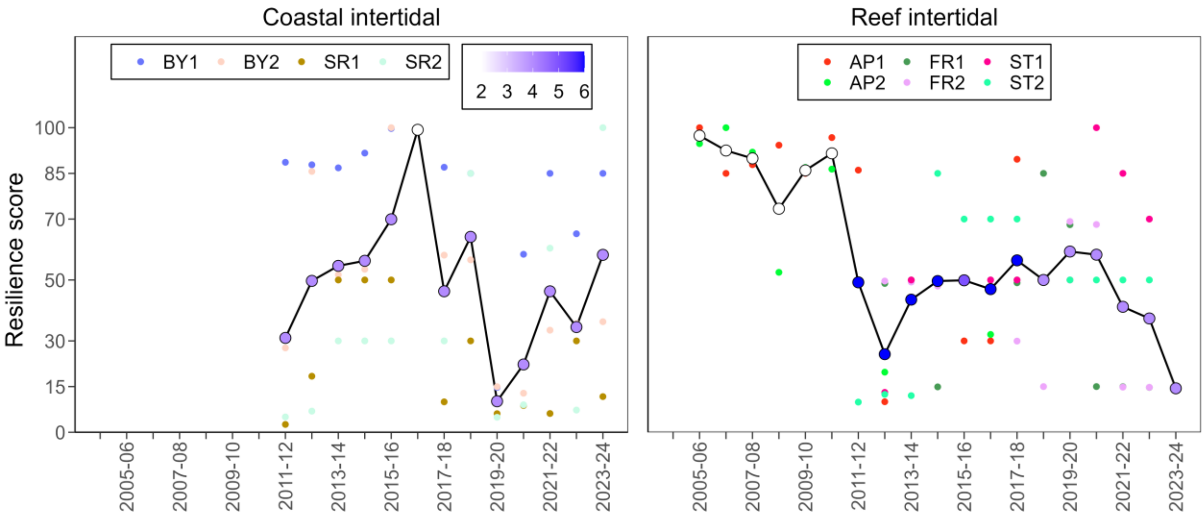



Figure 31. Temporal trend in the resilience score for each habitat monitored in the Cape York NRM region from 2005–2024. Coloured small points represent different sites. Shades of blue for the larger points indicate the number of sites that contribute to the score.

### *5.1.3.5 Epiphytes and macroalgae*

In 2023–24, epiphyte cover on seagrass leaf blades in intertidal coastal habitats decreased relative to the previous period, but remained slightly above the long-term average. Meanwhile, epiphyte cover in intertidal reef habitats remains below the long-term average for the sixth consecutive year (Figure 32). In subtidal waters, epiphyte cover at coastal and reef habitats was below the long-term average (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 seventh consecutive year (Figure 32b), whereas it has remained above at reef sites for the third year in a row (Figure 32f and 32h). 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 can be variable at subtidal habitats at both coastal and reef environments, and in 2023–24 continued to remain below the overall inshore Reef long-term average.

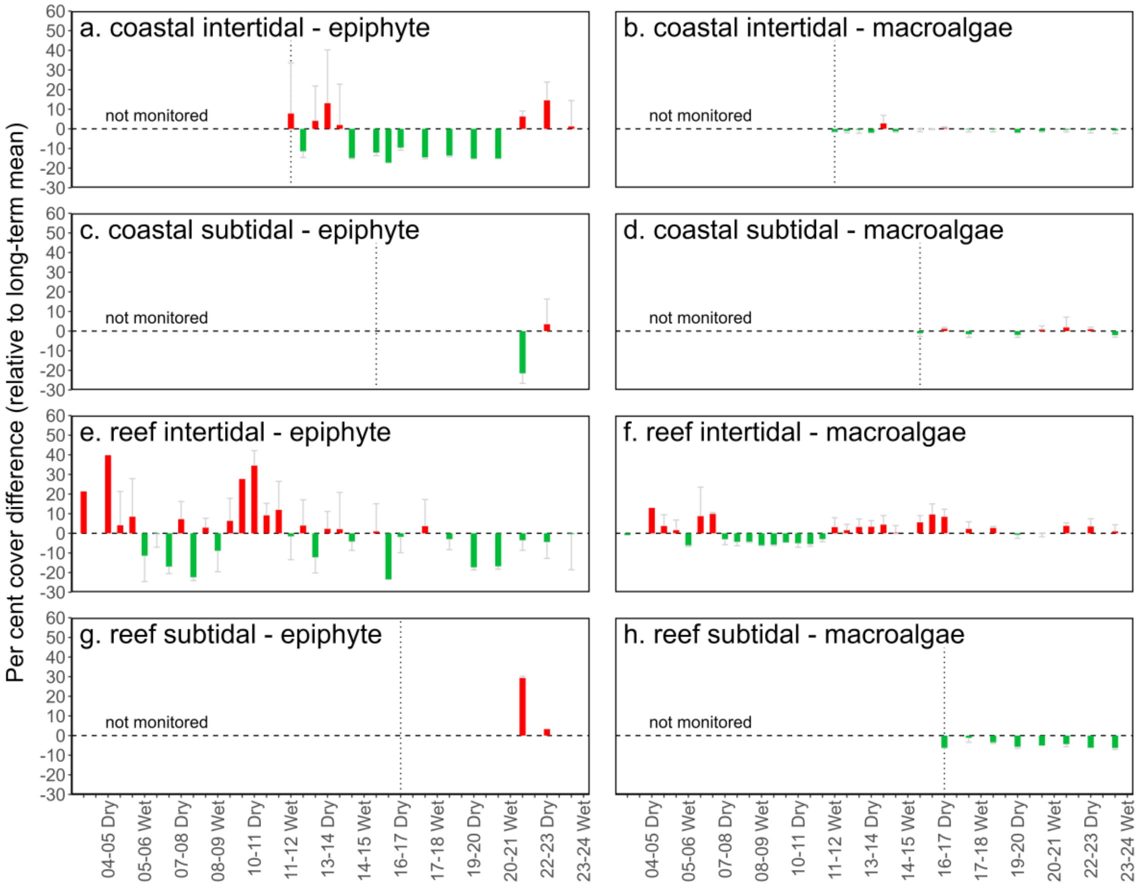



Figure 32. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Cape York, 2001–2024 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

## 5.2 Wet Tropics

### 5.2.1 2023–24 Summary

In 2023-24, seagrass habitats in the northern Wet Tropics were affected by above-average rainfall. There was moderate to intense rainfall associated with ex-cyclone Jasper particularly in the days after it made land fall. There was above-median river discharge reaching 5-6 times the average in the Barron and Daintree Rivers. There was also above-average exposure to turbid waters and below-average daily light. The elevated discharge from Wet Tropics basins. Exposure to primary (WT1) or secondary (WT2) turbid water was also higher than the long-term average across the northern Wet Tropics during 2023–24 but the area of seagrass exposed to water quality risk was around average for all risk categories combined. Daily light levels were below average but within-canopy temperature was around the long-term average.

Seagrass habitats in the southern Wet Tropics were predominantly affected by above-average rainfall, river discharge that was double the long-term average, turbid water (WT1 and WT2) exposure that was above average and below-average daily light. Within canopy temperature was around the long-term average.

Seagrass meadows within the Wet Tropics declined overall with the Seagrass Index dropping across the region in 2023–24. Seagrass condition in the northern Wet Tropics NRM region dropped to moderate grade, after reaching its highest score in five years for the sub-region in the previous year. Condition similarly deteriorated in the southern Wet Tropics, but remained poor (Figure 33). The combined regional condition was **poor** (Figure 33).

Contributing indicators in the north were:

- abundance was moderate
- resilience was moderate.

Contributing indicators in the south were:

- abundance was very poor
- resilience was moderate.

In the northern Wet Tropic areas, seagrass abundance declined during the 2023–24 period compared to earlier years, primarily due to reductions in coastal intertidal and reef subtidal sites. Likewise, resilience diminished across all habitats in the north, with the exception of Low Isles, where it was already quite low. These declines were attributed to adverse climatic and environmental conditions affecting the sub-region.

In contrast to the northern sub-region, abundances in the southern Wet Tropics were low and marginally increased overall in 2023-24. This was particularly attributed to the increase in abundance in the reef and coastal intertidal habitats. However, the persistently low abundances within this sub-region appear a legacy of the losses experienced between 2009 and 2011, caused by several years of severe weather, above-average rainfall, and elevated discharge. The recovery of seagrass meadows since 2011 has been challenged, particularly in the south, due to unstable substrates, chronic poor water quality compared to the north (characterised by high turbidity and light limitation) and limited recruitment capacity.

Resilience declined overall from good to moderate in the northern Wet Tropics due to declines at reef habitats. Resilience at reef intertidal sites was the lowest on record because there were no reproductive structures at all three sites, and there had not been for more than three years at two of the sites. There were also no seeds in reef intertidal habitats. Resilience also declined at reef subtidal sites where there were no reproductive structures. Resilience was the highest at coastal sites because abundance and composition ere above critical thresholds and reproductive structures were present. However, seed density was well below average.

In the southern Wet Tropics resilience declined but remained moderate for the third year in a row. There were no reproductive structures at the reef intertidal sites, where the score declined in 2023–24 compared to 2022–23. However, in reef habitats seed density was the highest on record since 2005–06 so there has been reproduction at some time in previous years. The score increased slightly at coastal sites and reef subtidal sites. But seed banks declined again in coastal habitats in 2023–24.

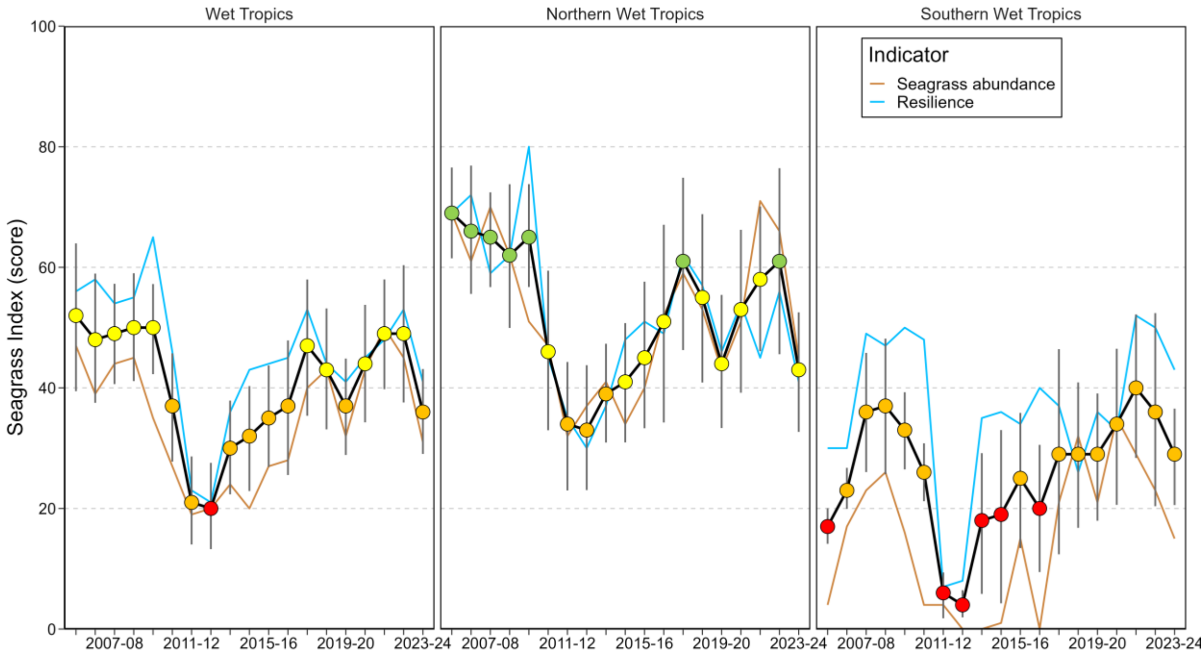



Figure 33. Temporal trend in the Seagrass Index (± SE) with contributing indicator scores for the Wet Tropics NRM region and sub-regions (average across habitats and sites). Values are indexed scores scaled 0–100 (± SE) and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor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

### 5.2.2 Climate and environmental pressures

In 2023-24, seagrass habitats in the northern Wet Tropics were predominantly affected by above-average rainfall, above-median river discharge, above-average exposure to turbid waters and below-average daily light.

Tropical Cyclone Jasper made landfall near the Wet Tropics and Cape York NRM region's boundaries and affected both regions. Jasper formed offshore reaching a category 5 tropical cyclone on the 7th December, but as it approached the shore it weakened then re-intensified making landfall as a category 2 cyclone at Wujal Wujal on the 13th December 2024. Jasper then weakened into a low and moved overland until the 18th December. There was moderate to intense rainfall associated with the system particularly in the days after it made land fall.

Annual daily rainfall in the northern Wet Tropics basins was almost double the long-term average for the region on average (Figure 34). The most northern basins had the highest deviations with rainfall being double the long-term average in the Daintree, Mossman and Barron River basins, while the southern rivers were around 1.5 times the long-term average.

Annual discharge was at least 1.5 to 2 times above median from all basins in the Wet Tropics, where the highest discharges relative to the long-term median were in the north (Table 11). Annual discharge was between 5-6 times the long-term median from the Barron and Daintree River basins in the north of the region, while discharges from the Herbert River basin in the south were 2–3 times the long-term median (Table 11).

Exposure to primary (WT1) or secondary (WT2) turbid water was also higher than the long-term average across the northern Wet Tropics during 2023–24 (Figure 34a, b). Sites were primarily exposed to WT2 except at Yule Point where there was more exposure to WT1 (Moran *et al.* 2025). Daily light levels at the intertidal sites (12.3 mol $m^{-2}$ $d^{-1}$ in 2023–24) were lower than the long-term average (16.0 mol $m^{-2}$ $d^{-1}$) in the northern Wet Tropics (Figure 34c, d). This is predominantly due to low light during the wet season at Green Island (Figure 99).

The risk of water quality exposure of mapped seagrass are assessed in the water quality report (Moran *et al.* 2025). In the Wet Tropics (north and south combined), there was a 9 % increase in exposure to the low-risk category in 2023–24 compared to the long-term average and decrease in exposure to the high-risk category (-12 %), leading to no significant change to exposure on average.

Intertidal within-canopy temperature in 2023–24 in the northern Wet Tropics was the same as the long-term average (Figure 34e). Maximum intertidal within-canopy temperatures exceeded 35.0 °C for a total of 50 days during 2023–24, 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 46.5 °C at Low Isles (LI1) on the 09 April 2024.

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.

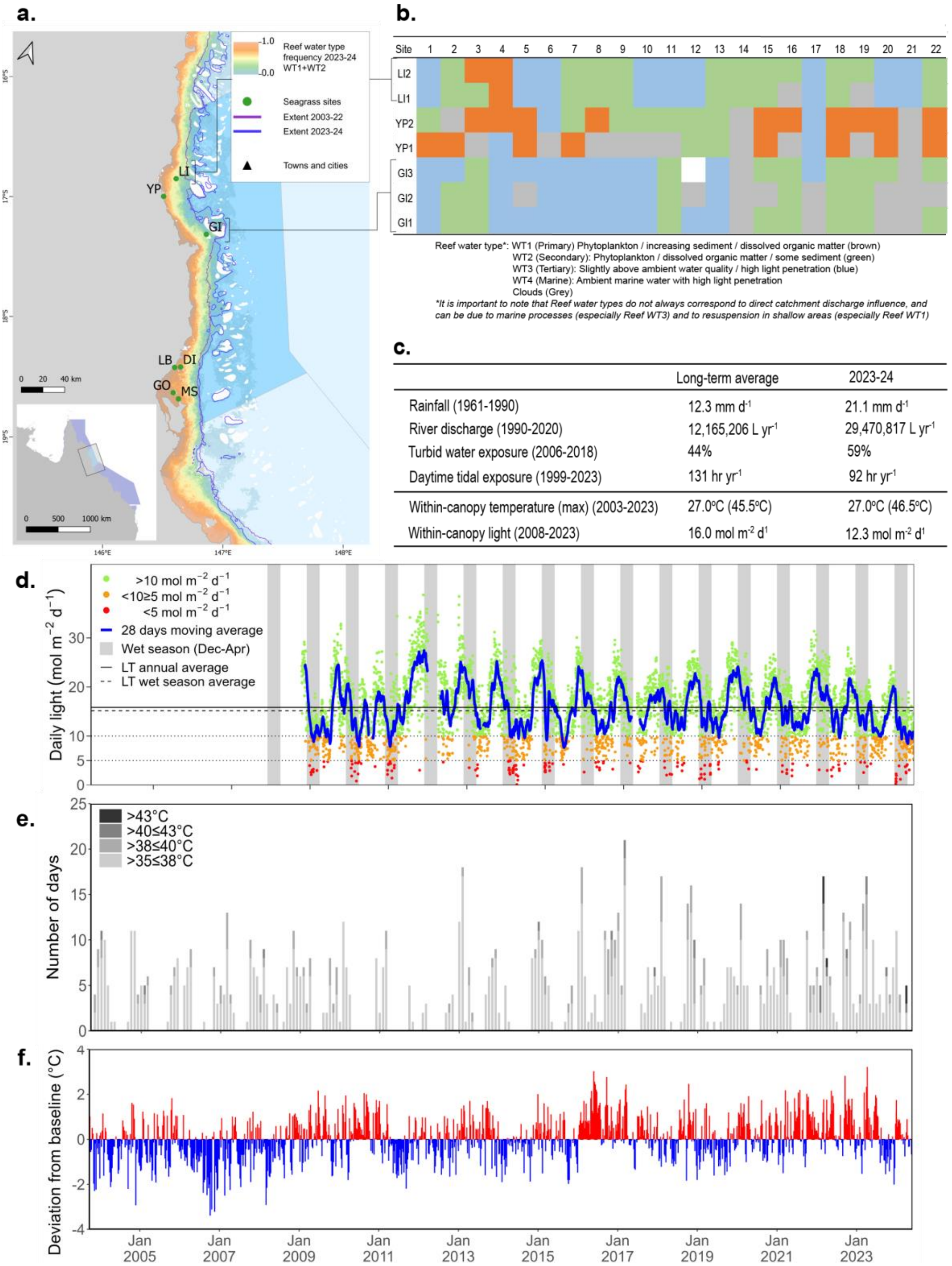



Figure 34. Environmental pressures in the northern Wet Tropics region including: a. frequency of exposure to primary (WT1) and secondary water (WT2) from December 2023 to April 2024 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the 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 Moran *et al* 2025); b. wet season water type at each site; c. average conditions and max temperature over the long-term and in 2023–23; 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 2023–24, seagrass habitats in the southern Wet Tropics were predominantly affected by above-average rainfall, river discharge and below-average daily light.

In the southern Wet Tropics, annual rainfall was greater in 2023–24 than the long-term average (Figure 35) and elevated in all river basins (Figure 5). Discharge from southern Wet Tropics rivers during the 2023–24 wet season was almost double the long-term average (Figure 5). Discharge was more elevated in the most northern Tully River where it was almost double the long-term average and discharge was less elevated towards the southern Rivers. Exposure to turbid water occurred on 91 per cent of weeks during the wet season, which was a lower level of exposure than average (97 per cent) (Figure 35a, c). There was limited exposure to WT1 (increasing sediment) and more exposure to WT2 (phytoplankton, dissolved organic matter, some sediment) at all sites including coastal sites at Lugger Bay (LB1 and LB2) and Missionary Bay (MS1 and MS2) (Figure 35b).

Light levels (with an annual average of 9.9 mol $m^{-2}$ $d^{-1}$) was considerably lower than the long-term average of 15.8 mol $m^{-2}$ $d^{-1}$ (Figure 35d, Figure 100), for the second year in a row. This decrease was due to very low wet season light levels while dry season light levels were around average (Figure 35d). It is important to note that light measurements were only recorded at Dunk Island in the southern Wet Tropics.

Dunk Island is also the only location where within-canopy temperatures are measured in the southern Wet Tropics. In 2022–23, temperatures were the same as the long-term average for the second year in a row (Figure 35b). However, the maximum intertidal within-canopy temperatures exceeded 35°C on just 3 days. The highest temperature recorded during this period was 37.2°C at DI2 on 26 October 2024 (Figure 35e, f). It is worth noting that daytime tidal exposure has been well below average for four consecutive years (Figure 35b, Figure 91, Figure 92), which could be a contributing factor to the lower temperatures.

In the Wet Tropics region, coastal sediments mainly consisted of fine sand, while reef habitats featured a mix of sand and coarser sediments (Figure 109, Figure 110). In 2023–24, sediments at the intertidal monitoring sites remained stable and similar to the long-term average (Figure 109, Figure 110). Subtidal sites, however, experienced a slight reduction in finer sediments with coarser sediments becoming more prevalent (Figure 109).

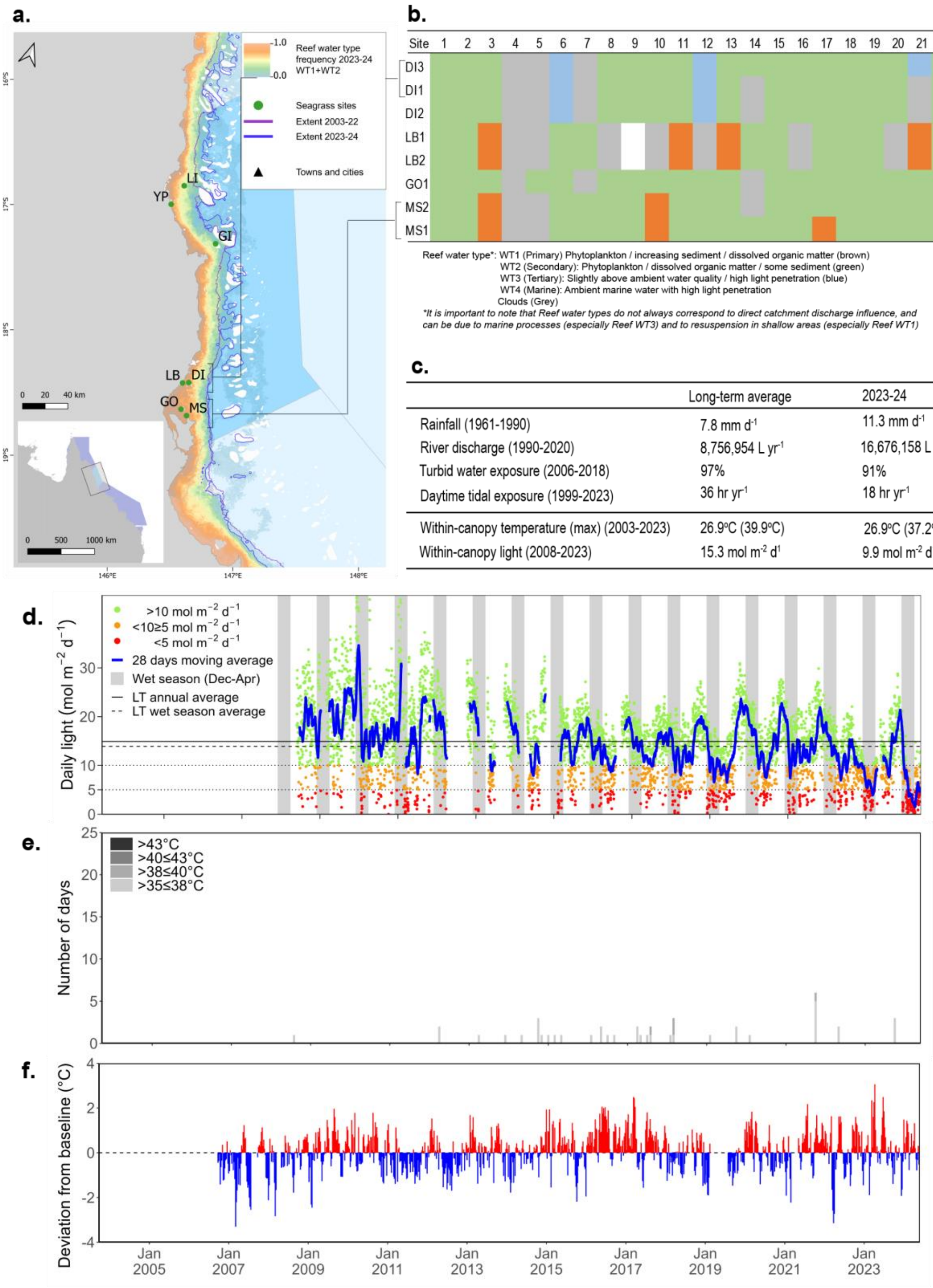



Figure 35. Environmental pressures in the southern Wet Tropics region including: a. frequency of exposure to primary (WT1) and secondary (WT2) water from December 2023 to April 2024 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the long-term average (2003–18) exposure boundary (purple line), and the first (blue line) and third quartile (white line) of the long-term average (from Moran *et al.* 2025); b. average conditions and max temperature over the long-term and in 2023–24; 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 13 of the 15 long-term monitoring sites in 2023–24 (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 2023–24, 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 2023–24 monitoring period, the Seagrass Index for the overall Wet Tropics region deteriorated from the previous period and was **poor** (Figure 33), the result of declines in both indicators. There were differences in the level of decline of the indicators between sub-regions, with the greatest declines in the northern Index.

In the northern Wet Tropics, seagrass abundance deteriorated with the indicator score declining by one-third, resulting in a grade change from good to moderate (Figure 33). This decline was observed across all northern habitats, as scores for coastal intertidal and reef subtidal halved during 2023–24 from the previous period, while decline in reef intertidal score was marginal. In the southern sub-region, abundance scores decreased for both subtidal habitats (coastal and reef), though coastal intertidal habitats remained stable. The only increase in abundance scores was noted in the reef intertidal meadow at Dunk Island, although its grade remained unchanged and poor. The long-term trend in seagrass per cent cover shows a period of decline from 2008 to 2012 (Figure 36), coinciding with Reef-wide declines associated with extreme weather. However, after this period of decline, seagrass per cent cover rebounded across the Wet Tropics. Since 2018, there have been only minor fluctuations in abundance compared to other regions, until the decline observed in 2023–24 (Figure 36).

Resilience in the northern Wet Tropics has shown annual fluctuations over the past six years, experiencing a series of increases and decreases, ultimately declining from the previous period in 2023–24 (Figure 36). The recent decline can be attributed to lower resilience scores observed at Green Island (both reef intertidal and subtidal) and Yule Point (intertidal coastal) habitats in 2023–24. Coupled with moderate to good abundance scores, this indicates that the intertidal meadows at Green Island and Yule Point have a higher capacity to recover from recent impacts. However, the reduced scores in the subtidal habitats at Green Island suggest these meadows may struggle to withstand additional pressures in the near future. The meadows at Low Isles (intertidal and subtidal) with very poor abundance and resilience may also be vulnerable to further pressures in future.

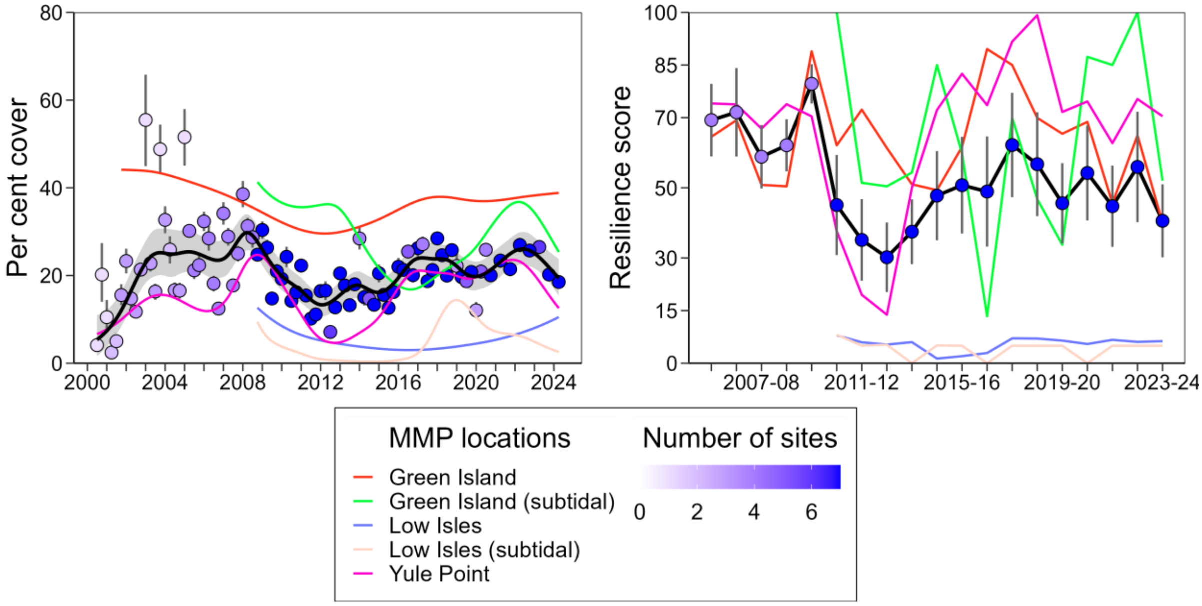



Figure 36. Temporal trends in the northern Wet Tropics seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area 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 for the second year after reaching its highest level in 2021–22 (Figure 33). This decrease was driven by deterioration in both abundance and resilience indicators. Since 2012–13, both the abundance and resilience indicators have been highly variable, often with what appears as an annual lag from abundance to resilience (Figure 33). The abundance indicator, which saw a drop for the third year in a row, was driven by reduced abundances at both the subtidal coastal and reef sites (Figure 37). The decline in the resilience indicator was attributed to diminished resilience at the reef intertidal sites (Dunk Island), which fell from very good to moderate. However, this decline was somewhat mitigated by increased resilience at the coastal intertidal sites (Lugger Bay), which improved from very poor to poor grade in 2023–24 (Figure 37).

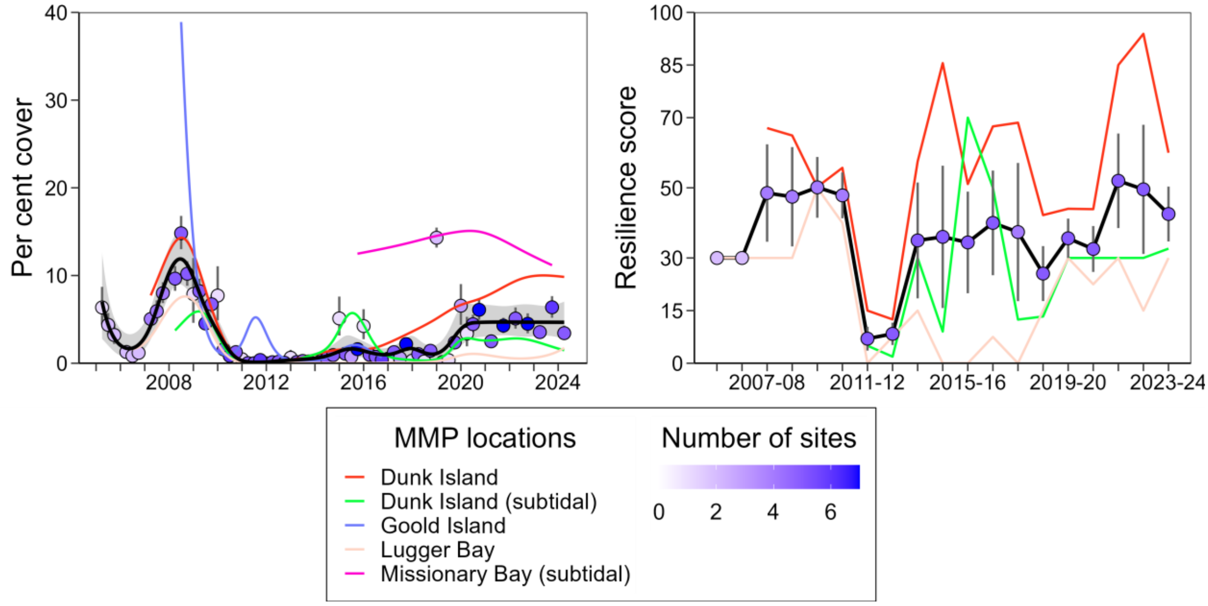



Figure 37. Temporal trends in the southern Wet Tropics seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area 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 2023–24, seagrass abundances declined on average across the northern Wet Tropics (Figure 38), primarily due to losses in coastal intertidal and reef subtidal habitats. The intertidal coastal meadows at Yule Point experienced a decrease compared to the previous period, and in 2023-24 were below the long-term average for the first time in nine years. Additionally, reef subtidal seagrass abundances at Green Island decreased for the second consecutive year, while at Low Isles, both intertidal and subtidal abundances remained low and relatively stable (Figure 38). Meanwhile, reef intertidal abundances at Green Island remained above the long-term average throughout the 2023-24 period (Figure 38).

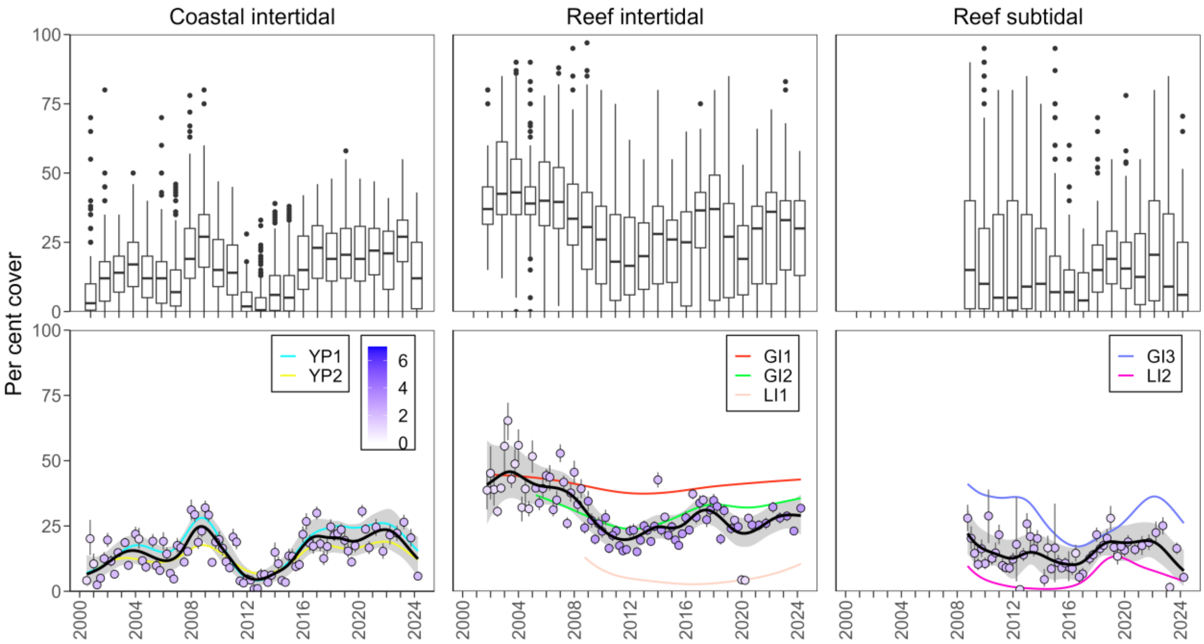



Figure 38. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends, for each habitat monitored in the northern Wet Tropics NRM region from 2001 to 2024. Whisker plots (top) show the box representing the interquartile range of values, where the boundary of the box closest to zero 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 fraction 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. In Lugger Bay's coastal habitats, seagrass meadows have struggled with complete loss for years, marking 2023–24 as the 15th consecutive year of abundances significantly 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. Coastal subtidal abundances have changed little since monitoring was established in 2015, with a marginal decline in 2023–24 (Figure 39). In contrast, intertidal reef seagrass abundance remains on an increasing trajectory since 2012–13, with abundances in 2023–24 being the highest since 2009. However, abundances at reef subtidal habitats have remained low over the long-term, deteriorating in 2023–24 to the lowest levels in six years (Figure 39).

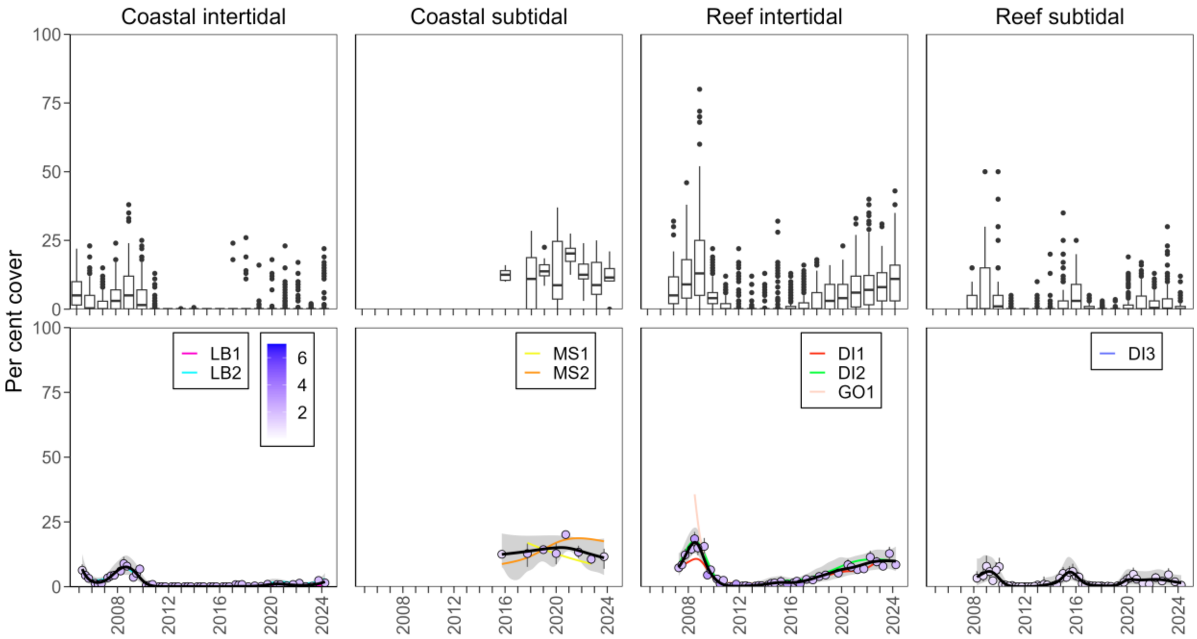



Figure 39. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends, for each habitat monitored in the southern Wet Tropics NRM region from 2001 to 2024. Whisker plots (top) show the box representing the interquartile range of values, where the boundary of the box closest to zero 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 (e.g., *Halophila* spp.) in the northern Wet Tropics has remained above the long-term average at reef habitats in 2023–24 (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.

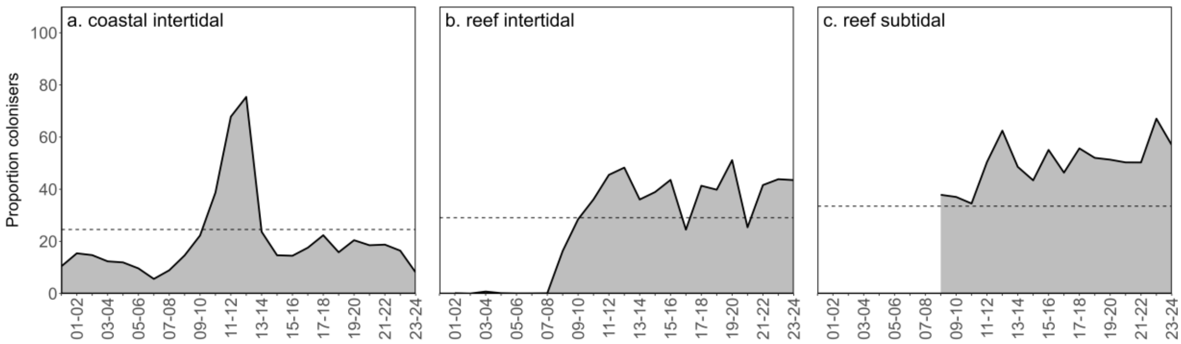



Figure 40. Proportion of seagrass abundance composed of colonising species at inshore intertidal habitats in the northern Wet Tropics region, 2001 to 2024. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

In the southern Wet Tropics, the proportion of colonising species remains variable across habitats (Figure 41). Coastal habitats appear unchanged, primarily dominated by opportunistic species, while the subtidal regions show a greater proportion of colonising species. Although colonising species remained in low proportions in reef habitats, their proportion increased intertidally during 2023–24.

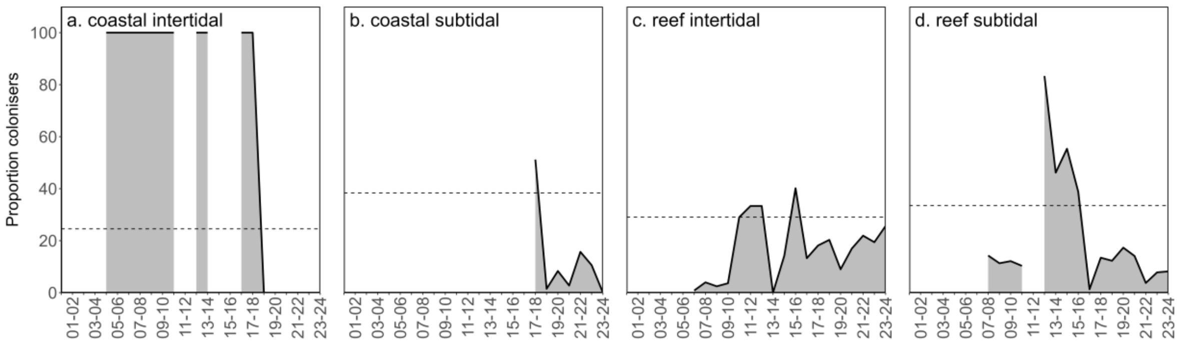



Figure 41. Proportion of seagrass abundance composed of colonising species at inshore intertidal habitats in the southern Wet Tropics region, 2001 to 2024. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

The spatial extent of seagrass meadows at all monitoring sites continues to show fluctuations both within and across years. In the intertidal reef habitats of the northern Wet Tropics, the relative extent of meadows has improved compared to the previous reporting period (Figure 42). Over the long term, the meadow at Green Island shows minimal annual variation, while the fluctuations in the intertidal reef meadows in the northern Wet Tropics are largely influenced by changes at the Low Isles meadow. The most considerable changes in 2023-24 occurred in the coastal intertidal and reef subtidal meadows towards the end of 2023 (Figure 42), which were severely affected by cyclone Jasper and the associated flooding. The intense wave action led to significant scouring of the coastal intertidal banks, resulting in considerable meadow fragmentation. For example, the extent of the coastal intertidal meadow at Yule Point (YP1) decreased from 3.14 ha prior to cyclone Jasper to 0.98 ha afterward. Additionally, the suspended sediments and floodwaters brought by the cyclone reduced light availability, contributing to the decline of the subtidal meadows.

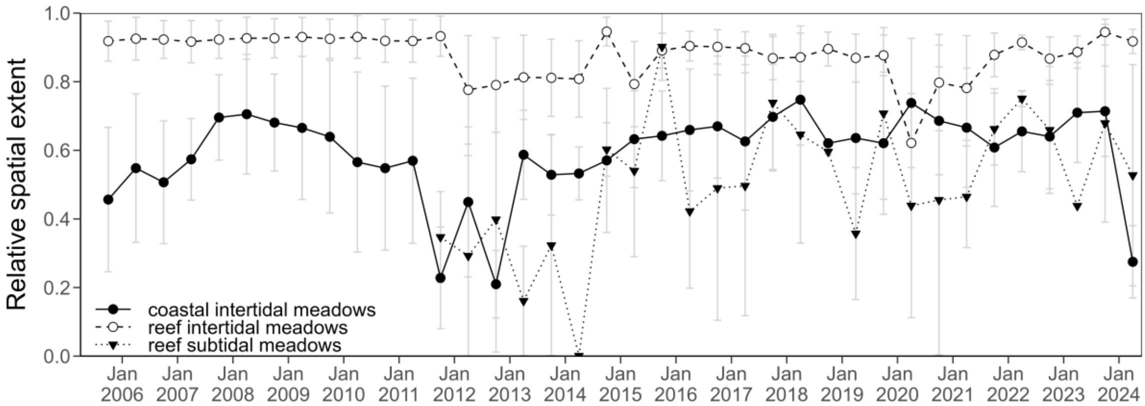



Figure 42. Change in relative spatial extent (±SE) of seagrass meadows within monitoring sites for each habitat and monitoring period across the northern Wet Tropics NRM region, 2005–2024.

In the southern Wet Tropics, seagrass meadows across all habitats were devastated in early 2011 as a consequence of cyclone Yasi (Figure 43). Since that time, intertidal reef meadows have progressively improved, reaching their greatest post–2011 extent in 2023–24 (Figure 43). Conversely, subtidal reef meadows greatly declined in 2023–24, following several years of significant recovery (Figure 43). For intertidal coastal habitats, recovery has been severely protracted since 2011, with colonisation delayed until mid-2018 (Figure 43). Following this, isolated seagrass patches have struggled to expand and coalesce in a highly dynamic environment with mobile sediments (pers. obs.).

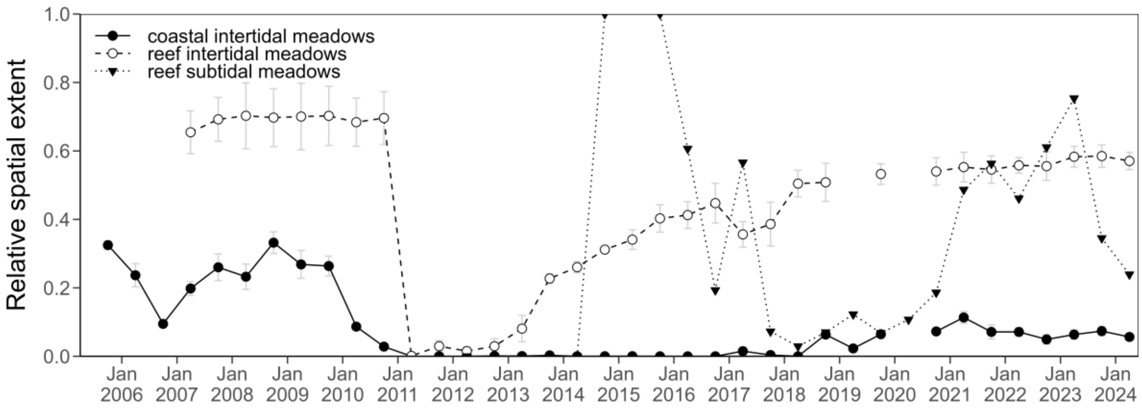



Figure 43. Change in relative spatial extent (±SE) of seagrass meadows within monitoring sites for each habitat and monitoring period across the southern Wet Tropics NRM region, 2005–2024.

#### *5.2.3.3 Seagrass reproductive status*

Reproductive effort is measured in both the late dry and late wet seasons in the Wet Tropics. Reproductive effort was again higher in the northern sub-region than the southern sub-region (Figure 44 Figure 45). In general, reproductive effort and seed density have been maintained in the northern Wet Tropics in the last six years, though with some variability among habitats and regions. In the northern Wet Tropics in coastal intertidal habitats (Yule Point), reproductive effort in 2023–24 was reduced compared to the previous two years and 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 there was reproduction of both foundational and colonising species. In intertidal reef habitats there was an increase in reproductive structures to the fourth highest level since 2005–06. This was in the late wet season, which is not typically the peak time of year for reproduction, but they were all colonising species' (*Halophila ovalis*) reproductive structures which have less distinct seasonal pattern of reproduction compared to foundational species. In reef subtidal habitats, reproductive effort in 2023–24 was reduced again and all reproductive structures were of colonising species (Figure 44).

Seed density at coastal intertidal habitats was well below the long-term average in the northern Wet Tropics in 2023–24. There were no seeds at YP1 in the dry season for the first time since 2015 and none at YP2 in the late wet season (Figure 44). To date, seed banks have remained very low across the region in reef habitats (Figure 44). There were no seeds in 2023–24 at any of the reef intertidal sites. This is likely the result of the greatly depressed reproductive effort in foundational species with most reproductive structures occurring on colonising species and the seeds of this species are not assessed in seed bank analysis because they are too small. 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). Reef subtidal sites are not assessed for seed banks.

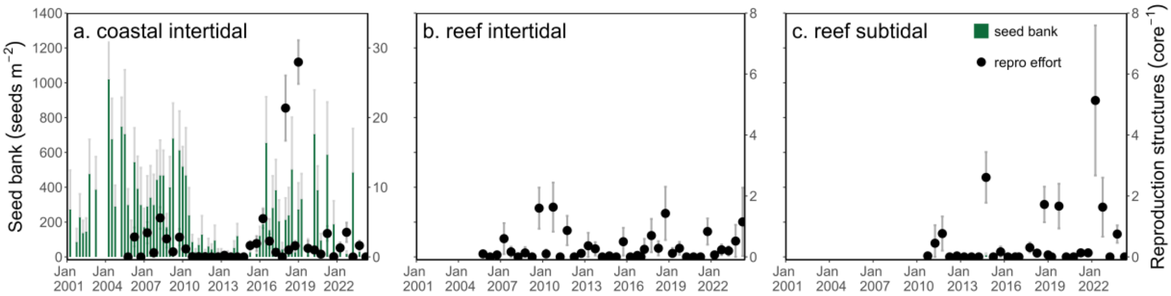



Figure 44. Seed bank and reproductive effort at inshore coastal intertidal and reef intertidal and subtidal habitats in the northern Wet Tropics region, 2001 to 2024. Seed banks presented as the total number of seeds per m$^2$ of sediment surface (green bars ±SE). Reproductive effort presented as the 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 were absent from coastal intertidal meadows for the 11$^{th}$ consecutive year (Figure 45). However, there were seeds in both the late dry and wet seasons although the density was reduced compared to 2022–23, so there has been reproduction in recent years that was not measured. At reef intertidal habitats, there were no seeds in the late dry season, but seed density was the highest on record in the late wet season (Figure 45).

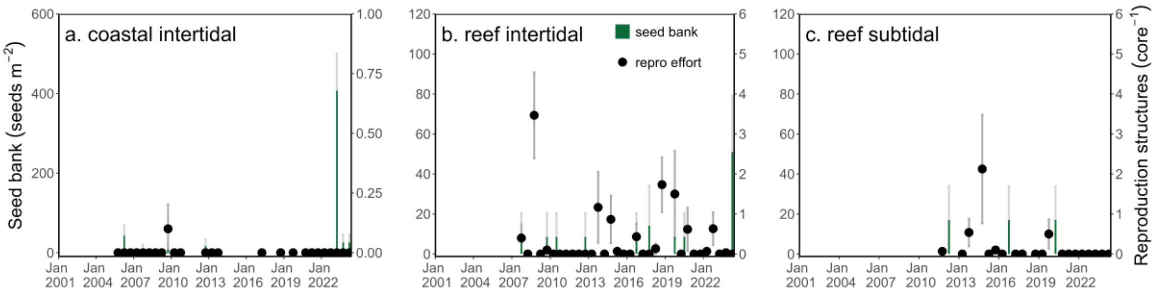



Figure 45. Seeds banks and reproductive effort for inshore coastal intertidal and reef intertidal and subtidal habitats in the southern Wet Tropics region for the late dry and late wet season, 2001 to 2024.Seed banks presented as the total number of seeds per m$^2$ sediment surface (green bars ±SE). 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 in 2023–24 declining from good in 2022–23 (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 there was a low count of structures (Table 23).

At reef intertidal sites, resilience declined in 2023–24 compared to the previous year and was the lowest on record. At Green Island, cover was above critical thresholds for abundance and composition, but reproductive structures were absent again and have been for more than three years at GI1 while GI2 had reproductive structures in 2022–23. At Low Isles, colonising species continue to dominate the species composition, resulting in a low resilience score.

Resilience decreased at Reef subtidal sites due to a large decline at Green Island (GI3) where there were no reproductive structures of foundational species but there had been in previous years. 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.

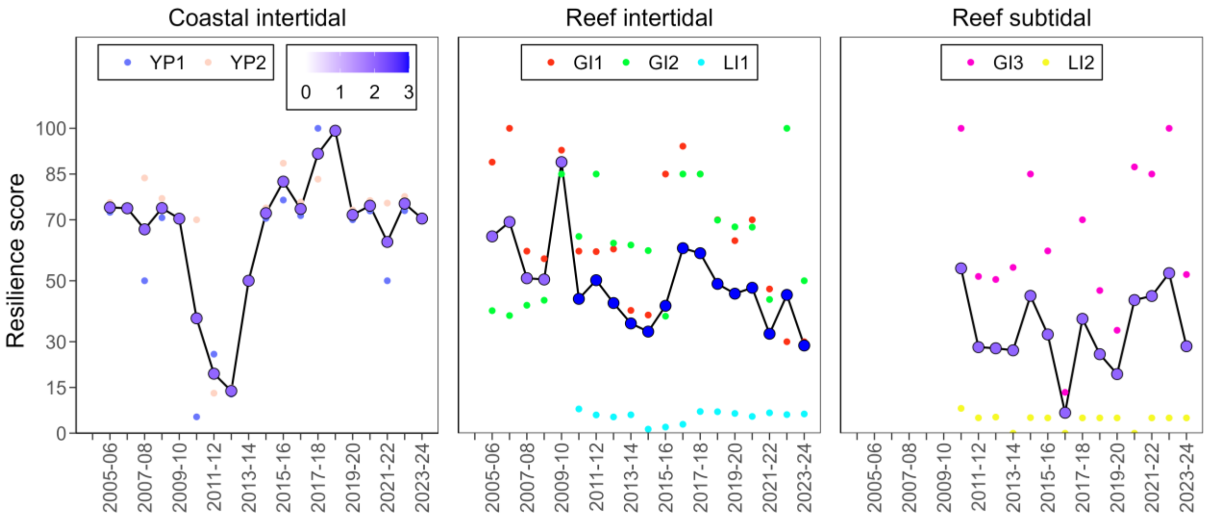



Figure 46. Resilience score for each habitat type in the northern Wet Tropics. Coloured small points represent different sites. Shades of blue for the larger points indicate the number of sites that contribute to the score.

In the southern Wet Tropics, resilience declined but remained moderate for the third year in a row. At the coastal intertidal sites at Lugger Bay, the meadow was above 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 (Figure 47 Table 23).

At reef intertidal sites at Dunk Island resilience declined at both sites because there were no reproductive structures present at either site, but at DI2, there was a higher count of persistent species resulting in the highest score (70) within category 2.1.2 and very low at DI1 resulting in the lowest score of the same category (50). At the reef subtidal sites, the resilience score was similar to the previous four 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 2023–24 or in the previous three years.

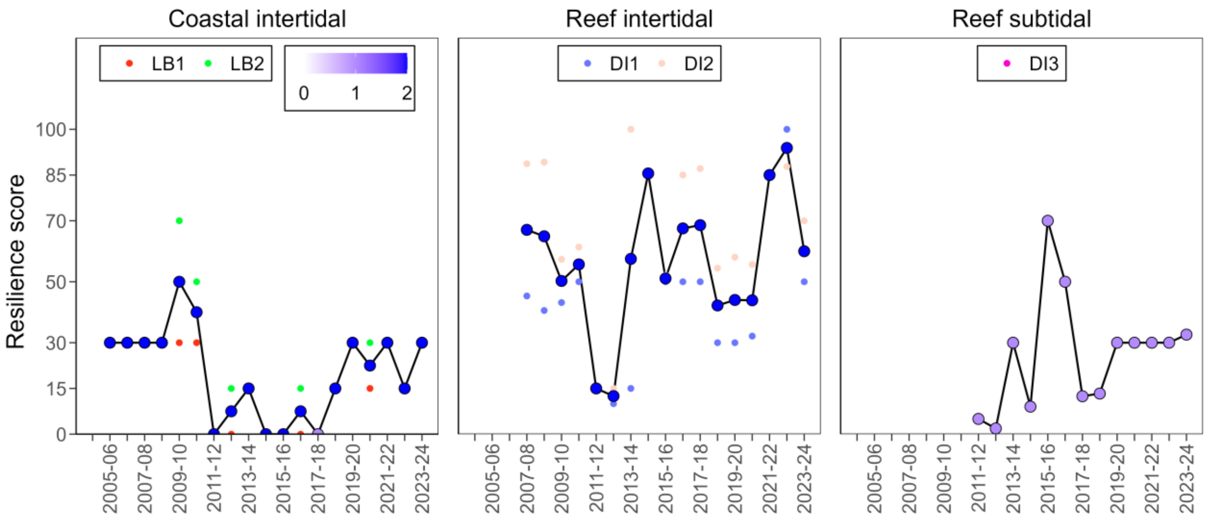



Figure 47 Resilience score for each habitat type in the southern Wet Tropics. Coloured small points represent different sites. Shades of blue for the larger points indicate the number of sites that contribute to the score.

### *5.2.3.5 Epiphytes and macroalgae*

Epiphyte cover on seagrass leaves in the northern Wet Tropics has consistently remained above the long-term average for the inshore reef intertidal habitat for the third consecutive year in 2023-24 (Figure 48). However, it has fallen below the long-term average in both coastal intertidal and reef subtidal habitats.

Macroalgae cover has remained below the Reef long-term average in both coastal intertidal and reef subtidal habitats during the wet and dry seasons for the seventh consecutive year (Figure 48). However, in reef intertidal habitats, macroalgae cover is typically higher as it attaches to coarser sediments and coral rubble, and has remained above the long-term average for over a decade (Figure 48). It only drops below the long-term average during the occasional wet season as a consequence of increased freshwater and reduced light. In 2023–24, macroalgae cover in reef intertidal habitats was slightly lower than the previous period (Figure 48).

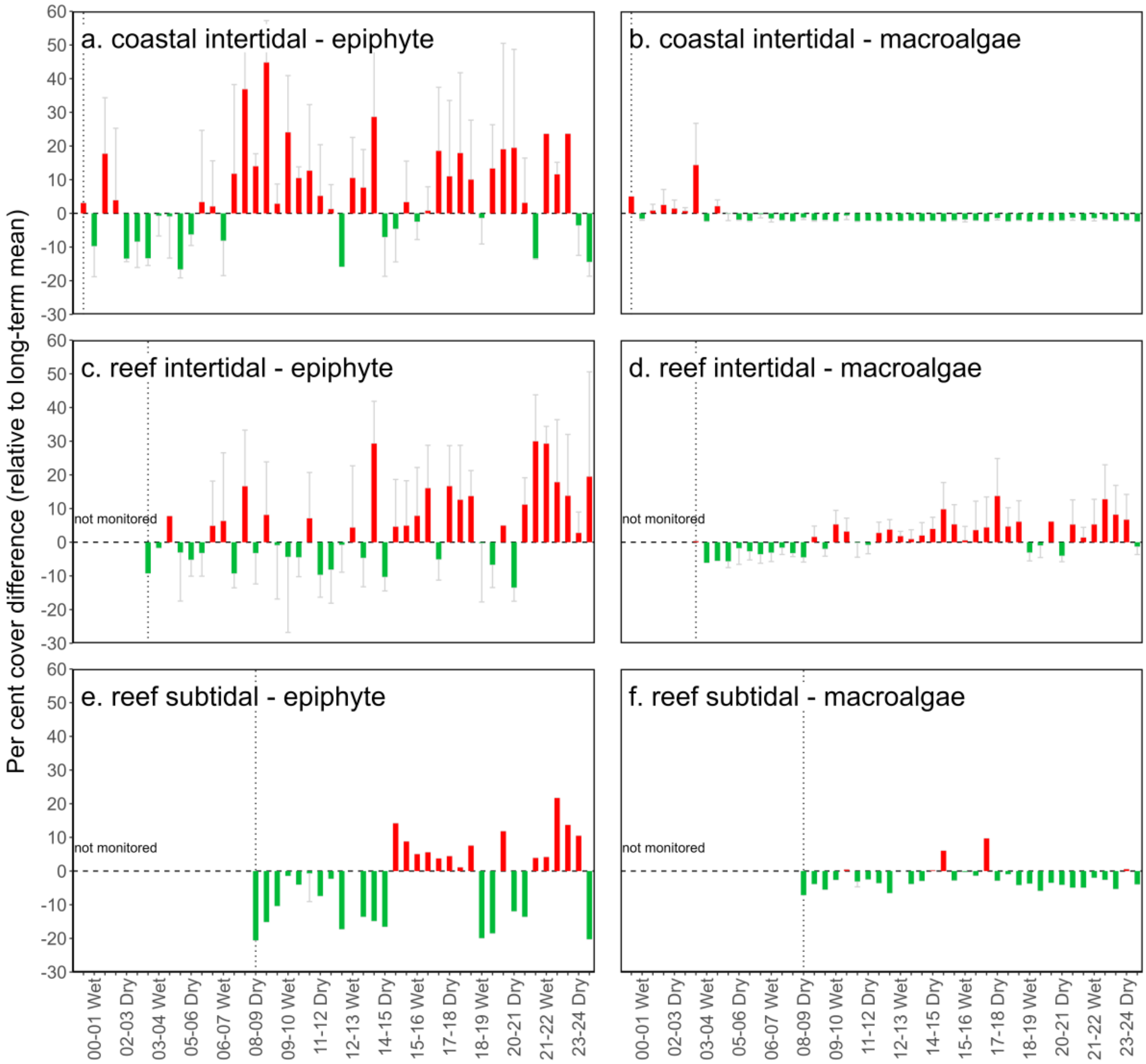



Figure 48. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the northern Wet Tropics region, 2001–2024 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

In the southern Wet Tropics, epiphyte cover in coastal intertidal habitats remained well below the Reef long-term average during 2023–24, similar to the previous period (Figure 49a). In contrast, epiphyte cover in both subtidal coastal and reef habitats remained above the long-term average over the same period (Figure 49a). At reef intertidal habitats, epiphyte cover continued to fluctuated both seasonally and annually, with higher cover in the late dry and lower in the late wet season.

Macroalgae cover is generally below the Reef long-term average in all habitats, with the exception of 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 (Figure 49g).

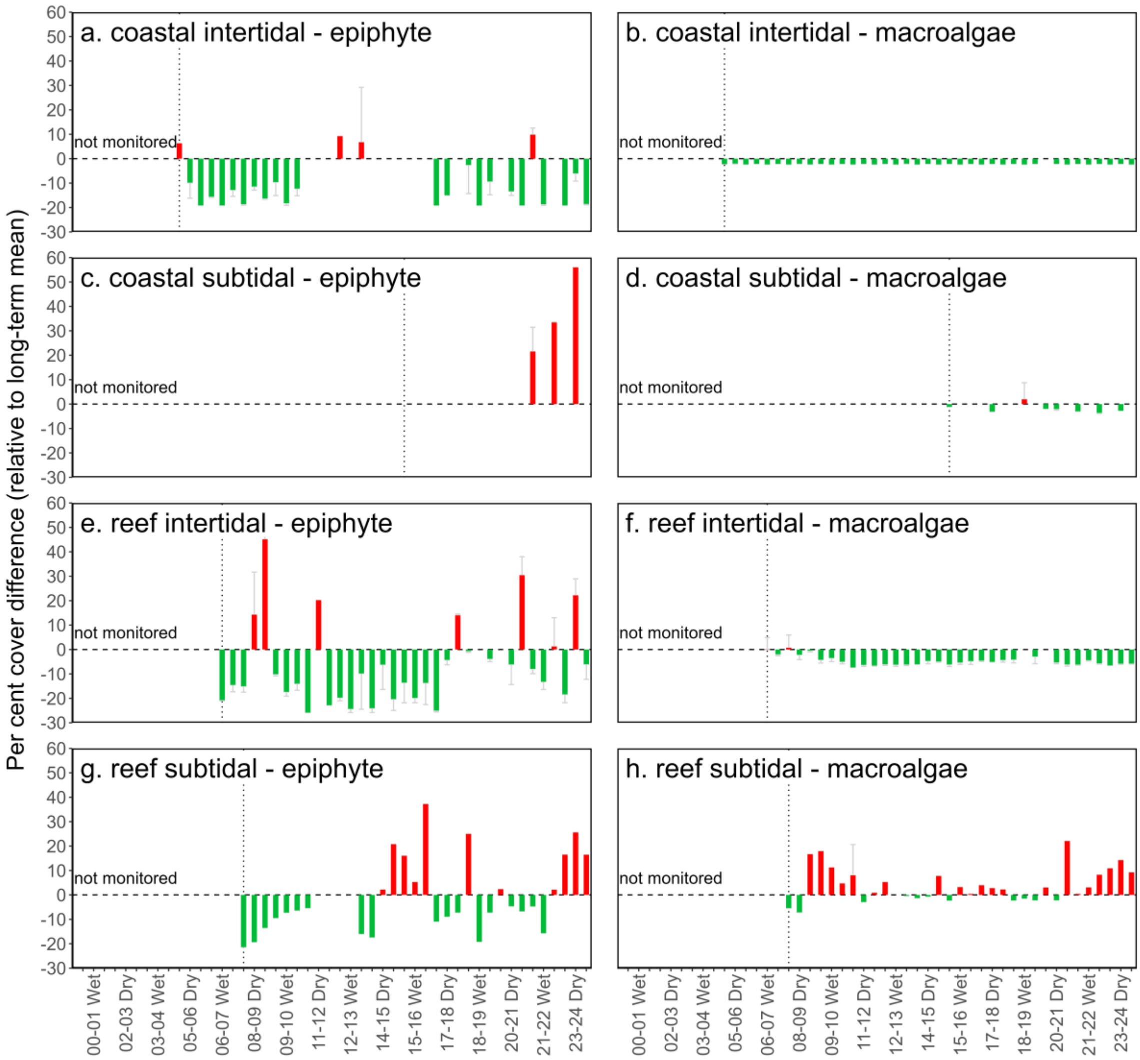



Figure 49. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the southern Wet Tropics region, 2001–2024 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

## 5.3 Burdekin

### 5.3.1 2023–24 Summary

In 2023–24, tropical cyclone Kirrily affect the Burdekin NRM region in 2023–24 bringing large waves and tidal surges. Wet season rainfall across the Burdekin basins was around the long-term average but river discharge was more than double the median for the region. Seagrass sites were exposed to turbid waters (WT I and II) throughout the wet season as is typical for the region. Daily light levels were lower than the long-term average at reef sites but within-canopy temperatures were below the long-term average for the region.

The condition of seagrass meadows across the Burdekin NRM region in 2023–24 deteriorated overall to **poor** (Figure 50). Condition indicators contributing to this were:

- abundance score was moderate
- resilience score was poor.

Seagrass abundance slightly decreased in the 2023–24 period, relative to the previous period, mainly due to cyclone Kirrily in early 2024. Reduced abundances were observed at both reef intertidal and subtidal habitats. In contrast, there were overall improvements in coastal intertidal habitats, as significant improvements at Bowen and Bowling Green Bay in the south outweighed decreases observed at Townsville in the north.

Compared with the previous reporting period, seagrass resilience declined in 2023–24 to low for the first time since 2013–14. The largest decline was at coastal sites where there no reproductive structures of foundational species at three of the sites and per cent cover was below the low resistance threshold at the other. There were also very low seed densities in coastal habitats. At reef intertidal habitats the resilience score also declined to poor, Colonising species dominated at MI2 resulting in a very low score. At MI1 reproductive structures were present but were very low density of foundational species. Seed density was also very low at reef intertidal sites. At the reef subtidal site per cent cover was below the low resistance threshold and the score was the lowest recorded.

Seagrass meadows in the Burdekin region have shown remarkable resilience since monitoring began, especially in their ability to recover. This resilience is likely attributed to a high level of species diversity and a substantial seed bank, both of which have enabled the meadows to adapt to disturbances. Additionally, the disturbances themselves, which are primarily caused by wind events (e.g., tropical cyclone) and Burdekin River discharges, which are episodic in nature.

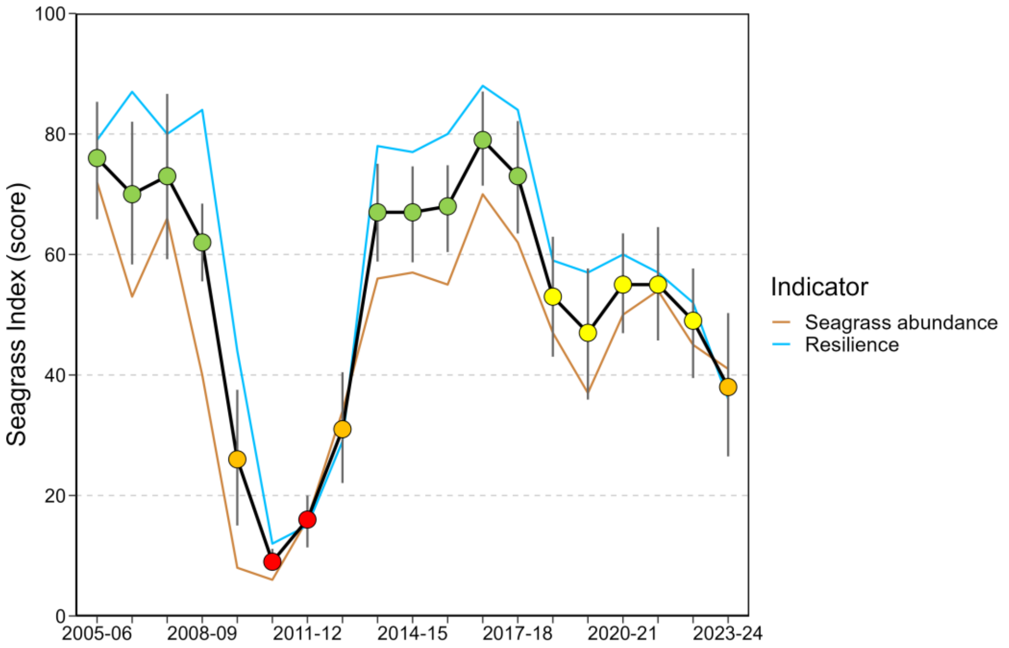



Figure 50. Temporal trend in the Seagrass Index (± SE) with contributing indicator scores for the Burdekin NRM region (averages across habitats and sites). Values are indexed scores scaled from 0–100 (± SE) and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40),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

### 5.3.2 Climate and environmental pressures

Tropical cyclone Kirrily affect the Burdekin NRM region in 2023–24 making landfall near Townsville on the 25th January 2024 when it weakened to a tropical low. Wet season rainfall across the region was similar to the long-term average overall (Figure 51) with small deviations above or below the long-term average in each basin (Figure 5). Despite that, annual river discharge was more than double the long-term median for the region (Figure 51). There was elevated discharges from the Haughton, Burdekin and Don Rivers that were more than double the long-term average, while discharges from the Black and Ross Rivers were around average.

Inshore seagrass sites in the region were exposed to turbid waters (water types I and II) in all weeks of the wet season that an exposure could be obtained. In 2023–24, 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, however there are many gaps in the data for Magnetic Island due to clouds (Figure 51a, b).

The risk of exposure of mapped seagrass to the water types was assessed in the water quality report (Moran et al 2025). In the Burdekin NRM region, there was a slight decline (-1%) in exposure to risk categories II-IV combined with an increase in category III moderate risk and decrease in the lowest and highest categories.

Daily light levels at intertidal locations in the Burdekin region were 11.7 mol $m^{-2}$ $d^{-1}$ on average in 2023–24, and therefore higher than the long-term average (11.0 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 coastal sites due to logger failure (Figure 101). Daily light levels at both of the reef intertidal sites were lower than average, but the difference was the largest at Picnic Bay (MI1) due to a prolonged period of low light in the wet season (Figure 101).

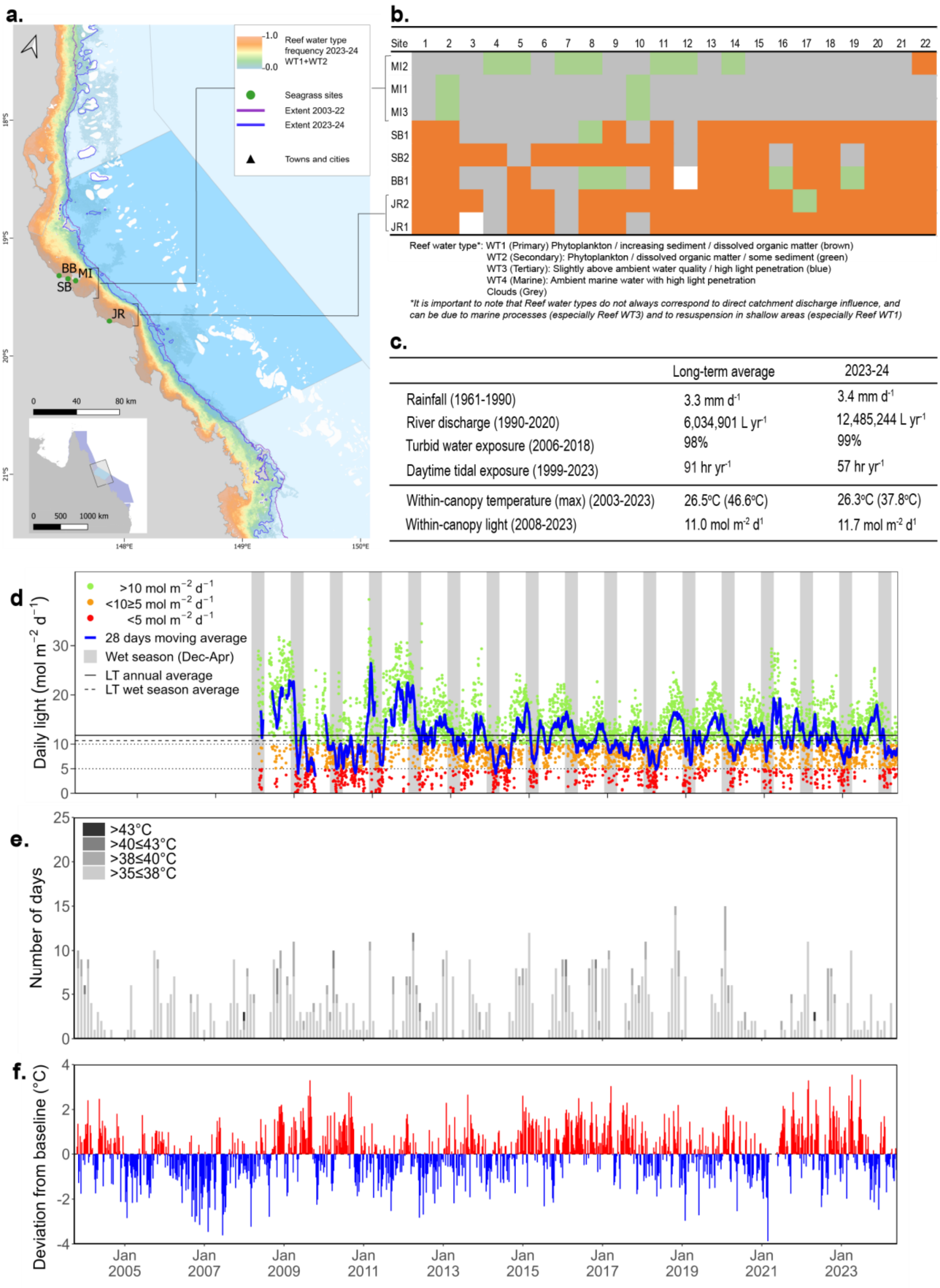



Figure 51. Environmental pressures in the Burdekin region including: a. frequency of exposure to primary (WT1) and secondary (WT2) water from December 2023 to April 2024 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the long-term average (2003–2018) exposure boundary (purple line), and the first (blue line) and third quartile (white line) of the long-term average (from Moran *et al.* 2025); b. wet season water type at each site; c. average conditions and max temperature over the long-term and in 2023–24; 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.

Intertidal within-canopy temperatures decreased again this year and were below the long-term average (Figure 51c, f). Maximum intertidal within-canopy temperatures exceeding 35°C for a total of 19 days, which is the third lowest count of exceedances since 2003–04. The highest temperature for the period was 37.8°C (Magnetic Island, 24 October 2023) (Figure 51e, f). Daytime tidal exposure was well below the long-term median at all sites for the 8th consecutive year (Figure 51c, Figure 93, Figure 94), which may alleviate some of the stresses (e.g., carbon limitation and desiccation) to seagrasses across the region.

The proportion of mud at Jerona (Barratta Creek, Bowling Green Bay) coastal meadows remains much higher than Townsville meadows (Bushland Beach and Shelley Beach) and has persisted well above the Reef long-term average (Figure 113). Following 2018, Townsville coastal meadows have largely been characterised by grainy sediments, such as medium sand While the amount of mud at Bushland Beach varied between 2018 and 2020, it has stayed well below the long-term average in recent years (Figure 113). In contrast, reef habitats continue to be primarily dominated by sand sediments, with the mud composition at Cockle Bay (MI2) remaining relatively stable (Figure 114, Figure 115).

### 5.3.3 Inshore seagrass and habitat condition

Three seagrass habitat types were assessed across the Burdekin region in 2023–24, 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 2023–24 monitoring period, the Seagrass Index for the Burdekin region decreased, dropping to a **poor** grade (Figure 50). The grade is influenced in part by the legacy of previous monitoring periods, which experienced above-average wet season rainfall and river discharge across the region in early 2019, effects that have persisted into 2023. Additionally, it reflects the impacts of cyclone Kirrily during the wet season in early 2024. The Seagrass Index in the Burdekin NRM is highly variable and it responds rapidly to changing pressures. Since monitoring commenced in 2005, it has been one of the few areas with scores ranging from good to very poor.

Both indicators declined in 2023–24 compared to the previous year. The two consecutive declines in the annual abundance indicator appear to be affected by lower-than-anticipated abundances during the late wet season of 2023, along with the effects of Cyclone Kirrily during the wet season of 2024.

The resilience indicator has similarly declined over the last few years, from moderate to poor, with was variable between habitats and sites, and in 2022–23 appears influenced by declines at the coastal intertidal and reef subtidal 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, followed by rapid recovery. However, drawing from these past trends, the recovery of seagrass habitats halted in 2022 and declined in 2023-24, with several sites falling well below historical maxima (Figure 52).

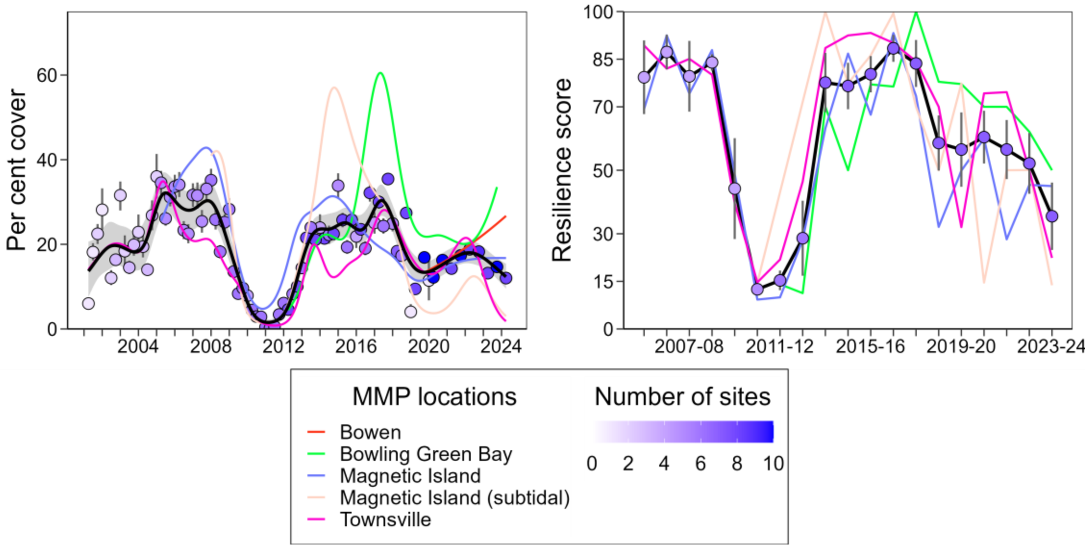



Figure 52. Temporal trends in the Burdekin seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area defining 95 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*

In the Burdekin region, overall seagrass abundance slightly declined in 2023–24, following two years of improvement. This decrease was a consequence of declines in reef intertidal and subtidal habitats. Conversely, coastal intertidal abundance increased overall for the region, primarily driven by significant improvements at Bowen and Bowling Green Bay in the south, which outweighed the declines observed at Townsville in the north due to Cyclone Kirrily (Figure 53).

The abundance of seagrass in the Burdekin region has exhibited a pattern of loss followed by recovery throughout 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 across different habitats (Figure 53). In the 2017–18 period, coastal habitats increased to their highest abundance since 2001, but this was quickly followed by significant declines in 2018–19. During that year, the region experienced notable decreases in abundance, particularly 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. In contrast, recovery in reef habitats has been more protracted, with minimal changes observed in intertidal abundances over the past few years, while there has been a significant loss of subtidal abundances in 2023–24 (Figure 53).

An examination of the long-term abundances across the Burdekin region indicates no significant regional trend (from first measure to 2022–23). However, a significant decline has been observed at one of the reef intertidal sites (MI2) and one coastal intertidal site (SB2) since monitoring commenced in 2005 (Table 22). In contrast, a significant long-term increase has been recorded at another coastal intertidal site (JR2).

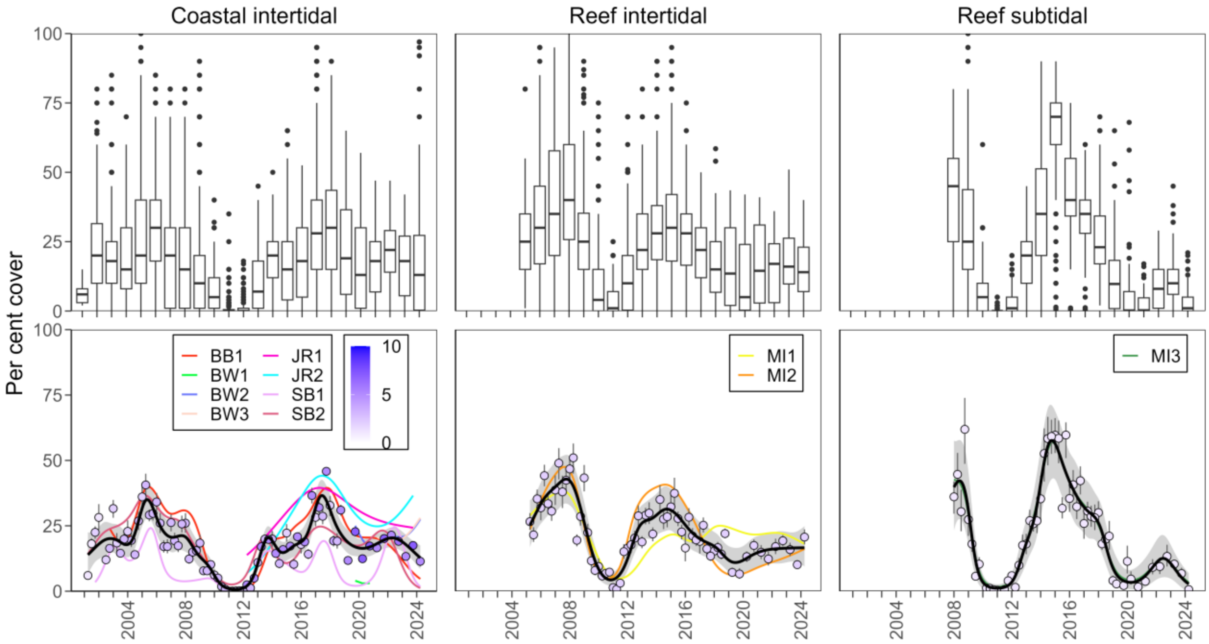



Figure 53. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends, for each habitat monitored in the Burdekin NRM region from 2001 to 2024. Whisker plots (top) show the box representing the interquartile range of values, where the boundary of the box closest to zero indicates 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 foundational seagrass species maintained their dominance in the coastal intertidal and reef subtidal meadows during 2023–24. Additionally, the proportion of species exhibiting colonizing traits, such as *H. ovalis*, remained above the long-term average for 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, following severe impacts from floodwaters. Additionally, *Cymodocea serrulata* has been absent since 2021–22. Colonising species play a crucial role in recovery following loss (Kilminster *et al.* 2015), however, the increased proportion of colonising species suggests some level of localised disturbance which is delaying recovery. In contrast, the coastal and reef subtidal habitats continue to be dominated by opportunistic species (*H. uninervis, Z. muelleri, C. serrulata*). Opportunistic foundation species have a capacity to resist stress (survive, through reallocation of resources) from acute disturbances (Collier *et al.* 2012b), which suggests that the current species composition in coastal and reef subtidal habitats enhances overall resilience within Burdekin meadows.

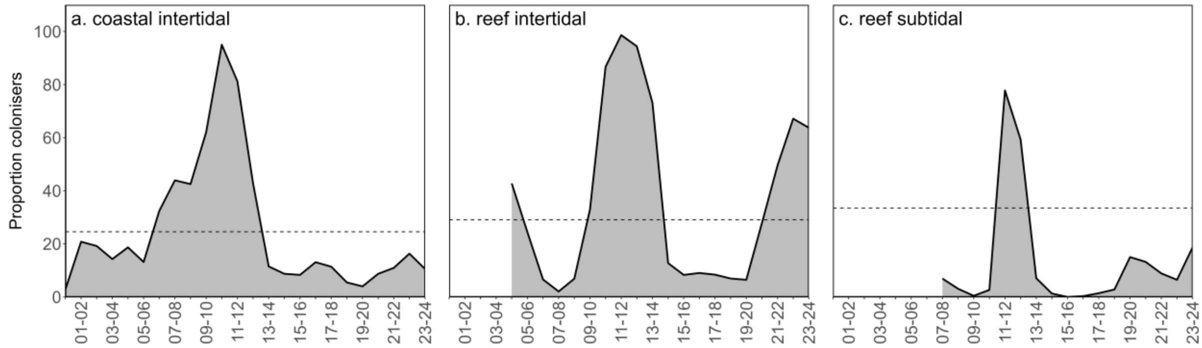



Figure 54. Proportion of seagrass abundance composed of colonising species at inshore intertidal habitats in the Burdekin region, 2001 to 2024. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

At the beginning of the 2023-24 monitoring period, specifically during the late dry season, the spatial extent of seagrass meadows remained relatively consistent compared to the previous year. However, after cyclone Kirrily impacted the region during the wet season, these extents declined to their lowest levels in years (Figure 55). The most significant losses were observed in the coastal intertidal meadows, which reached their lowest recorded extents since monitoring began, as well as in the reef subtidal meadows, which fell to their lowest levels in a decade. The reef intertidal meadows were the least affected (Figure 55), likely due to their location in small bays that provided better shelter from the damaging waves.

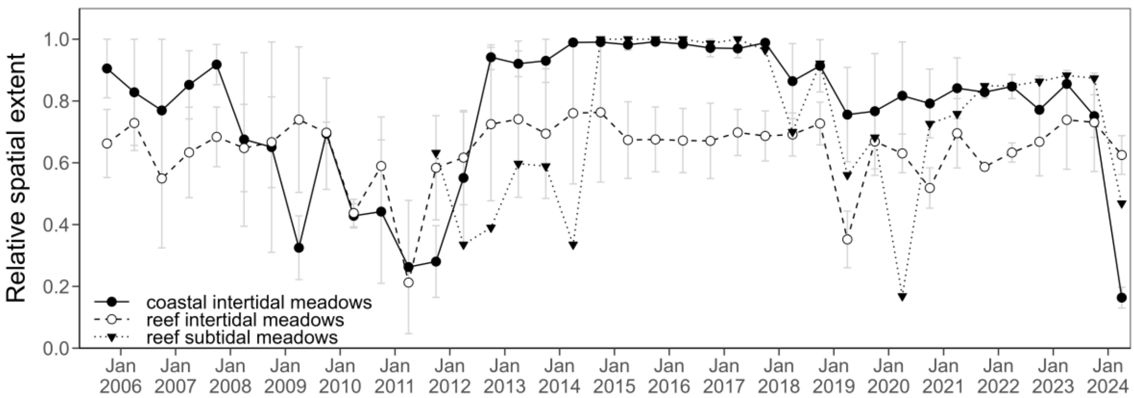



Figure 55. Change in spatial extent (± SE) of seagrass meadows within monitoring sites for each inshore intertidal habitat and monitoring period across the Burdekin region, 2005–2023.

### *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 increased at coastal intertidal sites in 2023–24 compared to 2022–23 but was substantially lower than average.

Reproductive effort in 2023–24 was low in coastal habitats and predominantly from colonising species (*Halophila ovalis*). It was low compared to historical levels and the long-term average at all sites, but particularly at Shelley Beach (SB1) where there were low numbers of flowers of colonising species only. At reef intertidal sites, reproductive effort in the late dry was at the highest level it has been for 10 years but it was almost entirely from colonising species with only 1 flower of foundational species across both sites. Reproductive effort was also increased at reef subtidal sites and was all from colonising species in the late dry season.

Seed banks persisted across the region in 2023–24, however, seed densities were very low in coastal habitats. This was due to reductions at all sites, but especially at Jerona. Seed density was also very low at reef intertidal habitats in 2023–24 and only present at MI2 and only in the late dry season (Figure 56a). Seed banks are no longer measured at subtidal sites.

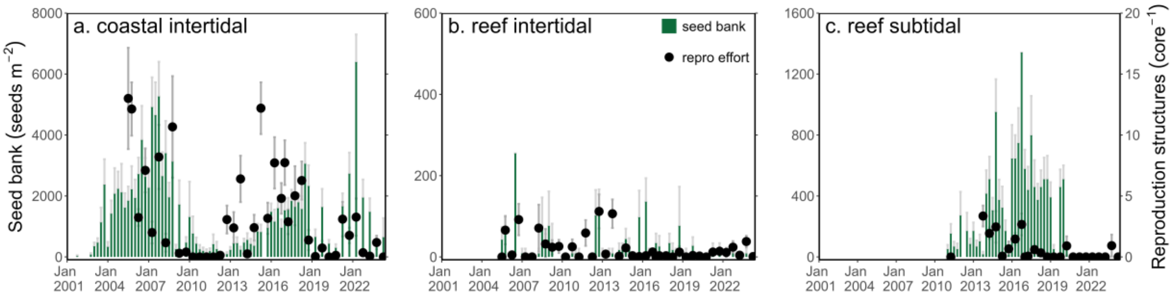



Figure 56. Seedbank and reproductive effort at inshore coastal intertidal and reef subtidal and intertidal habitats in the Burdekin region, for late dry season, 2002–24 Seed bank presented as the total number of seeds per m$^2$ sediment surface (green bars ±SE). Reproductive effort for the late dry season 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 declined in 2023–24 to low for the first time since 2013–14 when the region was in recovery from extreme weather events (Figure 50). The declines occurred at coastal intertidal and reef subtidal sites (Figure 57). The resilience score declined at coastal sites because there were no reproductive structures of foundational species at 3 of the 4 sites. At Bushland Beach (BB1) where the seagrass was reproductive and at Shelley Beach (SB1), the per cent cover was below the resistance threshold and both sites were category 1.2. At reef intertidal sites, the average score was unchanged, but there were large differences between sites. At MI2 colonising species continued to dominate, resulting in the lowest ever recorded resilience score for the sites. While at MI1 reproductive structures and persistent species were again present.

At the reef subtidal site, the resilience score in 2023–24 was the lowest it has been (Figure 57). Cover was below the threshold for low resistance and although reproductive structures were present, they were only of colonising species flowers.

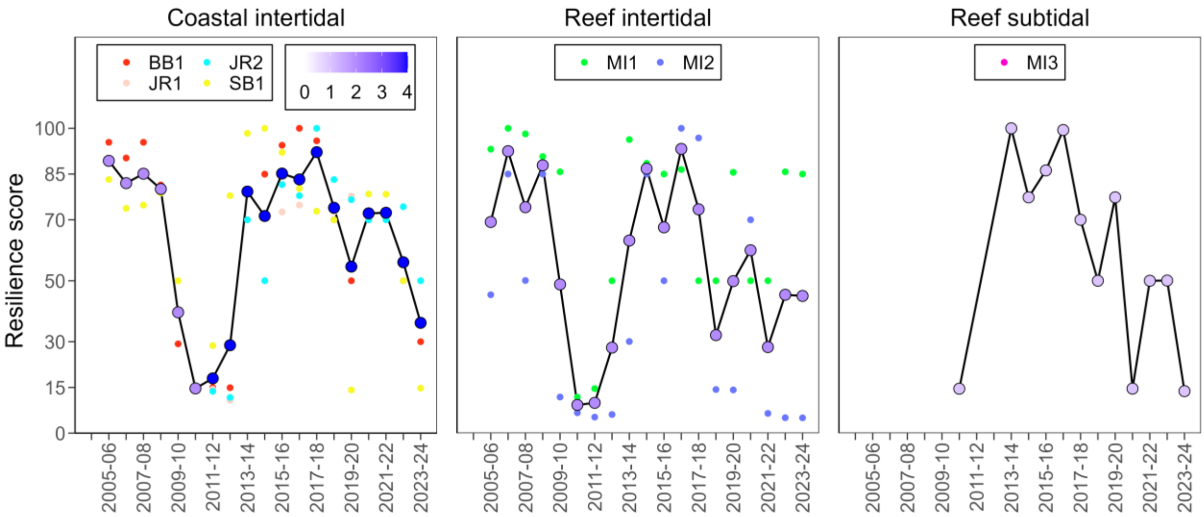



Figure 57. Resilience score in each habitat in the Burdekin, 2006 to 2024. Coloured small points represent different sites. Shades of blue for the larger points indicate the number of sites that contribute to the score.

#### *5.3.3.5 Epiphytes and macroalgae*

Epiphyte cover on seagrass leaf blades during the 2023-24 period was consistent with the previous period, but varied across different habitats. At coastal intertidal habitats, the cover was lower and did not exceed the long-term average (Figure 58a). In contrast, at reef intertidal and subtidal locations, coverage fluctuated with the seasons but stayed above the inshore reef average throughout the year (Figure 58c, e). On the other hand, macroalgae abundance in 2023-24 remained low, staying below or around the long-term average for the fourth consecutive year across all seagrass habitats in the region (Figure 58).

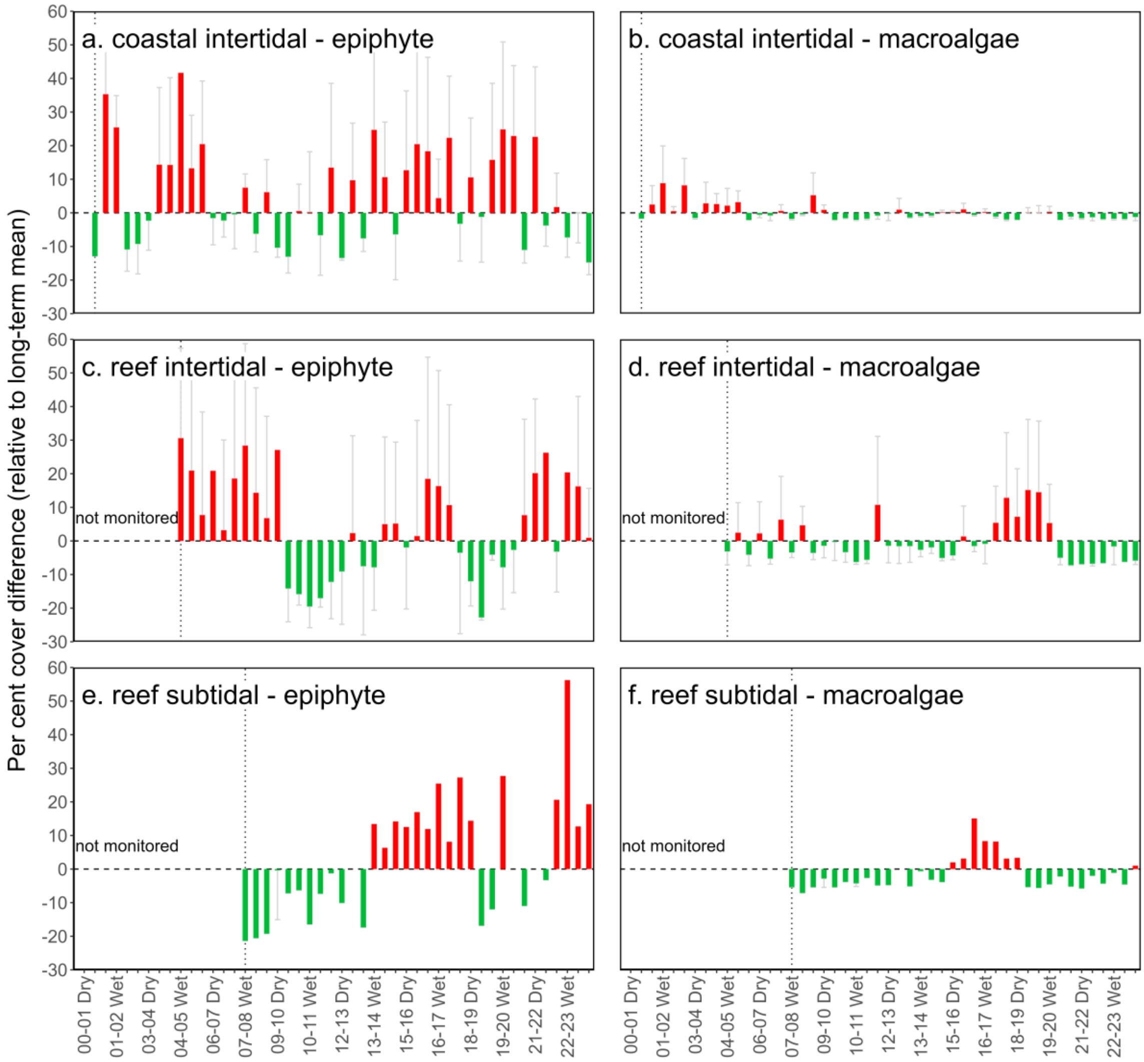



Figure 58. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Burdekin region, 2001–2024 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

## 5.4 Mackay–Whitsunday

### 5.4.1 2023–24 Summary

Environmental conditions were more optimal for seagrass than the long-term average in the Mackay–Whitsunday region in 2023–24. No cyclones affected the region, rainfall and river discharge were below-average for the region and for each of the river basins, and daily light was higher than the long-term average. Average within-canopy temperature for 2023–24 was around the long-term average, however, the number of days of exposure to temperature extremes was the second highest on record, and only slightly less than the previous period.

Inshore seagrass meadows across the Mackay–Whitsunday NRM region marginally declined in overall condition in 2023–24, and the condition grade remained **moderate** (Figure 59). Indicators for the overall condition score were:

- abundance was moderate
- resilience was moderate.

Seagrass condition in the Mackay–Whitsundays has fluctuated between poor and moderate since 2010–11 which appears to be due to a range of environmental pressures at both regional and local scales.

The seagrass abundance score marginally improved in 2023–24 for the second year in a row, driven by improvements in reef intertidal and subtidal habitats. Estuary intertidal and coastal subtidal abundance scores remained stable, however, coastal intertidal decreased.

The overall resilience score for the Mackay–Whitsunday region declined slightly in 2023–24 but remained moderate for the third year in a row. There were declines in most habitat types, but a slight increase in reef intertidal habitats because per cent cover at LN1 increased above the low resistance threshold but there was no reproduction of foundational species, only colonisers. In both estuarine and coastal habitats sites met thresholds for abundance and composition, and there were some reproductive structures but not as many as in 2022–23. The resilience score declined at the reef subtidal site where there were reproductive structures of foundation special species, but there had been in 2022–23. There were no seeds at estuarine and reef intertidal sites, but at coastal intertidal sites seed density was around the long-term average.

Up until 2016–17, the Mackay–Whitsunday regional seagrass condition had been improving since its lowest level in 2010–2011. After that time, the recovery trend abated and condition deteriorated 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 recently. This appears the first indication that seagrass habitats in the region may be recovering from past disturbances. This improvement is likely due to alleviation of localised pressures and possibly chronic changes that aren't easily detectable across all sites and habitats.

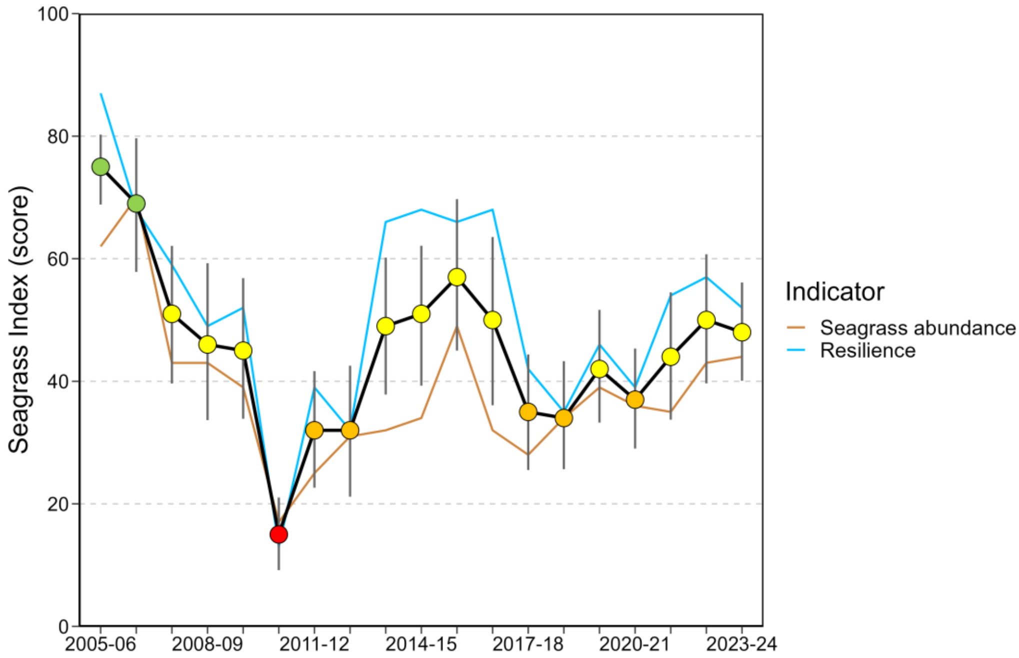



Figure 59. Temporal trend in the Seagrass Index (± SE) with contributing indicator scores for the Mackay–Whitsunday NRM region (averages across habitats and sites). Values are indexed scores scaled from 0–100 (± SE) and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor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

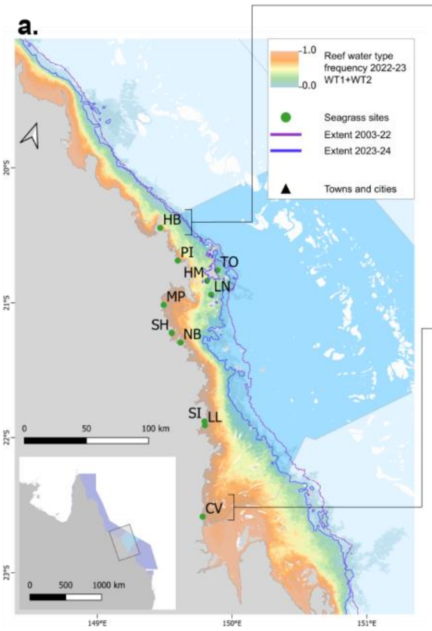
### 5.4.2 Climate and environmental pressures

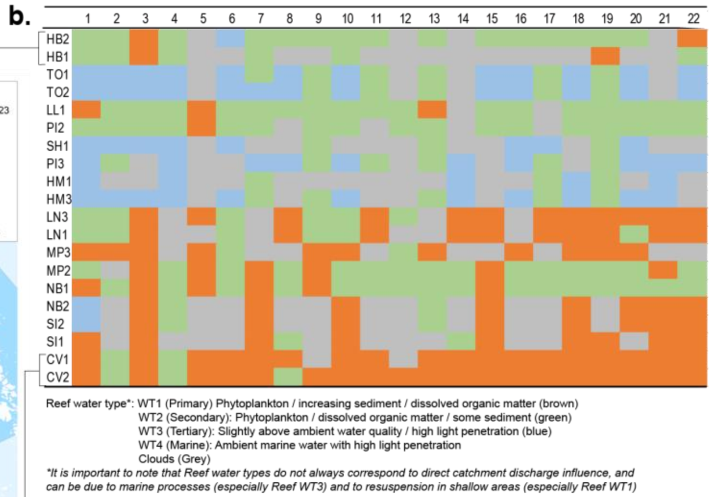
Environmental conditions were more optimal for seagrass than the long-term average in the Mackay–Whitsunday region in 2023–24. There were no cyclones to affect the region and rainfall and river discharge were below average for the region as a whole and for each of the river basins.

Exposure of inshore seagrass to turbid waters during the wet season were below the long-term averages (Figure 60a, c). Estuarine and coastal sites from Lindeman Island and south were exposed to turbid waters of primary (WT1) or secondary (WT2) for almost the entire wet season. Exposure to either of these water types was variable among seagrass habitats (Figure 60b). Northern sites from Hideaway Bay (HB2) to Hamilton Island (HM3), Midge Point (MP2) and Newry Bay (NB1) were exposed to secondary waters more often than to primary waters in the wet season while all other sites were exposed to primary waters (Figure 8, Figure 60b).

The risk of exposure of mapped seagrass to the water types are assessed in the water quality report (Moran et al 2025). In the Mackay–Whitsunday NRM region in 2023–24, there was a decrease (-14 %) in the likelihood that seagrass was at risk to water quality exposure compared to the long-term average.

Daily light was higher than the long-term average combined within the region (Figure 8, Figure 60c, Figure 102). At Lindeman Island (LI3) and Midge Point (MP2) light was higher in 2023–24 (13.1 mol $m^{-2}$ $d^{-1}$, 17.4 mol $m^{-2}$ $d^{-1}$) than the average of previous years (12.1 mol $m^{-2}$ $d^{-1}$, 15.5 mol $m^{-2}$ $d^{-1}$), however both sites were missing some data from during the wet season (Figure 102). At Hamilton Island, the average light level in 2023–24 (12.2 mol $m^{-2}$ $d^{-1}$) was lower than the long-term average (14.1 mol $m^{-2}$ $d^{-1}$) for another year (Figure 102). Daily light at Sarina Inlet is not included in these regional summaries as there are considerable gaps in the data where wipers failed to keep loggers clean.




**c.**

| | Long-term average | 2023-24 |
|---|---|---|
| Rainfall (1961-1990) | 7.7 mm d$^{-1}$ | 6.2 mm d$^{-1}$ |
| River discharge (1990-2020) | 3,370,027 L yr$^{-1}$ | 2,441,816 L yr$^{-1}$ |
| Turbid water exposure (2006-2018) | 89% | 79% |
| Daytime tidal exposure (1999-2022) | 50 hr yr$^{-1}$ | 39 hr yr$^{-1}$ |
| Within-canopy temperature - intertidal (2003-2022) | 25.5ºC (46.5ºC) | 25.6ºC (46.3ºC) |
| Within-canopy light (2010-2022) | 12.6 mol m$^{-2}$ d$^{1}$ | 14.3 mol m$^{-2}$ d$^{1}$ |

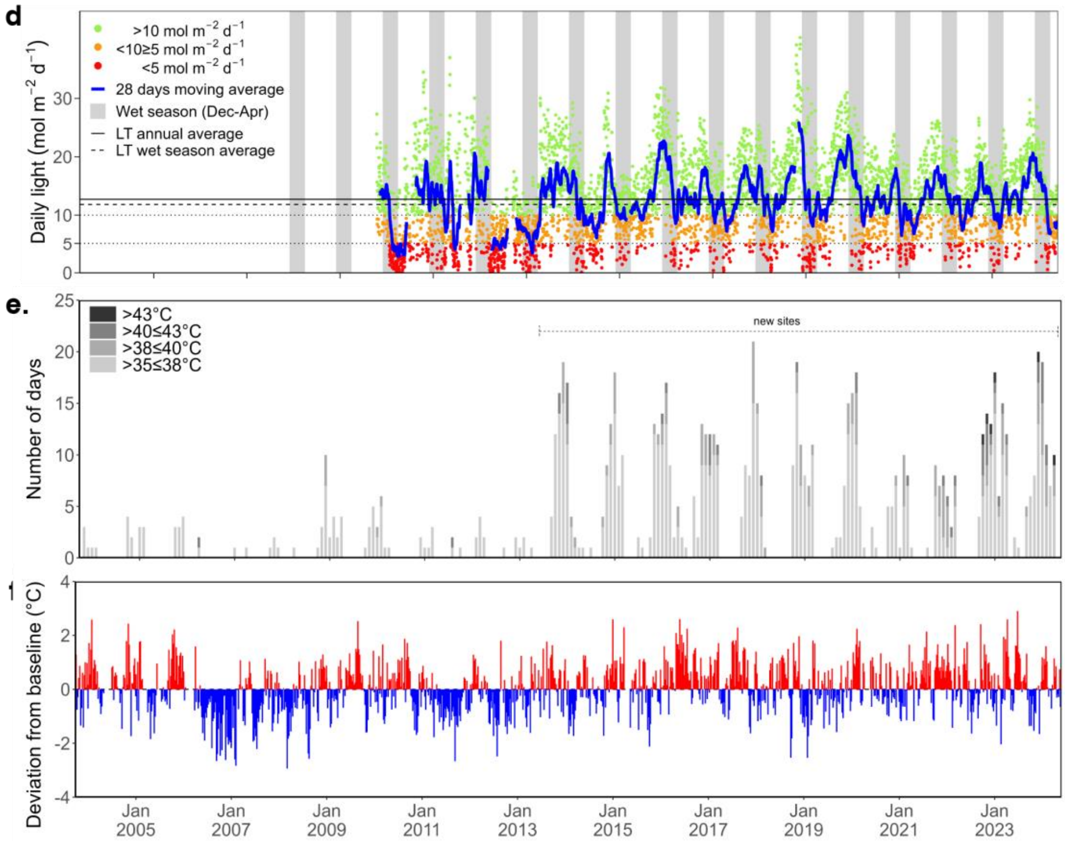



Figure 60. Environmental pressures in the Mackay–Whitsunday NRM region including: a. frequency of exposure to primary (WT1) and secondary (WT2) water from December 2023 to April 2024 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the 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 Moran *et al.* 2025); b. wet season water type at each site; c. average conditions and max temperature over the long-term and in 2023–24; 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 2023–24 reporting period, intertidal within-canopy temperatures were similar to the long-term average (Figure 60c,f). Maximum intertidal within-canopy temperatures exceeded 35°C for a total of 89 days during 2023–24. There were 2 days where temperatures exceeded 43°C, including reaching 46.3°C (Midge Point, 23 December 24) (Figure 60e, f). Daytime tidal exposure at all habitats was below the long-term average in 2023–24 (Figure 60c, Figure 95), which may have resulted in decreased desiccation stresses at these intertidal sites.

Monitoring the sediment grain size composition of seagrass habitats has revealed notable changes in the Mackay–Whitsunday NRM region during 2023–24, both in the short and long term. Compared to the previous period, the amount of mud in the sediments of estuarine sites has decreased, while it has increased in coastal seagrass monitoring sites (Figure 116). Since 2021, the estuarine sites at Sarina Inlet have been gradually becoming sandier, characterized by large sand ridges shifting across the intertidal banks. In 2023–24, the proportion of mud was now below the long-term average for estuarine habitats. In comparison, the proportion of mud across coastal habitats, fluctuating over the long-term within and between both meadows and years, while now exceeding the long-term average at all sites (Figure 117). The proportion of fine grain sizes decreases 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 2023–24 relative to the previous period, with the exception of Lindeman Island when the component of mud increased well above the Reef long-term average for reef intertidal habitats (Figure 118).

### 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 2023–24 (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 2023–24 monitoring period, the Mackay–Whitsunday region Seagrass Index marginally decreased from the previous year, and remained **moderate** (Figure 61). The decreased was due to a decline in the resilience indicator offsetting the marginally increased in abundance indicator. The abundance score marginally improved and remained moderate, driven by improvements in reef intertidal and subtidal habitats. Estuary intertidal and coastal subtidal abundance scores remained stable, however, coastal intertidal decreased.

The resilience score experienced a slight decline but remained at a moderate level, with differing trends observed across various habitats and sites. The most significant drops were seen in coastal intertidal and reef subtidal habitats, which decreased by up to 20% and nearly 33%, respectively. The only habitat where resilience saw improvement was in the intertidal reef, which nearly doubled.

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.

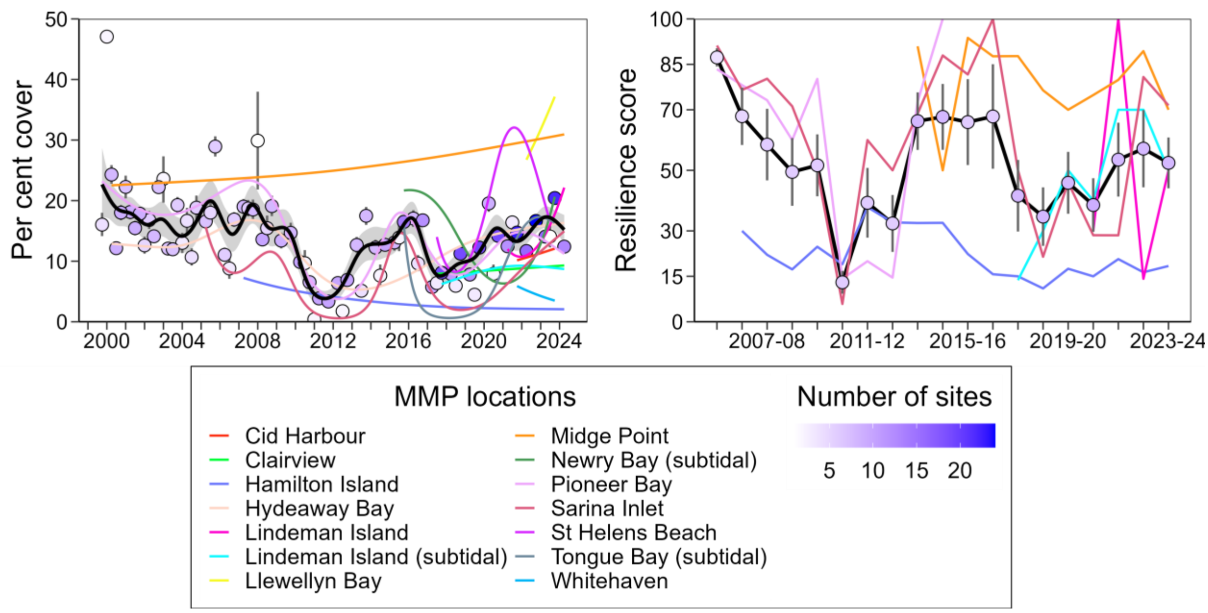



Figure 61. Temporal trends in the Mackay–Whitsunday seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area defining 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 in the Mackay–Whitsunday region continued to show improvement in 2023–24 for the third straight year. Some habitats experienced little to no change, while minor declines were noted in others (Figure 62). Estuary habitats remained unchanged after four years of improvement, following previous declines from 2017 to 2019. Coastal intertidal habitats saw a slight decrease, after abundances had remained relatively stable for three consecutive years. Abundances at all other habitats improved during the 2020–21 reporting period, with the largest increase observed in coastal subtidal habitats (Figure 62).

Seagrass abundance (per cent cover) in the Mackay–Whitsunday region in 2023–24 was higher in coastal habitats (intertidal = 18.7 ±0.4 per cent, subtidal = 20.2 ±0.8 per cent) than estuarine (13.1 ±0.6 per cent) or reef habitats (intertidal = 13.6 ±0.5 per cent, subtidal = 8.7 ±0.5 per cent), respectively.

Seagrass abundance at estuarine and coastal habitats has fluctuated greatly over the years, with some sites experiencing total or near total loss followed by recovery (Figure 62). The long-term regional trend suggests a declining trajectory (Table 22), although habitats are gradually recovering from repeated losses over the past decade.

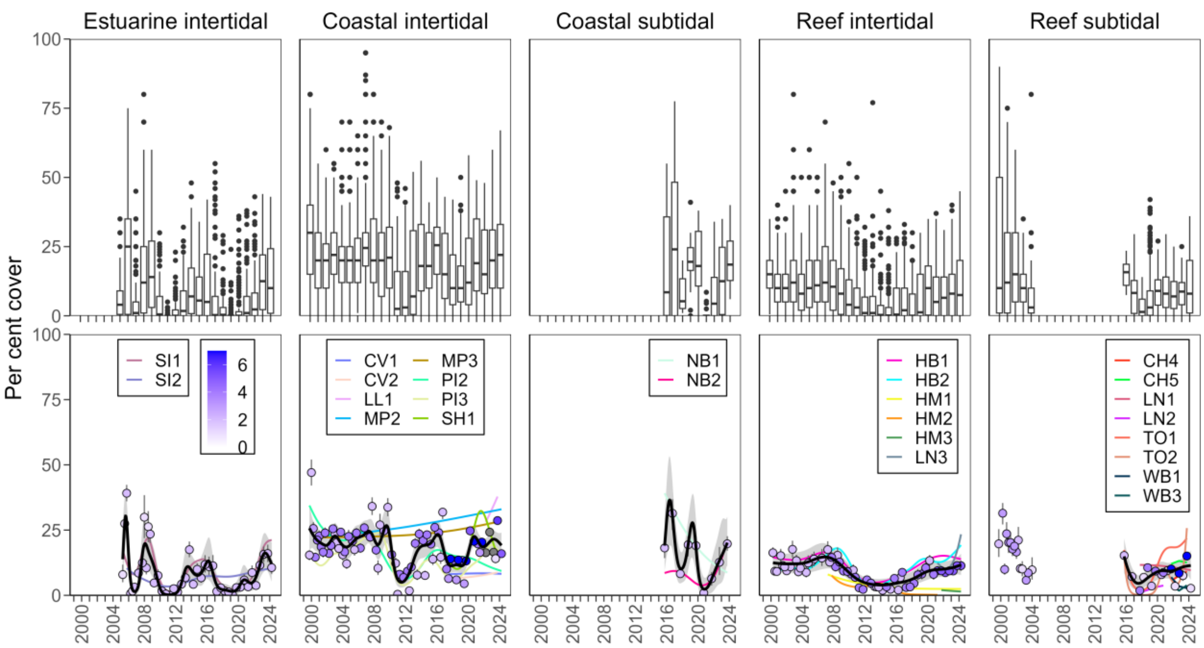



Figure 62. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends, for each habitat monitored in the Mackay–Whitsunday NRM region from 1999 to 2024. Whisker plots (top) show thee box representing the interquartile range of values, where the boundary of the box closest to zero 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 predominant seagrass species found throughout various habitats in the Mackay–Whitsunday NRM region include *H. uninervis* and *Z. muelleri*, often accompanied by the colonising species *H. ovalis*. In the years immediately following extreme weather events (such as those in 2011 and 2017), colonising species typically dominate in intertidal meadows across the Mackay–Whitsunday region; however, variations can occur between different habitats. can experience significant fluctuations both between and within years, and recently, the proportion of colonisers has exceeded the Reef long-term average (Figure 63).

Coastal subtidal habitats have been monitored for only the past six years, yet they are currently dominated by colonising species. In reef intertidal habitats, the proportion of colonising species has risen in recent years, although it still remains below the long-term average. Conversely, there has been a decline in colonising species within coastal intertidal and reef subtidal habitats in recent years. Except for coastal subtidal habitats, opportunistic foundational species (*H. uninervis* and *Z. muelleri*) currently dominate habitats across the region (Figure 63), indicating that these meadows may have an improved ecosystem resistance to tolerate disturbances (Figure 63).

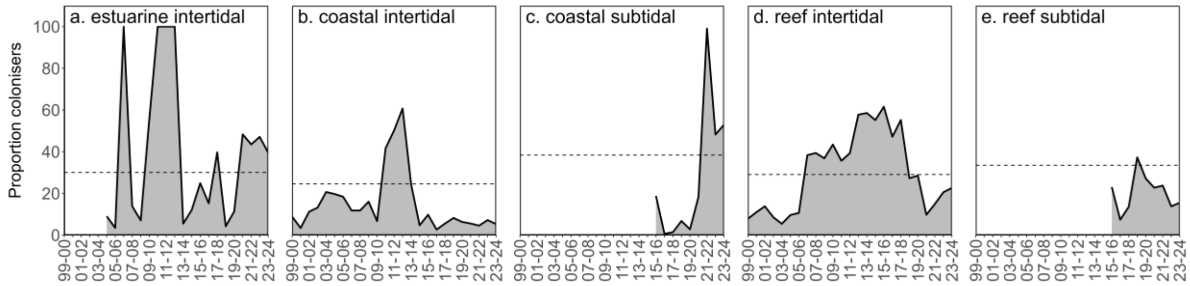



Figure 63. Proportion of seagrass abundance composed of colonising species at inshore intertidal habitats in the Mackay–Whitsunday region, 1999 to 2024. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

Seagrass meadow landscape mapping was conducted within all sentinel monitoring sites in October 2023 and May 2024 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 last year, the spatial extent has either increased or stayed constant throughout the region compared to the prior period, although there were seasonal decreases during the late wet season, especially in reef subtidal habitats.

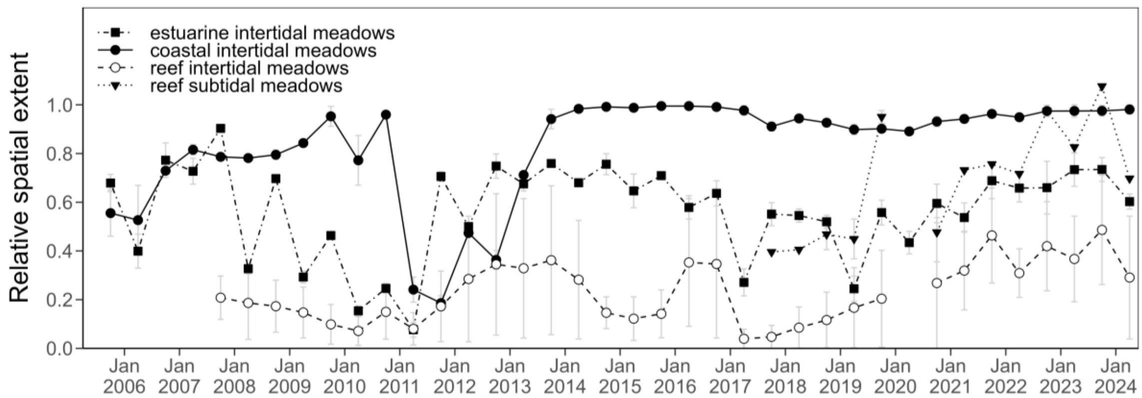



Figure 64. Change in spatial extent (± SE) of seagrass meadows within monitoring sites for each inshore intertidal habitat and monitoring period across the Mackay–Whitsunday NRM region, 2005-2024.

### *5.4.3.3 Seagrass reproductive status*

Reproductive effort in the Mackay–Whitsunday NRM region was reduced in 2023–24 relative to the long-term average and compared to 2022–23 (Figure 65). Reproductive effort was reduced in the late dry season. There was no reproduction in the late wet season as is typical for habitats predominantly composed of foundational species (*Z. muelleri*). There were no seeds at estuarine sites in 2023–24. At coastal sites, reproductive effort was also reduced but seed density was similar relative to the long-term average and compared to 2022–23. The reproductive effort was composed almost entirely of foundational species at both estuarine and coastal sites.

Reproductive effort at reef intertidal sites was the highest observed since 2012–13. This was driven by flowering of colonising species (*Halophila ovalis*) at Lindeman Island and there was no flowering of foundational species or at Hamilton Island. There were no seeds of foundational species at reef intertidal habitats, and the small seeds of colonising species are not quantified. Similarly reproductive effort at the reef subtidal site was the highest on record (i.e. 2017–18) and this was also due to flowering of colonising species at Lindeman Island (Figure 65).

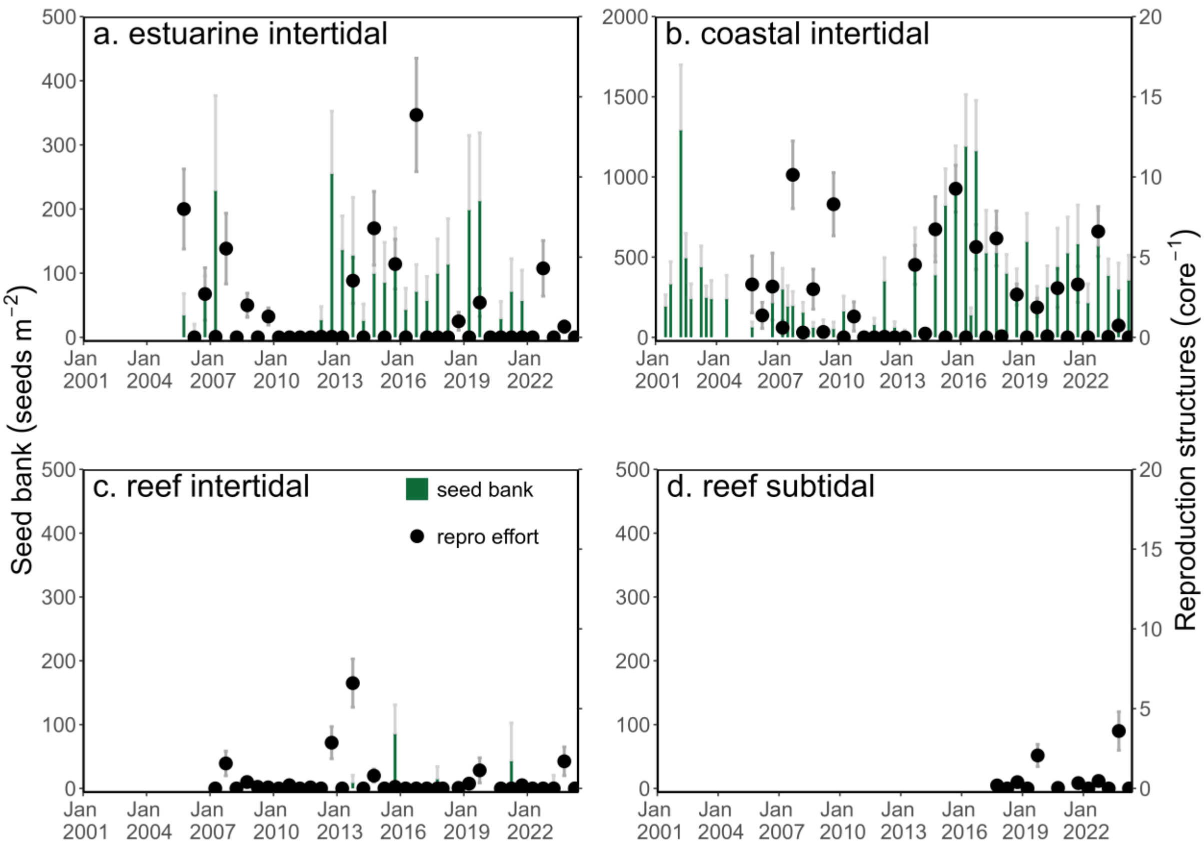



Figure 65. Seed bank and reproductive effort at inshore estuarine intertidal, coastal intertidal and reef intertidal and subtidal habitats in the Mackay–Whitsunday region, 2001–2024. Seed bank presented as the total number of seeds per $m^2$ sediment surface (green bars ±SE), and late dry season reproductive 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 in 2023–24 was moderate for the third year in a row but declined slightly (Figure 59). There were declines in most habitat types but not at reef intertidal (Figure 66). In estuarine habitat at Sarina Inlet, the score remained high because both of the sites met thresholds for abundance and composition, and there were some reproductive structures of foundational species (*Z. muelleri*) but not as many as in 2022–23. The resilience score declined slightly to 70 at the coastal intertidal habitat due to a lower count of reproductive structures compared to 2022–23 when the score was higher.

Resilience increased at reef intertidal sites the per cent cover of seagrass was above the resistance threshold (20$^{th}$ percentile for the site) at two sites, including at LN1 where it was below in the threshold in the previous. But there were no reproductive structures at those sites and no reproductive history. At the Hamilton Island site (HM3), colonising species dominated. The resilience score declined at the reef subtidal site where abundance and composition were above thresholds. There were no reproductive structures of foundation special species, but there had been in 2022–23 so the score was on the lowest margin for category 2.1.2.

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.

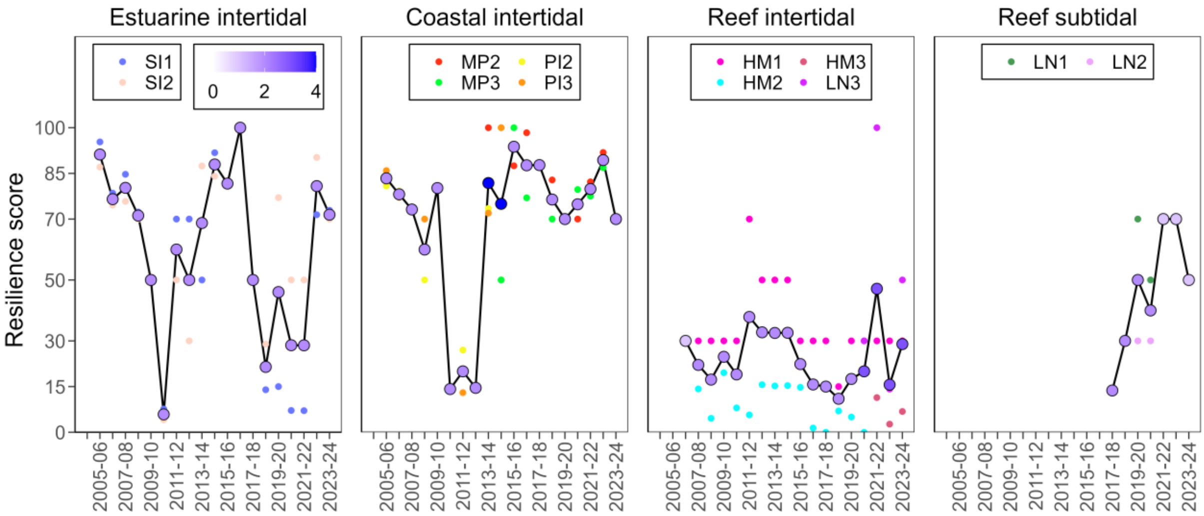



Figure 66. Resilience for each habitat type in the Mackay–Whitsunday region, 2006 to 2024. Coloured small points represent different sites. Shades of blue for the larger points indicate the number of sites that contribute to the score.

### 5.4.3.5 *Epiphytes and macroalgae*

Epiphyte cover on seagrass leaf blades in 2023–24 remained at or below the long-term average in both the dry and wet seasons across all habitats, with the exception of coastal intertidal (Figure 67). In coastal intertidal habitats, epiphyte cover exceeded the long-term average during the late dry season, showing a slightly higher abundance compared to 2022–23 (Figure 67c). Except for coastal subtidal habitats, the percentage cover of macroalgae remained unchanged; at or below the overall long-term average for inshore reefs across all seagrass habitats throughout 2023–24 (Figure 67). At coastal subtidal habitats, macroalgae abundance increased during the late dry season, although levels in 2023-24 we lower than those observed the previous year.

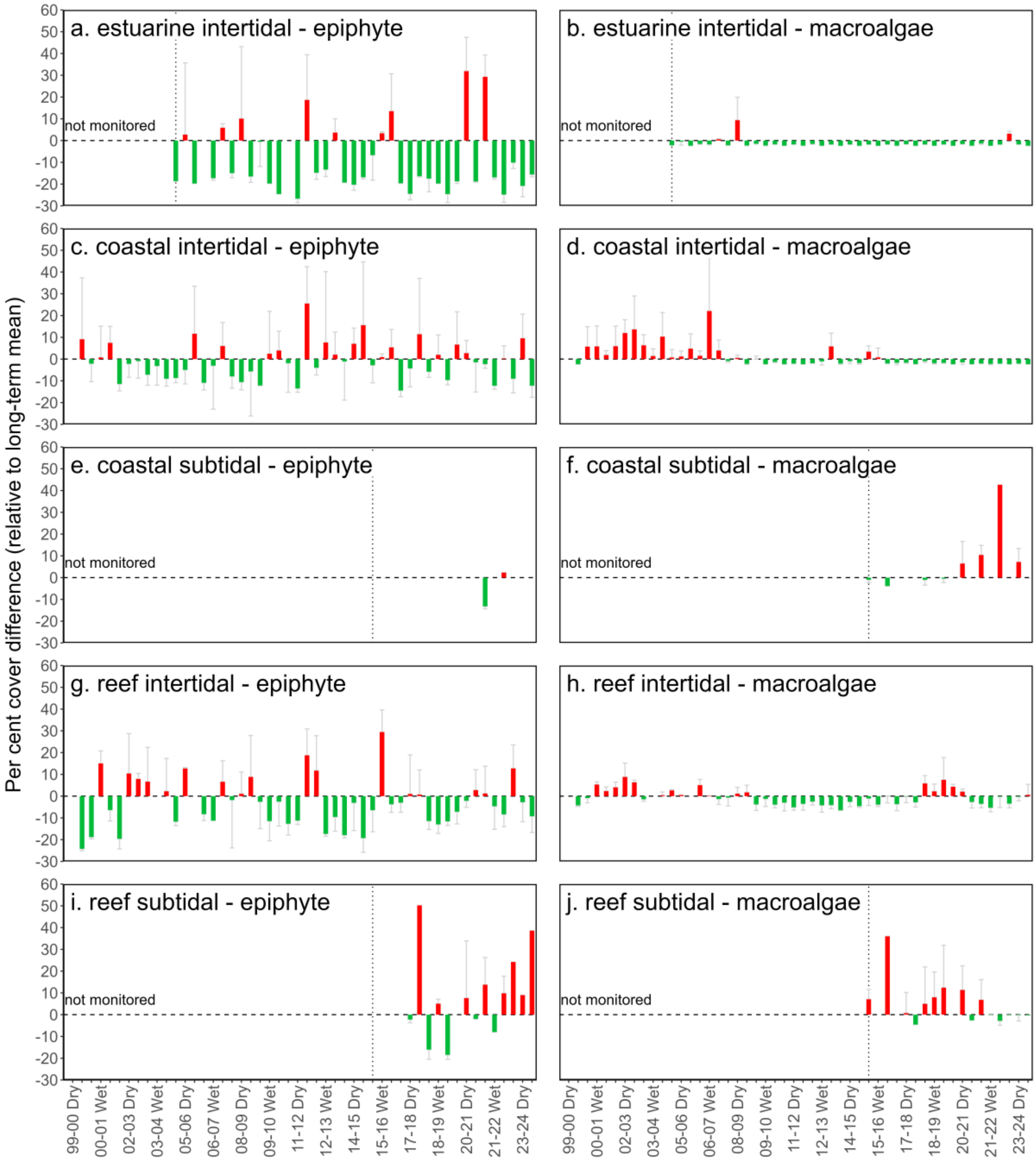



Figure 67. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Mackay–Whitsunday region, 1999–2024 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

## 5.5 Fitzroy

### 5.5.1 2023–24 Summary

Environmental pressures in the Fitzroy region in 2023–24 were around the long-term median for river basin discharge and water quality was relatively good. However, annual average daily light was below average, and there were a very high number of extreme temperature days and also the highest within-canopy temperatures on record for the Reef.

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 relatively benign, with conditions around or below the long-term average.

Overall, the seagrass condition score for the Fitzroy NRM region improved but remained **poor** in 2023–24 (Figure 68). There were improvements in both indicators. Condition indicators contributing to this were:

- abundance score was poor
- resilience was poor.

Seagrass abundance score significantly improved from the previous period, achieving its highest score since 2009–10. The increase can be attributed to better improved conditions in estuarine and coastal habitats, while the status of reef habitats has remained unchanged.

Resilience in the Fitzroy region improved in 2023–24 but was poor. At estuarine sites there were reproductive structures but one of the sites was in the low resistance category due to low per cent cover. At coastal sites in Shoalwater Bay, there was some albeit very low levels of reproduction at one site leading to an increase in the score compared to last year when there was none. At reef intertidal sites the score was the lowest ever recorded (1 on average), declining due to an increase in the proportion of colonising species.

For the first time since the 2019–20 period, inshore seagrass meadows in the region have shown signs of improvement. While some sites are experiencing local-scale impacts and processes that are hindering progress, others within the same habitat are thriving. Due to the limited number of sites in the Fitzroy region, changes in one site can greatly influence the overall score in comparison to other regions.

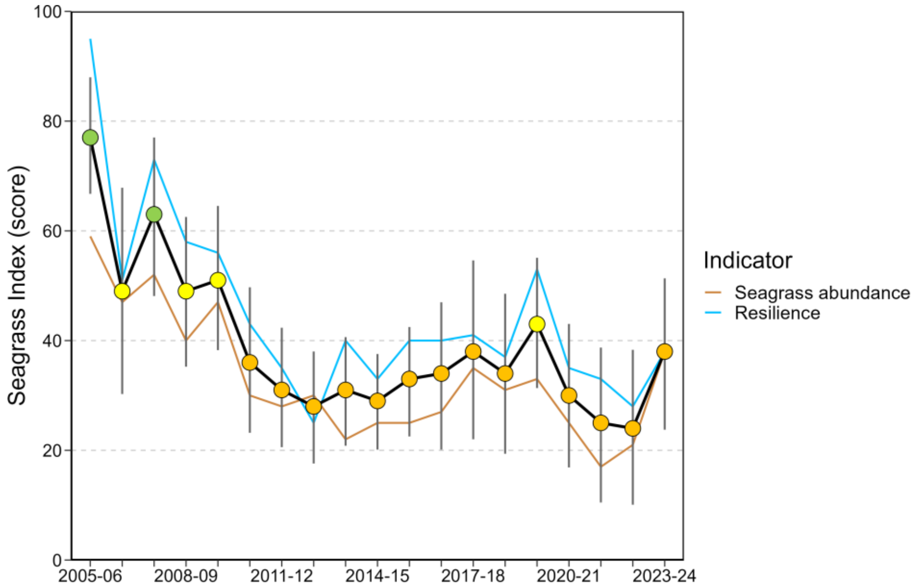



Figure 68. Temporal trend in the Seagrass Index (± SE) with contributing indicator scores for the Fitzroy NRM region (averages across habitats and sites). Values are indexed scores scaled from 0–100 (± SE) and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40), ●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

### 5.5.2 Climate and environmental pressures

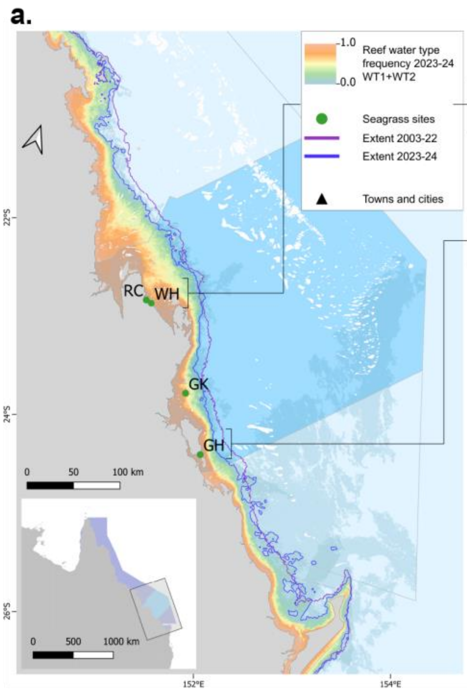
Environmental pressures in the Fitzroy region were around the long-term average for discharge and water quality but there was a very high number of extreme temperature days and the highest temperature on record.

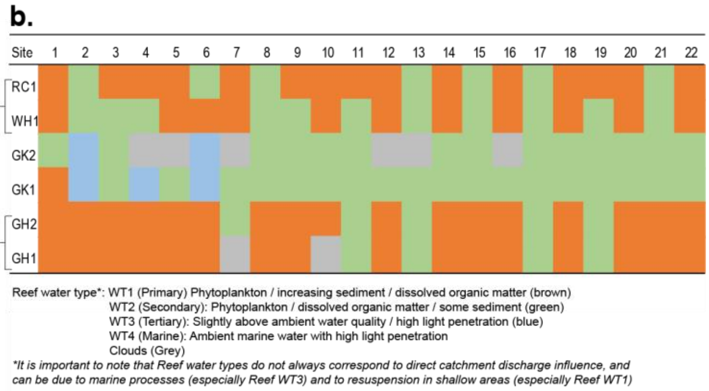
Wet season rainfall and discharge from the Fitzroy basins in 2023–24 was around the long-term average for the region (Figure 69c). Inshore coastal and estuarine seagrass habitats were exposed to turbid waters of primary (WT1) or secondary (WT2) for 96% of weeks during the wet season, which is similar to the long-term mean (Figure 69c). There was relatively more secondary 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). Water type exposure can be influenced by inshore processes such as resuspension as well as river discharge.

Annual averaged daily light availability in 2023–24 was lower than the long-term average for the region, but the average for this year does not include Shoalwater Bay due to logger issues where light is often high (Figure 8, Figure 69c, d). Daily light in Gladstone Harbour in 2023–24 (10.4 mol $m^{-2}$ $d^{-1}$) was below the long-term average (11.8 mol $m^{-2}$ $d^{-1}$) while at Great Keppel Island in 2023–24 daily light (15.4 mol $m^{-2}$ $d^{-1}$) was higher than the long-term average (15.0 mol $m^{-2}$ $d^{-1}$) (Figure 103).

2023–24 within-canopy temperatures were similar to the long-term average for the region (Figure 69c,f). Maximum intertidal within-canopy temperatures exceeded 35°C for a total of 98 days during 2023–24, the highest number since 2003-04. The highest temperature was 50.8°C (Shoalwater Bay, 25 October 23), which exceeds the previous maximum temperature by 4.3°C in the Mackay–Whitsunday region in 2022–23 (Figure 69e). Daytime tidal exposure in 2023–24 was below the long-term average (Figure 69c, Figure 95).

Estuarine habitat sediments in 2023–24 were composed primarily of finer sediments, with the mud portion increasing above the overall inshore Reef long-term average at both sites (Figure 121). The mud portion also increased in coastal habitat sediments at both sites in Shoalwater Bay, while reef habitat sediments remain dominated by fine sand/sand, (Figure 122, Figure 123).




c.

| | Long-term average | 2023-24 |
|---|---|---|
| Rainfall (1961-1990) | 2.9 mm d$^{-1}$ | 2.9 mm d$^{-1}$ |
| River discharge (1990-2020) | 5,060,907 L yr$^{-1}$ | 5,353,476 L yr$^{-1}$ |
| Turbid water exposure (2006-2018) | 97% | 96% |
| Daytime tidal exposure (1999-2023) | 117 hr yr$^{-1}$ | 106 hr yr$^{-1}$ |
| Within-canopy temperature (max) (2003-2023) | 24.1°C (41.9°C) | 24.2°C (50.8°C) |
| Within-canopy light (2009-2023) | 15.1 mol m$^{-2}$ d$^{-1}$ | 12.9 mol m$^{-2}$ d$^{-1}$ |

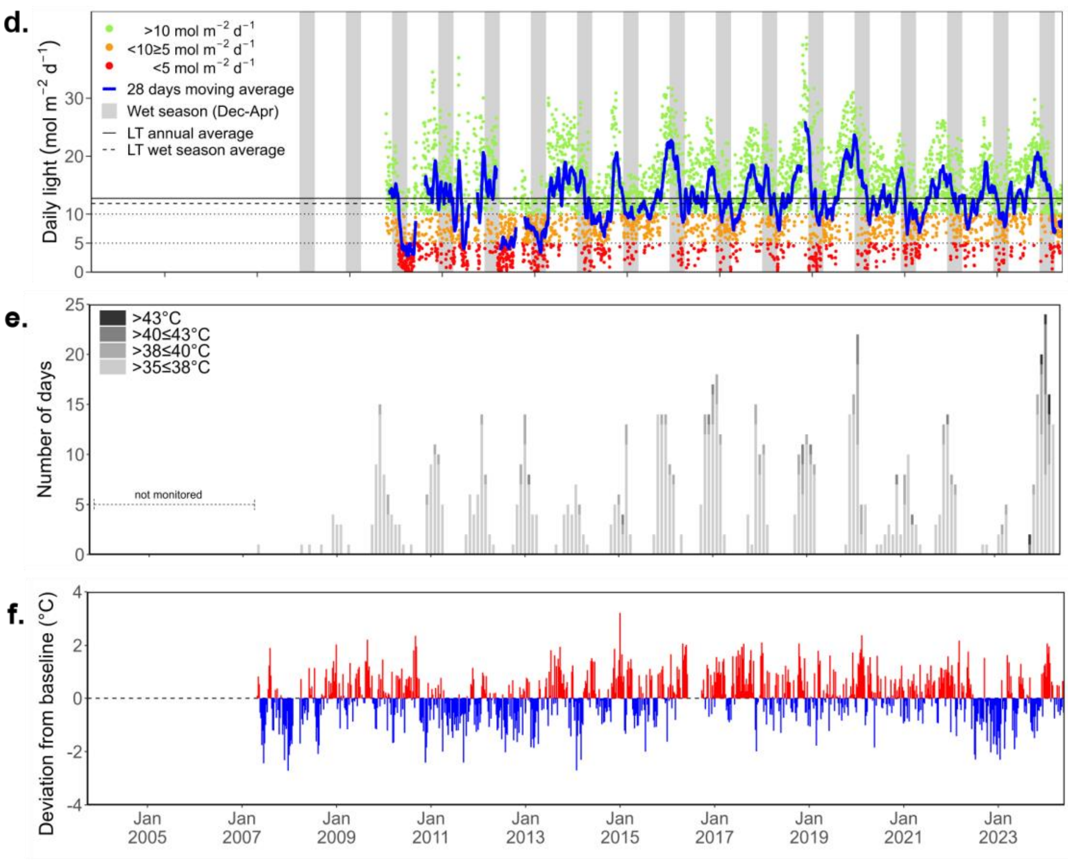



Figure 69. Environmental pressures in the Fitzroy region including: a. frequency of exposure to primary (WT1) and secondary (WT2) water from December 2023 to April 2024 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the long-term average (2003–2018) exposure boundary (purple line), and the first (blue line) and third quartile (white line) of the long-term average (from Moran *et al.* 2025); b. wet season water type at each site; c. average conditions and max temperature over the long-term and in 2023–24; 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 2023–24, 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 2023–24 monitoring period, the Seagrass Index improved but remained a **poor** grading (Figure 68). The Index was the highest in the last 4 years and the eighth highest since monitoring began in the Fitzroy NRM.

In 2022–23, the abundance score significantly increased from the previous period, achieving its highest score since 2009-10; even though the overall condition remained in a poor state (Figure 70). The increase stemmed from the improved abundance conditions in estuarine and coastal habitats, while reef habitats remained unchanged (Figure 70).

The resilience score similarly increased, achieving its highest level in four years (Figure 70). This improvement was primarily due to enhanced resilience in the estuarine meadows of Gladstone Harbour, and to a lesser extent, the coastal meadows in Shoalwater Bay. Conversely, the resilience of reef habitats at Great Keppel Island continued to diminish (Figure 70)

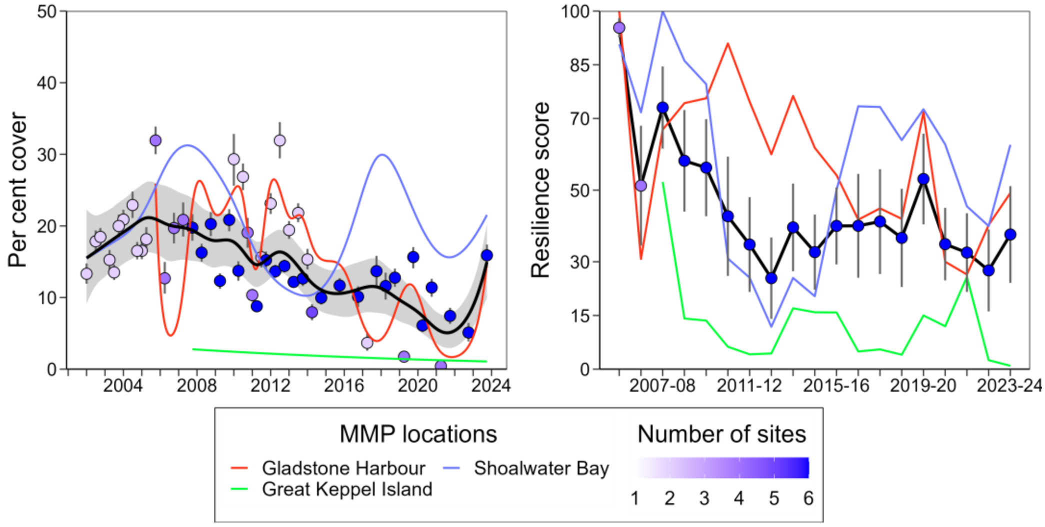



Figure 70. Temporal trends in the Fitzroy seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area defining 95 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 2023–24, seagrass abundances across the Fitzroy region increased from the previous reporting period, with the exception of reef habitats which remained unchanged (Figure 71). At the estuarine habitat, one site (GH1) showed a significant increase, quadrupling its abundance in 2023–24, reaching its peak level in a decade, after a steady improvement over the past four years. Meanwhile, the other site (GH2) managed to recover from the losses it experienced in the prior three years.

Seagrass abundance (percent cover) in the Fitzroy region during 2023–24 was notably greater in coastal habitats (26.2 ±0.5 per cent) compared to estuarine (14.7 ±0.7 per cent), and reef habitats (1.8 ±0.3 per cent) (Figure 71). Over the years of the monitoring program, seagrass abundance in estuarine and coastal intertidal habitats has varied significantly, with some sites experiencing complete or nearly complete loss followed by recovery (Figure 71). In 2023–24, all monitored habitats in the Fitzroy region showed seagrass abundances above the long-term average (not significantly) for the first time since 2015–16. Furthermore, in the estuarine meadows of Gladstone Harbour, seagrass abundance surpassed the long-term average for the first time in seven years.

Examination of the long-term trend in seagrass abundance (per cent cover) throughout the region reveals a significant decrease (Figure 70, Table 22). This decrease is mainly influenced by individual sites in estuarine and reef habitats (GH1 and GK1, respectively), although two-thirds of all monitoring sites in the region, including coastal habitats, show no significant trend (Table 22).

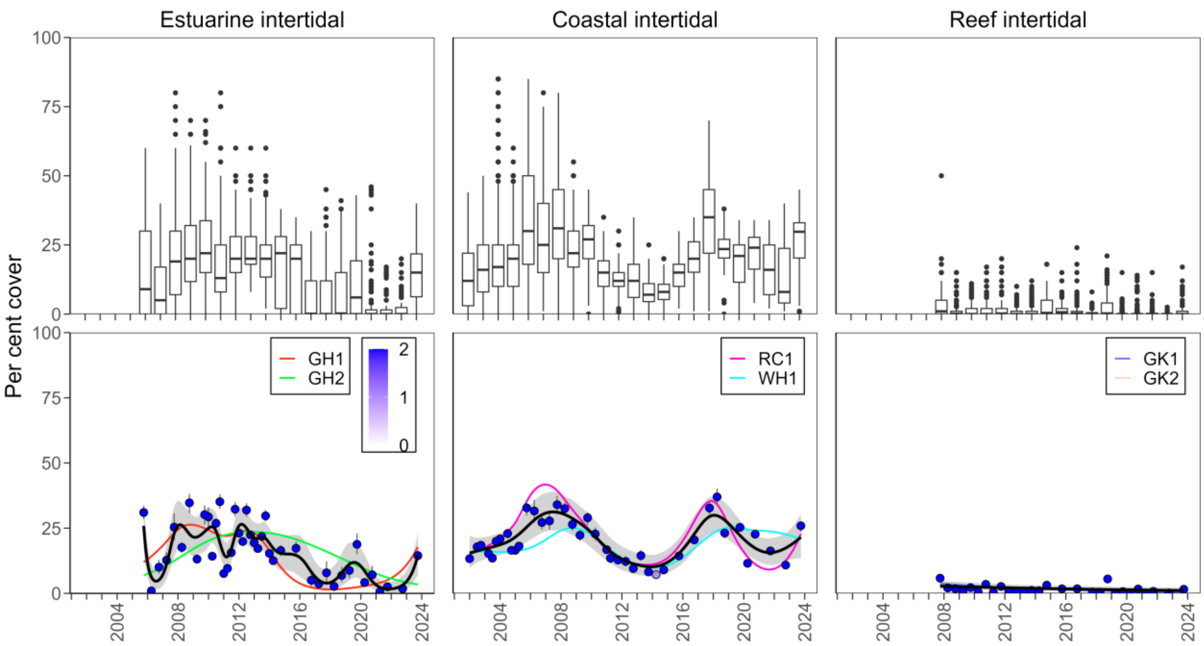



Figure 71. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends, for each habitat monitored in the Fitzroy NRM region from 2002 to 2024. Whisker plots (top) show the box representing the interquartile range of values, where the boundary of the box closest to zero indicates 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.

With an increase in seagrass abundance, the estuarine meadows at Pelican Banks (Gladstone Harbour) have shown a rise in the dominance of the foundational seagrass *Z. muelleri*, while the presence of colonising species (*H. ovalis*) has diminished. In the coastal meadows of Shoalwater Bay (Ross Creek and Wheelans Hut), *Z. muelleri* continues to dominate, also with low proportions of colonising species (*H. ovalis*). The proportion of colonising species (*H. ovalis*) peaked following the extreme climatic events of 2011, and has gradually been declining since then (Figure 72). Over the past two years, the proportion of the opportunistic species has increased, yet it remains below the Reef long-term average at coastal habitats (Figure 72). Conversely, colonising species have continued to dominate in the reef habitat sites, exceeding the overall inshore Reef long-term average, while there has been a decline in the *H. uninervis* over the last two years (Figure 72).

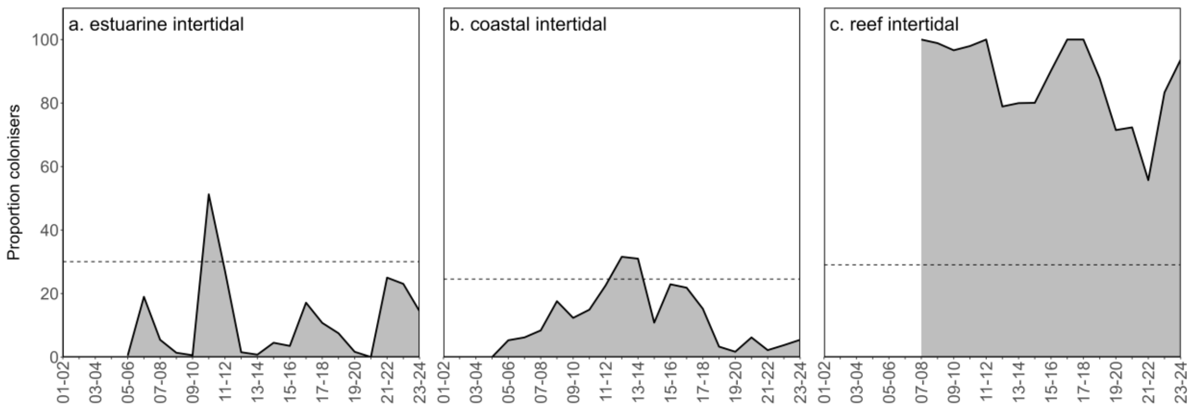



Figure 72. Proportion of seagrass abundance composed of colonising species in inshore intertidal habitats of the Fitzroy region, 2001–2024. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

Despite a slight decline in coastal meadow extent at the end of 2023 compared to the previous period, monitoring sites in Shoalwater Bay have shown overall improvement over the past two years. The estuarine meadows at Pelican Banks in Gladstone Harbour have experienced significant fluctuations in extent since 2015–16, when one site suffered a major reduction 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, between 2020–21 and 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 in 2023–24, the overall meadow extent reached its highest level in a decade. Meanwhile, the meadows on the reef flat at Great Keppel Island have remained highly fragmented since the losses in 2015–16 and have shown considerable fluctuations over the last five years, with declines noted in 2023–24 (Figure 73).

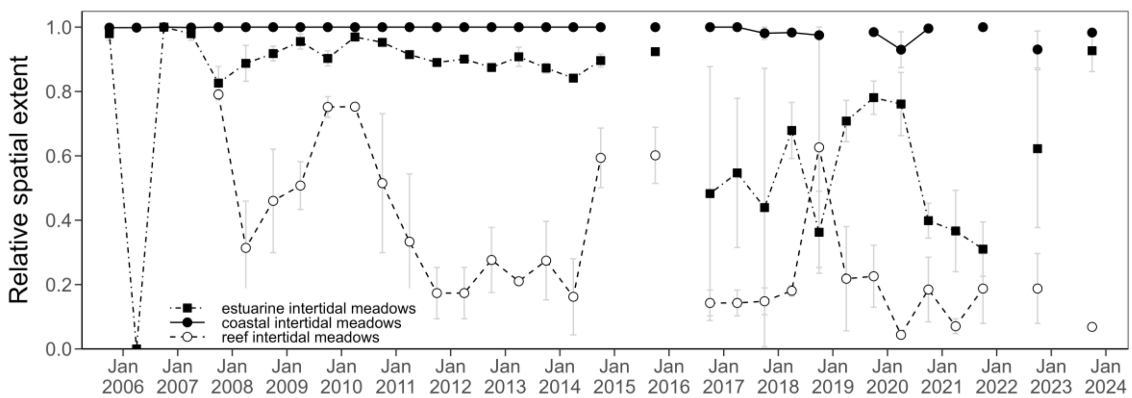



Figure 73. Change in spatial extent (± SE) of seagrass meadows within monitoring sites for each inshore intertidal habitat across the Fitzroy NRM region, 2005–2024.

### 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). Since 2021, seagrass assessments have been conducted only during the dry season each year. In 2023-24, the overall reproductive effort declined by approximately two-thirds compared to the previous.

Reproductive effort in estuarine sites (Gladstone Harbour) during 2023–24 fell to its lowest dry season level since 2016). In contrast, coastal sites (Shoalwater Bay) saw an increase in reproductive effort, reaching the highest level since 2018 (Figure 74). Over the past decade, a seed bank has remained in both estuarine and coastal intertidal habitats; however, its density has decreased at estuarine sites compared to the previous year, while it tripled at one coastal site (RC1). For the third consecutive year, reproductive structures were absent at reef sites, and seeds have never been found in the reef meadows at Great Keppel Island. This absence hinders the meadow's recovery capacity, making them particularly susceptible 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).

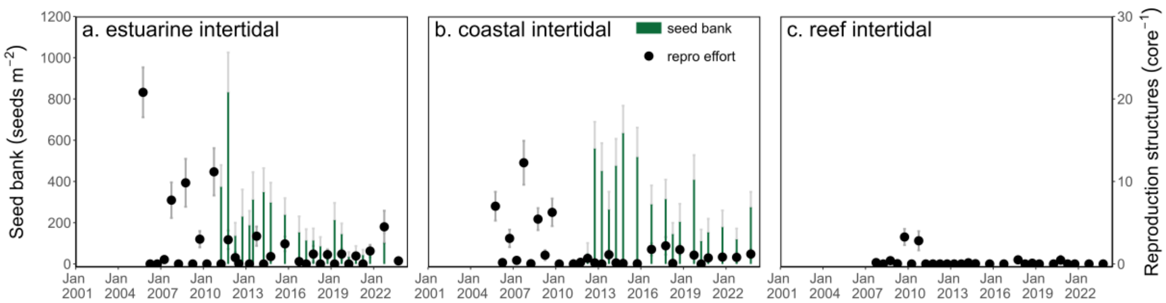



Figure 74. Seedbank and reproductive effort at inshore intertidal coastal, estuarine and reef habitats in the Fitzroy region, 2005–2024. Seed bank presented as the total number of seeds per m² of sediment surface (green bars ±SE). Reproductive effort for the late dry season presented as the average number of reproductive structures per core (species and sites pooled) (circles ±SE).

### 5.5.3.4 Resilience

Overall resilience in the Fitzroy region improved but was poor in 2023–24 (Figure 70). There were improvements at estuarine and coastal intertidal sites but the score declined at reef intertidal sites (Figure 75).

At estuarine intertidal habitats in Gladstone there were reproductive structures at both sites. This lead to an increase in the score at GH2 which was in the low resistance category 1.2 because the per cent cover of seagrass was below the low resistance threshold. The score increased in coastal intertidal habitats because there was some albeit very low reproductive effort of foundational species (*Z. muelleri*) at WH1 but not at RC1.

At reef intertidal sites at Great Keppel Island, the score was the lowest ever recorded. The sites were dominated by colonising species and there were no reproductive structures so were in category 1.1. The scores were very low within this category because there was 100% *H. ovalis* at GK1 and 87% at GK2 leading to scores of 0 and 2, respectively.

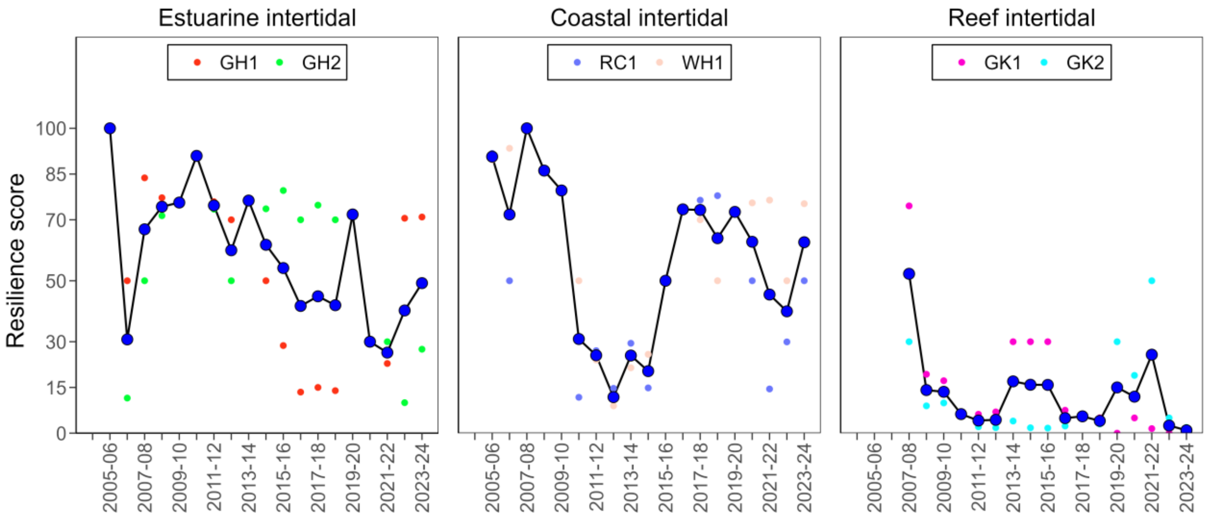



Figure 75. Resilience in each habitat in the Fitzroy region 2006 to 2024. Coloured small circles represent different sites. Shades of blue for the larger circles indicates the number of sites that contributed to the score.

### *5.5.3.5 Epiphytes and Macroalgae*

In 2023–24, epiphyte cover on estuarine seagrass leaves increased slightly during the late dry 2023, before abating over the wet season. At coastal and reef sites, epiphyte cover remained below inshore Reef long-term average for both habitats (Figure 76).

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

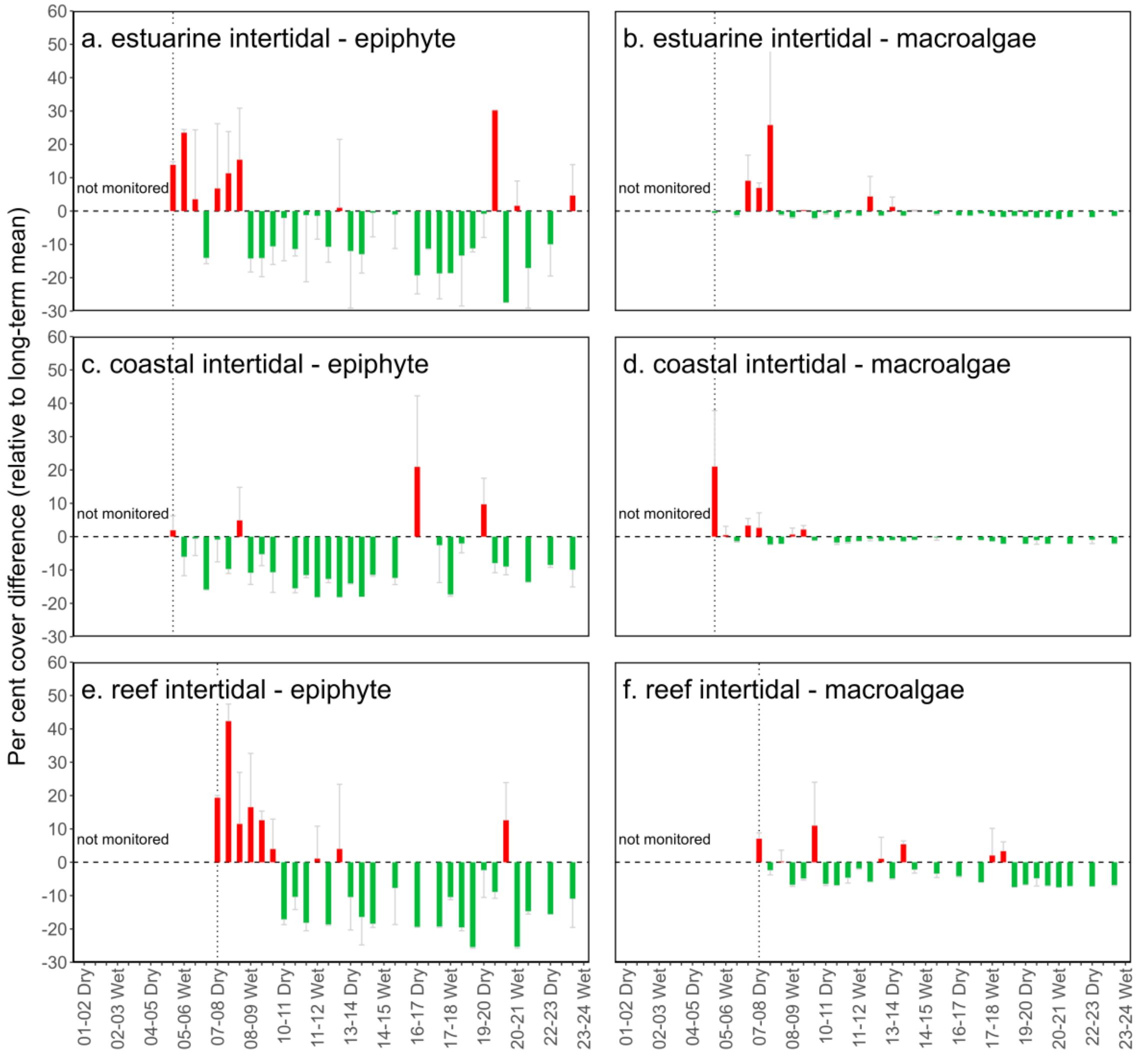



Figure 76. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Fitzroy region, 2005–2024 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

## 5.6 Burnett–Mary

### 5.6.1 2023–24 Summary

In the Burnett–Mary region in 2023–24 there were several moderate environmental pressures. Annual rainfall and river discharge were above the long-term average and median, respectively. Seagrass monitoring sites were exposed to turbid waters (WT1 and WT2) for most of the wet season as is typical in the region. Within-canopy daily light was below the long-term due to reductions at both estuarine locations. Within-canopy temperatures in 2023–24 were warmer than the long-term average, but the number of temperature extremes (>35°C) was the lowest since 2007.

Inshore seagrass meadows across the Burnett–Mary NRM region improved in overall condition in 2023–24, with the Seagrass Index increasing to a **poor** grade (Figure 77). Contributing indicators to the overall score were:

- abundance score was moderate
- resilience score was poor.

The seagrass abundance score for the NRM region improved from very poor in 2022–23 to moderate in the current period. This was the first improvement since 2018-19, reversing a downward trend, and also the highest score since the MMP began. This recovery was limited to estuarine habitats, which also increased to their largest spatial extent in around eight years. In contrast, coastal habitats continued to experience declines, likely a consequence of discharges from the Burrum River, which were more than three times the long-term median.

Resilience increased in the region in 2023–24, but remained poor overall for the third year in a row. Improvements occurred because the proportion of foundational species increased (UG1 and UG2) and per cent cover increased (RD2, RD3, BH1) leading to a jump in resilience category from 1.2 to 2.1.1 for those sites, although reproductive structures were only observed at RD1. Despite this, meadows throughout the region have a higher capacity to recover as seed banks persist, although replenishment ability has been diminished at coastal habitats, leaving these meadows vulnerable to future significant disturbances.

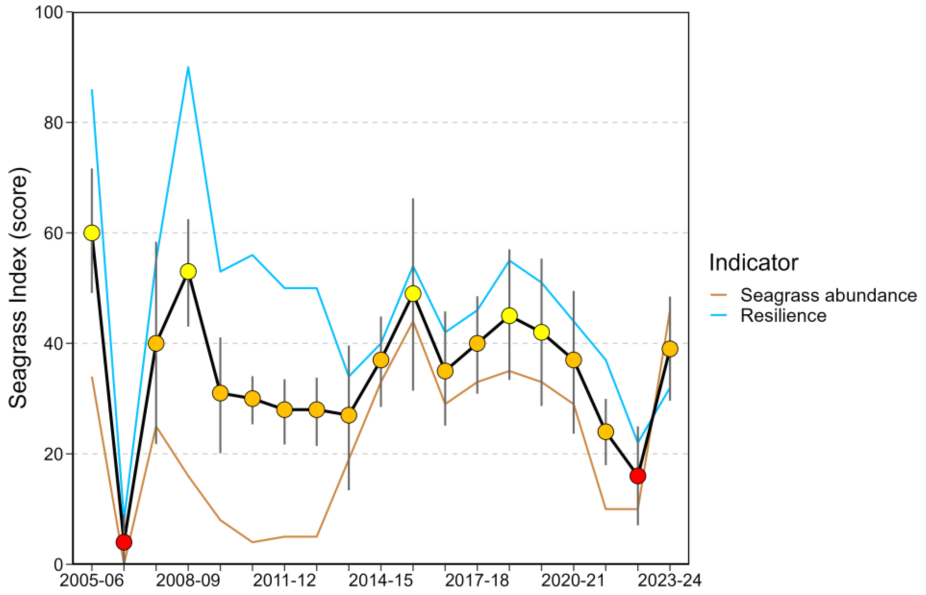



Figure 77. Temporal trend in the Seagrass Index (± SE) with contributing indicator scores for the Burnett–Mary region (averages across habitats and sites). Values are indexed scores scaled from 0–100 (± SE) and graded: ● = very good (81–100), ● = good (61–80), ● = moderate (41–60), ● = poor (21–40),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

### 5.6.2 Climate and environmental pressures

Rainfall in 2023–24 was higher than the long-term average for the region (Figure 78), and it was higher in all of the basins of the Burnett-Mary NRM region (Figure 5). River discharge was also higher than the long-term average in the Burnett–Mary region and elevated from all rivers with the greatest being the Mary River which was almost double the long-term average (Table 11).

In the Burnett-Mary region there are only estuarine and coastal monitoring locations, and these are generally exposed to high frequencies of primary and secondary turbid waters (WT1 and WT2) and in 2023–24 it was for 98% of weeks in the wet season which is consistent with the long-term average (100%) (Figure 78a, b). Within-canopy daily light levels in 2023–24 (10.1 mol $m^{-2}$ $d^{-1}$) were below the long-term average (11.9 mol $m^{-2}$ $d^{-1}$). This was due predominantly to lower than average light in 2023–24 at Rodds Bay (5.3 mol $m^{-2}$ $d^{-1}$) compared to the long-term average (8.4 mol $m^{-2}$ $d^{-1}$), and at Urangan in 2023–24 (12.3 mol $m^{-2}$ $d^{-1}$) compared to the long-term average (11.1 mol $m^{-2}$ $d^{-1}$) (Figure 104). Daily light was higher in 2023–24 at Burrum Heads (12.8 mol $m^{-2}$ $d^{-1}$) compared to the long-term average (13.9 mol $m^{-2}$ $d^{-1}$).

Within-canopy temperature in 2023–24 was 0.4°C warmer than the long-term average. This follows a cooler year when in 2022–23 temperature was 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 9 days during 2023–24 (the lowest since 2007) (Figure 78e), with the highest temperature recorded at 37.8°C (Urangan, 22 February 2024).

Daytime tidal exposure was well below the regional long-term average in 2023–24 (Figure 78c) (Figure 97). Exposure was the lowest at Rodds Bay and the third lowest at Urangan since 2003–04. The less than long-term average exposure may have reduced the risk of 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. Over the previous two years, the sediments at the southernmost estuarine location (Urangan) were dominated by fine sands with a surface layer of dispersive soils, deposited across the intertidal banks by the floods in early 2022. In 2023–24, the proportion of mud in the estuarine habitats increased above the Reef long-term average, and the dispersive soils at Urangan, has dissipated and moved offshore. Meadows in the north varied, with a noticeable increase in fine sand content at one site (RD3), while the other site remained unchanged and dominated by mud (Figure 124). Coastal meadows in 2022–23 continued to be dominated by fine sand with little change from the previous year (Figure 125).

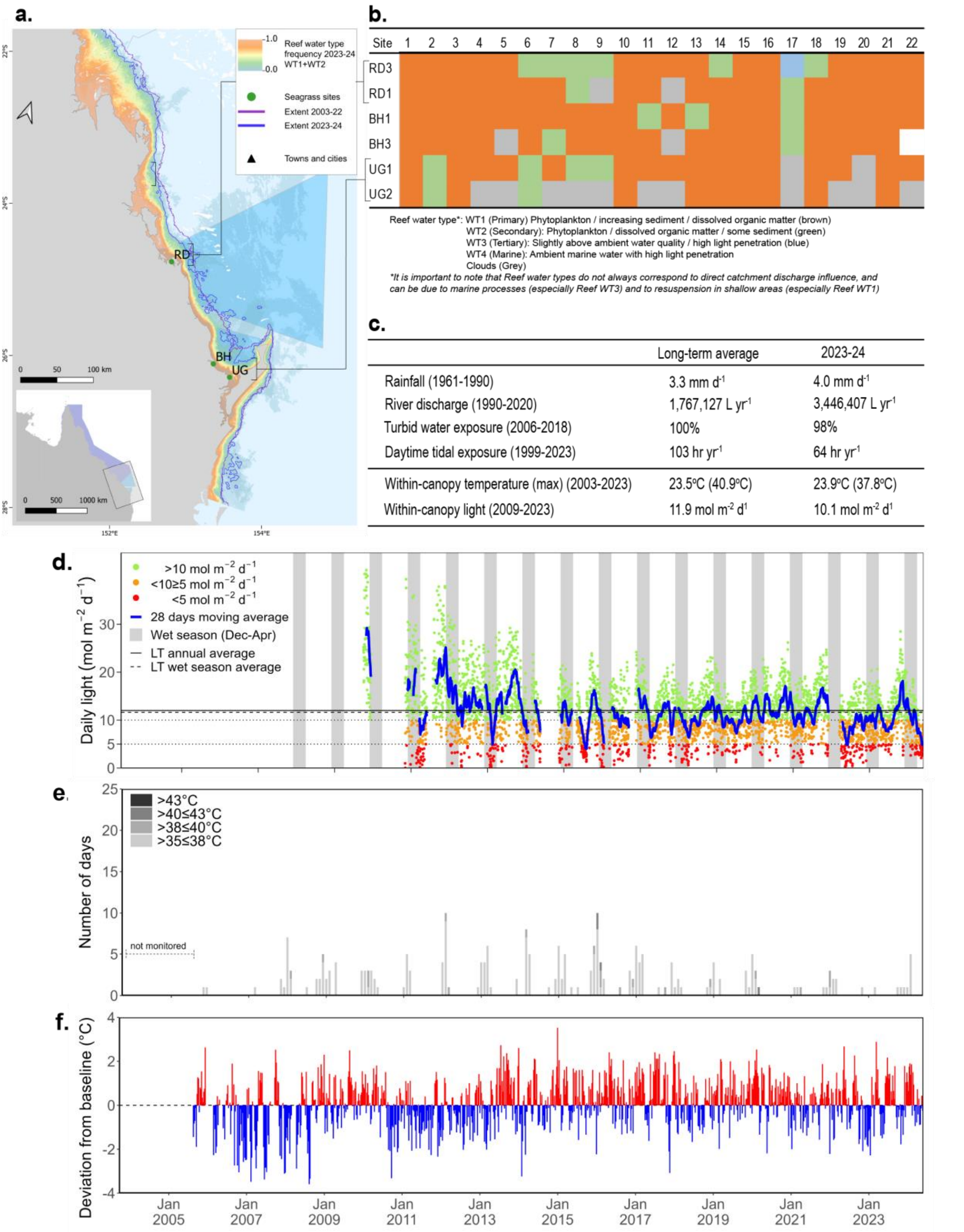



Figure 78. Environmental pressures in the Burnett–Mary region including: a. frequency of exposure to primary (WT1) and secondary (WT2) waters from December 2023 to April 2024 ranging from frequency of 1 (orange, always exposed) to 0 (pale blue, never exposed) (white = no data), also showing the long-term average (2003–2018) exposure boundary (purple line), and the first (blue line) and third quartile (white line) of the long-term average (from Moran *et al.* 2025); 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 Inshore seagrass and habitat condition

Only estuarine and coastal habitats were assessed across the Burnett–Mary region in 2023–24, 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 | ■ | ■ | ■ | ■ | ■ | ■ | ■ |

#### *5.6.3.1 Seagrass Index and indicator scores*

During the 2023–24 monitoring period, the Seagrass Index for the Burnett–Mary region improved from a very poor to a **poor** rating, marking its highest score in four years (Figure 77). This improvement reverses the downward trend observed since 2018–19, with changes in both indicators contributing to this positive result (Figure 79).

Over the long term, the average abundance of seagrass in the region has fluctuated greatly, marked by both loss and recovery phases. From 2012 to 2016, the estuarine meadows at Urangan experienced a notable increase in seagrass abundance, which fell sharply starting in 2017 and was entirely lost by 2022 due to extensive flooding in the area. Similar declines were reported at other estuarine and coastal locations from 2019. The improvement in 2023–24, resulted in the highest abundance score since the MMP began in 2005–06. This recovery was limited to estuarine habitats, as coastal habitats continued to experience declines, with discharges from the Burrum River, which exceeded triple the long-term median, likely playing a significant factor (Figure 79).

Seagrass resilience improved in 2023–24 across all locations in the Burnett–Mary region (Figure 79). This enhancement was largely due to substantial increases observed at individual sites within both coastal and estuarine habitats, specifically at BH1 and RD3, respectively.

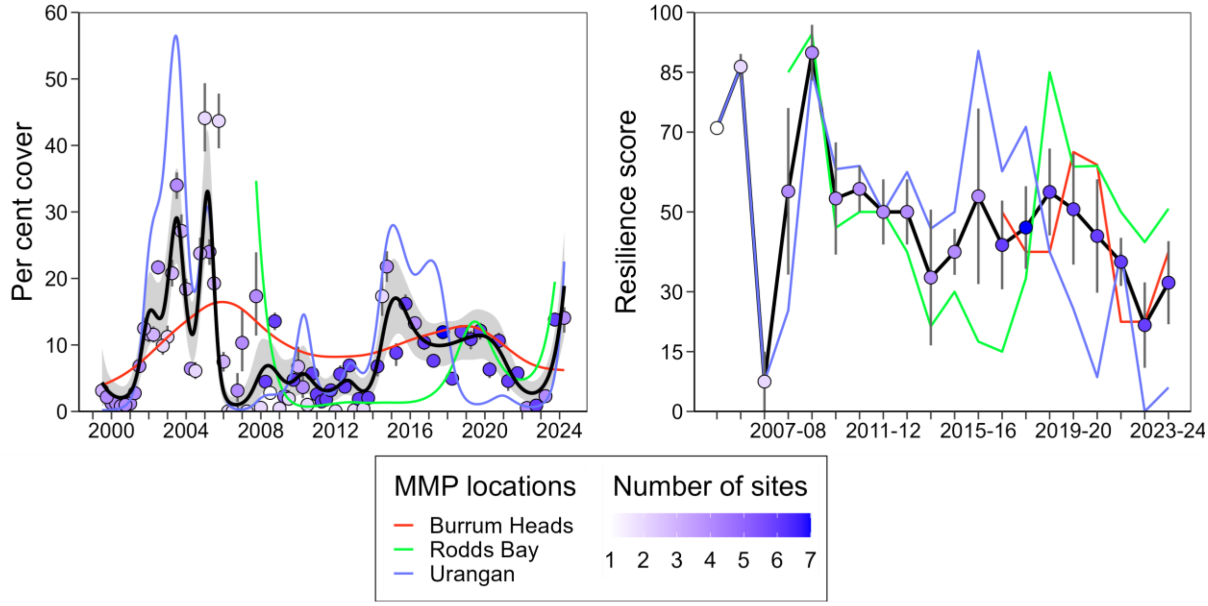



Figure 79. Temporal trends in the Burnett–Mary seagrass indicators used to calculate the Seagrass Index: a. average (circles, ±SE) seasonal abundance (per cent cover) and GAM plots of seagrass abundance trends for each location (coloured lines) and the region (black line with grey shaded area defining 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 2023–24 (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 the 2023-24 period, seagrass abundance at estuarine habitats reached 16.7 ±0.6 per cent, surpassing long-term averages. However, coastal habitats maintained a similar abundance to the long-term average at 9.0 ±0.4 per cent for the second consecutive year (Figure 80). Overall, the Burnett-Mary region experienced its first significant improvement in seagrass abundance during 2023-24, ending four years of decline. The largest improvement was in the estuarine meadows at Urangan, which had been completely lost during the late dry season of 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, with substantial gains occurring throughout 2023–24 (Figure 80). In the last monitoring period, the observed gains were mainly attributed to the rise of the colonising species, *H. ovalis.* However, during 2023–24, the foundation species, *Z. muelleri,* began to dominate (Figure 81). The increase in foundation species indicates that the meadows are likely to have a considerably enhanced ability to resist moderate disturbances in the future.

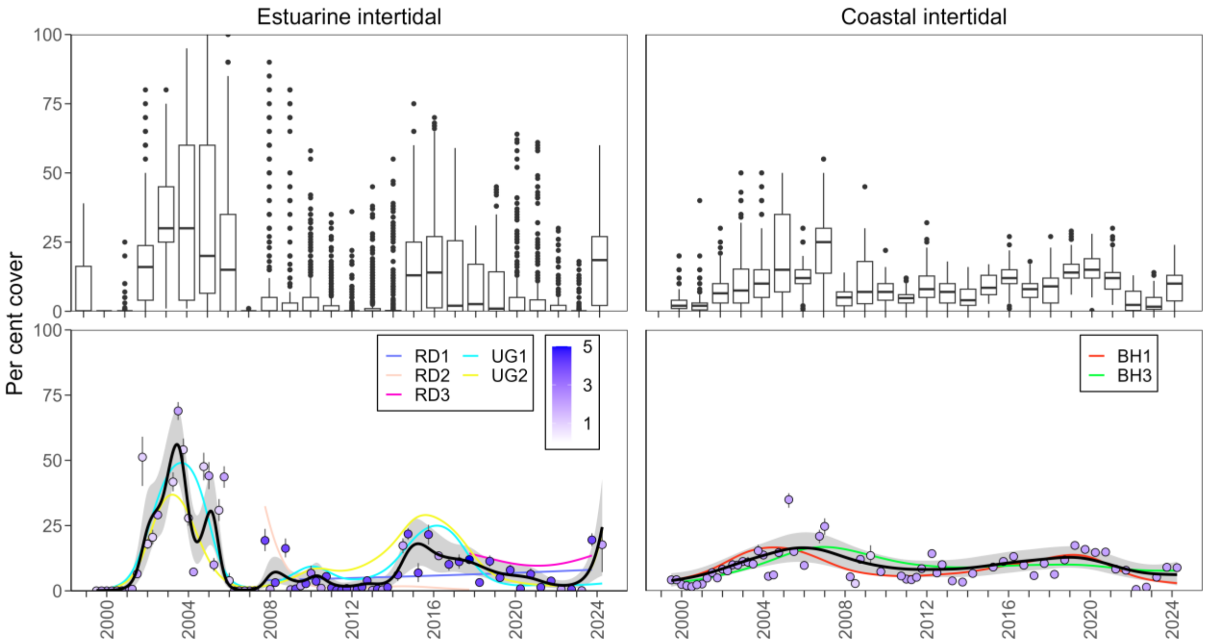



Figure 80. Seagrass per cent cover measures per quadrat (sites pooled) and long-term trends, for each habitat monitored in the Burnett–Mary NRM region from 1999 to 2024. Whisker plots (top) show the box representing the interquartile range of values, where the boundary of the box closest to zero indicates 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.

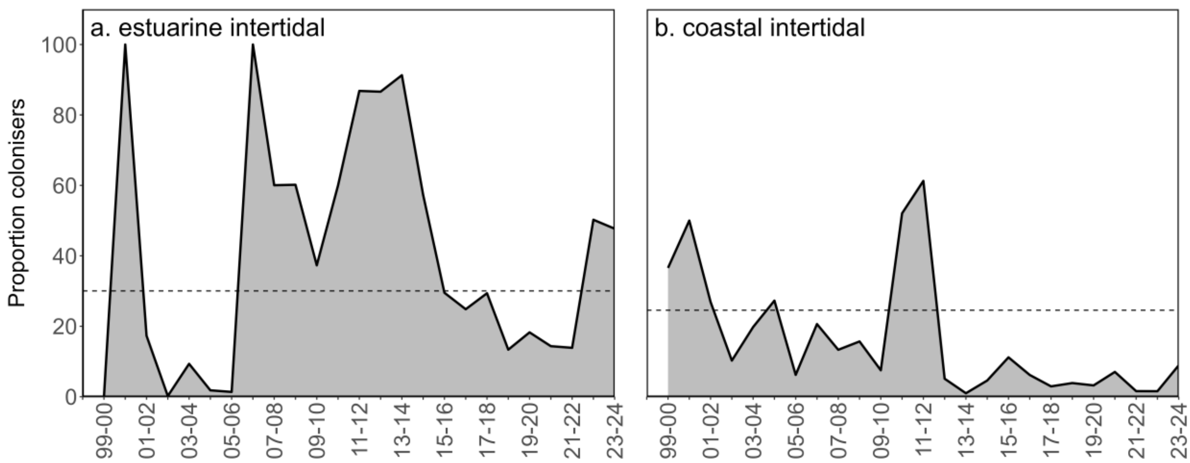



Figure 81. Proportion of seagrass abundance composed of colonising species at: a. estuarine and b. coastal habitats in the Burnett–Mary region, 1998 to 2024. Dashed line represents Reef long-term average proportion of colonising species for each habitat type.

Meadow spatial extent slightly improved relative to the previous year at coastal meadows in late dry 2023, before decreasing in the late wet 2024 (Figure 82). Estuarine meadows showed the greatest improvement in late dry 2023, before, similarly declining slightly in the late wet 2024. The greatest improvement was at one of the southern sites at Urangan (UG2), where the meadows, 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.

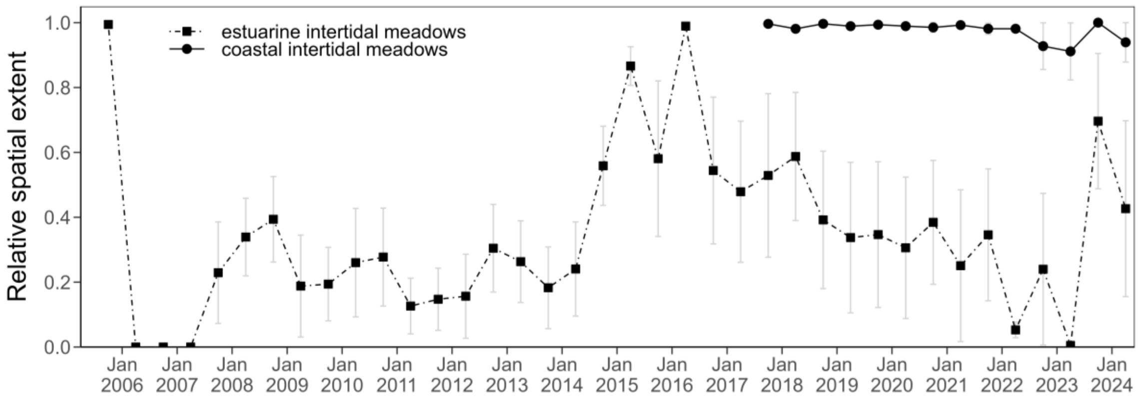



Figure 82. Change in spatial extent (± SE) of estuarine seagrass meadows within monitoring sites for each habitat and monitoring period across the Burnett–Mary NRM region, 2005-2024.

### 5.6.3.3 Seagrass reproductive status

Over the past eight years, the reproductive effort, measured by the number of sexual reproductive structures per core, in the Burnett-Mary region has consistently fallen below the regional average of 0.97 reproductive structures per core. However, during the 2023–24 period, reproductive effort peaked at its highest level in five years, reaching 0.68 (Figure 83). Notably, this effort was exclusively observed in estuarine habitats in both the northern and southern regions, during the dry season. Despite these observations, no sexual reproductive structures were detected in the coastal meadows at Burrum Heads. Nevertheless, a seed bank is still present at both coastal monitoring sites, indicating that reproduction had taken place, albeit not during the sampling period. Seed banks were also found in estuarine meadows in both the northern and southern regions during the 2023–24 period. A significant seed bank ranging from 358 to 866 seeds per square metre persists at Rodds Bay in the north, while a smaller seed bank of 57 to 85 seeds per square metre remains at Urangan in the south (Figure 83).

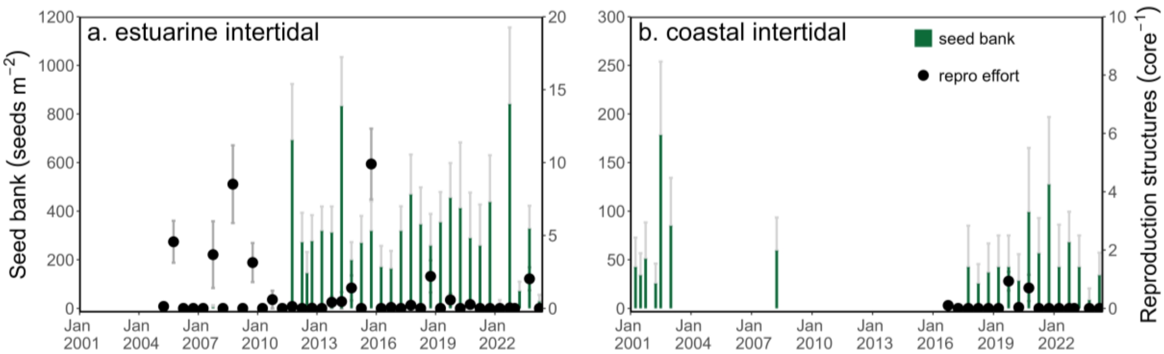



Figure 83. Seedbank and reproductive effort at inshore estuarine (a.) and coastal (b.) intertidal habitats in the Burnett–Mary region, 2001-2024. Seed bank presented as the total number of seeds per m$^2$ sediment surface (green bars ±SE). Reproductive effort for late dry season presented as the average 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 2023–24 but increased compared to 2022–23. The improvements occurred in both estuarine and coastal intertidal habitats (Figure 84).

At both Urangan sites, percent cover and composition were below thresholds for resistance (percent cover was <1%) as the proportion of foundational species increased even though colonising species still dominated. At RD3, per cent cover increased to above the low resistance threshold but there no reproductive structures leading to only a small increase in the score for the site. At RD1 abundance and composition were above low resistance thresholds, and it was the only site where reproduction was observed.

At coastal intertidal sites at Burrum Heads, at BH1, abundance increased and was above the threshold indicative of low resistance. There were no reproductive structures but there had been three years' prior so the site was elevated to category 2.1.2. 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 the score was in the lowest for category 2.1.1.

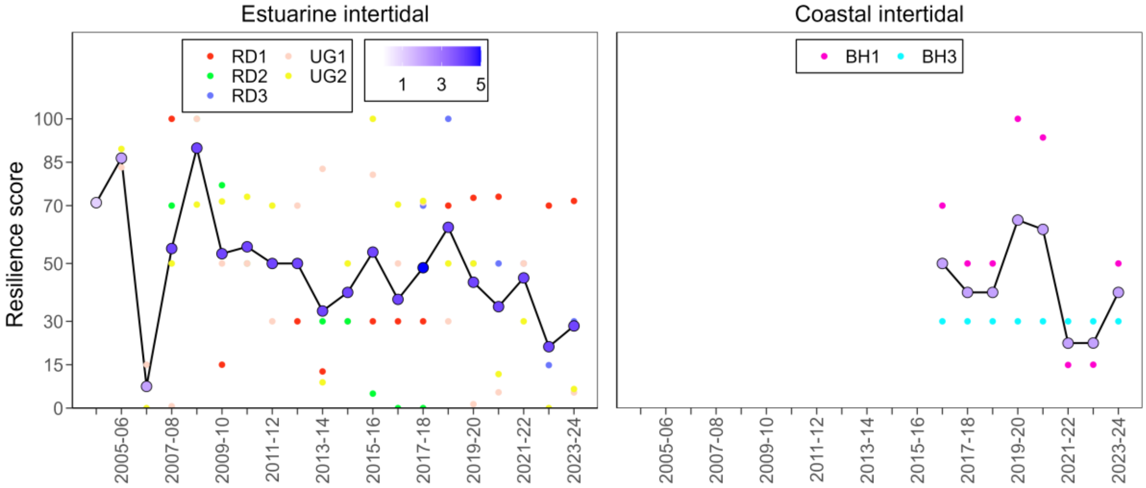



Figure 84. Resilience score in each habitat in the Burnett–Mary region from 2006 to 2024. Coloured small circles represent different sites. Shades of blue for the larger circles indicate the number of sites that contributed to the score.

### *5.6.3.5 Epiphytes and macroalgae*

Epiphyte cover on seagrass leaf blades in 2023–24 generally decreased, but remained above the long-term average for the tenth consecutive year at estuarine habitats (Figure 85a). At coastal habitats, epiphyte abundance remained below the long-term average (Figure 85c).

Per cent cover of macroalgae remained below the long-term average at coastal habitats for the ninth consecutive year (Figure 85d). However, in the estuarine habitat, there was an acute increase during the late dry 2023, driven by excessive algal growth at the Urangan meadows, which dissipated over the wet season (Figure 85b).

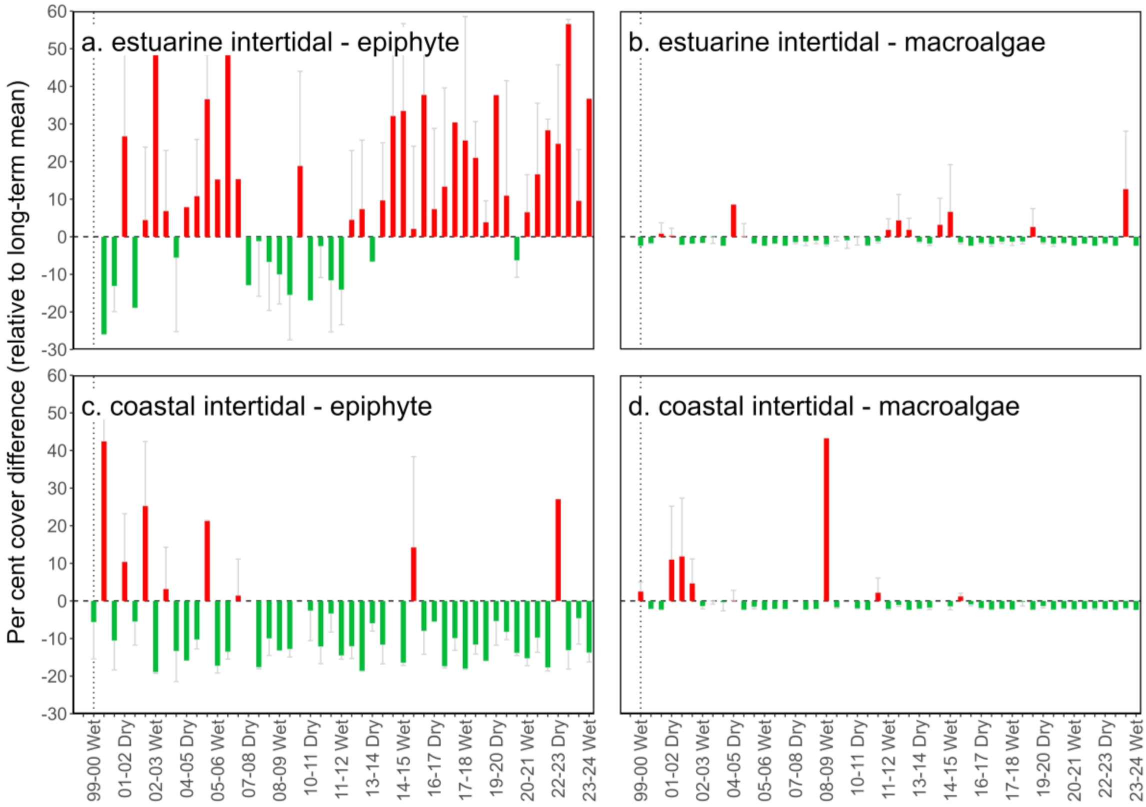



Figure 85. Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Burnett–Mary region, 2000–2024 (sites pooled, ±SE). Vertical dotted lines represent the first monitoring event for each habitat type.

# 6 Discussion

Inshore seagrass condition was largely unchanged in 2023–24 with marginal decreases in both indicators. However, there were regional differences, with deterioration of condition in the northern NRM regions (Wet Tropics and Burdekin), improvements in the southern regions (Fitzroy and Burnett–Mary) while the far northern (Cape York) and central regions (Mackay–Whitsunday) remained largely unchanged.

In 2023–24, the Seagrass Index declined to **poor** in both northern regions (Wet Tropics and Burdekin), but based on previous recovery trajectories, recovery rates post 2023-24 may differ between regions. Prior to the events of 2023–24, seagrass in the Burdekin region was in a moderate and slightly declining state, showing limited recovery after the elevated rainfall and discharge events in 2018–19. The sustained moderate condition over several years and depressed pre-event resilience may hinder recovery in this region, especially at coastal intertidal and reef subtidal habitats near Townsville. Conversely, in the northern Wet Tropics subregion, coastal intertidal and reef subtidal habitats were in a good condition prior to 2023–24 and likely retain some (albeit depressed) seed banks and patches of colonising and foundational species. Drawing from recovery patterns following the extreme weather events from 2009 to 2011, there is potential for recovery with the next year or so, but this is contingent on ongoing environmental conditions.

Improvements in the seagrass Index in 2023–24 occurred in the Fitzroy (to the highest since 2009–10) and Burnett–Mary regions (improving from very poor) but both remained **poor**. In the Fitzroy region, improvements in abundance occurred in both estuarine and coastal habitats in Gladstone and also at Shoalwater Bay, respectively. The cause of previously low abundances in the region was likely local-scale processes, such as sediment movement. Improvements in the Burnett–Mary region were driven by large increases in abundance of estuarine habitats (Rodds Bay and Urangan), which are historically highly variable. This signifies recovery from large riverine discharges in the 2001–22 wet season that caused considerable loss of seagrass. At Urangan, there was also highly dispersive sodic sediments at the sites, which were easily resuspended and delayed the onset of recovery but have now moved from the site. Riverine discharge was again double the long-term median in 2023–24 but this follows a relatively benign year of environmental conditions in 2022–23, which probably facilitated recovery of abundance, while resilience remains depressed in the Burnett–Mary region. These trends highlight that there is an interplay between local-scale processes (i.e. XX), and region wide pressures (i.e. XX) influencing seagrass condition in the southern regions. Quantitative indicators (e.g. XX) of local-scale processes would enable these to be integrated into routine pressures analysis affecting the inshore seagrass habitats.

The Index was relatively stable and remained **moderate** in Cape York and the Mackay–Whitsunday regions. The trajectories over previous years could affect whether there are further improvements in future years in addition to environmental condition in coming years. There were increases in abundance at estuarine and coastal subtidal habitats in the Mackay–Whitsundays, and variable trends in coastal intertidal and reef intertidal and subtidal habitats. But over a longer period, there have been positive signs of recovery in the Mackay–Whitsunday region when in 2022–23, the Seagrass Index reached the highest level since 2016–17 due to relatively benign conditions. In Cape York, there have been no overall signs of recovery in the Index for four years driven by variable trends among sites. The most stable were the most northern sites at Shelburne Bay and Piper Reef which are less influenced from large riverine discharges. 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 2023–24 wet season, the declines in subtidal and reef intertidal abundances are likely the legacy of flooding event in early February 2022 and above-average rainfall and discharges more than three times above the long-term median in the 2022–23 wet season. There were elevated discharges again in 2023–24 that will hamper recovery and potentially cause further declines.

Of concern, is that temperature extremes (>40 ºC) are also becoming more common. In the Fitzroy region in 2023–24 was the highest temperature on record (50.8 ºC) which was 4.3 ºC above the previous record in 2022–23 in the Mackay–Whitsunday region. These anomalous events not only appear to be increasing in frequency over the past decade but are also occurring earlier—shifting into the main seagrass growing season, before summer. The effects of temperature on other biological processes critical to resilience remain largely unknown. For instance, temperature likely influences factors such as the timing and density of flowering, seed development, sediment condition, seed viability, and germination. Addressing these knowledge gaps are also becoming increasingly urgent as they may influence resilience of habitats to other pressures such as water quality. Opportunities for proactively building resilience to temperature impacts in seagrass meadows can be derived from addressing these knowledge gaps. Some potential strategies include: facilitating adaptation to future conditions through assisted gene flow by introducing ‘pre-adapted individuals’ into areas within the current distribution range; thermally priming seedlings before restoration initiatives; and, selecting genetic variants of species with greater thermal tolerance for upcoming restoration projects.

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. Implementing these updates is critical to ensuring the resilience and long-term health of the inshore seagrass habitats, given the escalating pressures they face. The most urgent improvements include:

1. **Developing a spatial inshore thermal stress risk model** (currently underway) and refining temperature thresholds to better understand their impact on resilience. This is vital for addressing the growing threat of temperature-induced stress.
2. **Updating light indicators and thresholds** to enhance the effectiveness of in situ light monitoring for intertidal habitats while exploring ways to leverage existing tools (e.g., eReefs) to improve pressures reporting for inshore subtidal habitats. These updates are essential for more accurate assessments of light stress which is the most prevalent pressure facing inshore seagrass habitats.
3. **Creating a fragmentation index** based on current and historical seagrass extent data and establishing protocols for drone use in spatial extent and fragmentation monitoring. This is key to better understanding when habitats approach tipping points that could accelerate loss.
4. **Incorporating quantitative indicators of local-scale processes** into routine pressure analyses. This would enable a more comprehensive evaluation of the factors affecting inshore seagrass habitats and to identify local versus broad-scale management actions.
5. **Scaling monitoring efforts** to broader levels to fully capture habitat decline and recovery. This would allow for a more accurate inference of the potential ecological consequences of habitat changes.
6. **Developing methods to summarize cumulative pressures and indices of pressure** is crucial. With multiple pressures occurring simultaneously or successively, it is often difficult to pinpoint the cause of damage. A more integrated approach would provide critical insights into the combined effects of these pressures, beyond extreme events such as large discharges or cyclones.

Addressing these updates is not just important—it is imperative for safeguarding the future of the Reef’s inshore seagrass ecosystems and their ecological functions.

# 7 Conclusion

In 2023–24 inshore seagrass meadows across the Reef remained largely unchanged in overall condition, with the Seagrass Index remaining **moderate**. Reef-wide inshore seagrass abundance was largely unchanged in 2023–24, showing only a marginal decline in score after a slight improvement in the previous period. Resilience continued to decline in 2023–24, mirroring the overall Index, and reached its lowest score in a decade. The abundance indicator remained moderate and the resilience indicator remained poor.

Environmental conditions varied across the Reef, with cyclones impacting the northern NRM regions bringing considerable rainfall, particularly in southern Cape York and the northern Wet Tropics, along with acute physical disturbance to the Burdekin. Northern NRM regions were exposed to greater than average turbid coloured waters, while turbid water exposure in other regions was similar or less than the long-term average. Overall, daily average benthic light availability for seagrass was below the long-term average and plants were exposed to above average water temperatures, with the hottest seawater temperature ever recorded (50.8 °C) at Shoalwater Bay in the Fitzroy region.

In 2023–24, the inshore seagrass of the Reef was in a **moderate** condition in the far northern and central NRM regions, but in a **poor** condition in the northern and southern most regions. The score declined in the northern regions compared to the previous monitoring period, increased in the southern regions and was largely unchanged in the far northern and central regions.

The inshore Reef seagrass meadows 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).

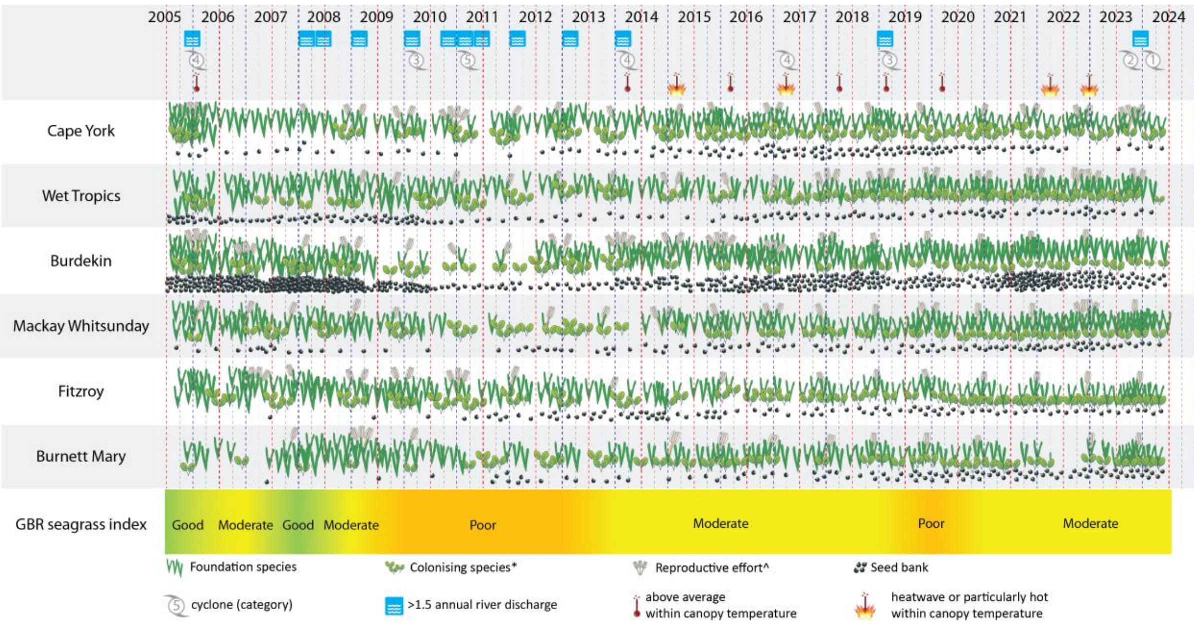



Figure 86. Summary of inshore seagrass state illustrating pressures, abundance of foundation / colonising species, seed bank and reproductive effort in each NRM from 2005 to 2024. * colonising species are represented by the genus *Halophila*, however, *Zostera* and *Halodule* can be both colonising and 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 had been buoyed across northern and central regions by a few years of low to negligible climatic pressures, while in the most southern regions (Fitzroy and Burnett–Mary) consistent declines undermined improvements. Nevertheless, the events of 2023–24 have reversed these trends, resulting in considerable deterioration in the northern regions due to cyclones and associated flooding, while the southern regions experienced significant recovery with more favourable conditions for seagrass growth.

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The sustained improvement of the Reef's inshore seagrass meadows depends on various factors, such as favourable growth conditions and effective environmental protection measures. While we cannot control weather patterns, we can mitigate their impact on seagrasses by implementing initiatives like the Paddock to Reef Program that reduce terrestrial runoff into the Reef. It is essential to prioritize the resilience of seagrass meadows, particularly their capacity to recover from damage, in our research and management strategies.

To ensure the long-term health of the Reef's seagrass ecosystems, it is vital to advance our understanding of ecosystem science related to resilience and recovery. In addition to comprehensive research, adaptive resilience-based management is crucial. This approach should prioritize forecasting tools to guide planning and actions, along with monitoring and diagnostic tools to refine and implement strategies that enhance resilience, optimize recovery, and lessen 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 80$^{th}$, 50$^{th}$ and 20$^{th}$ 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 80$^{th}$ percentile was changed to 75$^{th}$ 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 50$^{th}$ and 20$^{th}$ 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).

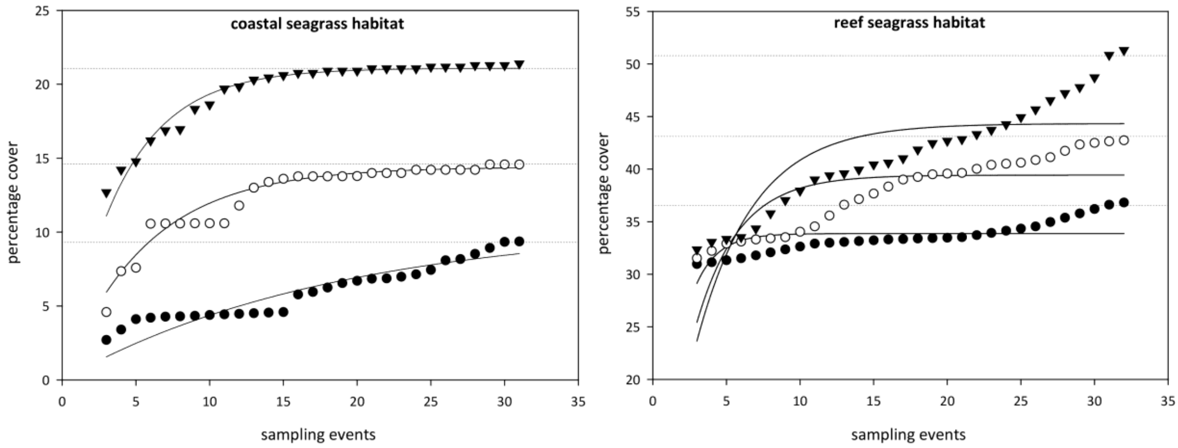


Figure 87. Relationship between sample size and the error in estimation of percentile values for seagrass abundance (per cent cover) in coastal and reef seagrass habitats in the Wet Tropics NRM. ▼ = 75th percentile, ○ = 50th percentile,● = 20th percentile. Horizontal lines are asymptotic averages for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

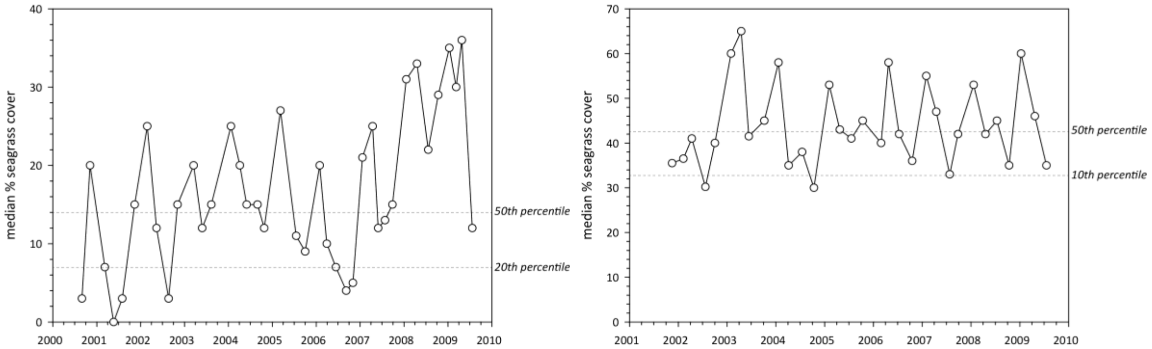


Figure 88. Median seagrass abundance (per cent cover) at Yule Point (left) and Green Island (right) plotted against the 50th and 20th percentiles for coastal and intertidal reef seagrass habitat in the Wet Tropics.

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).

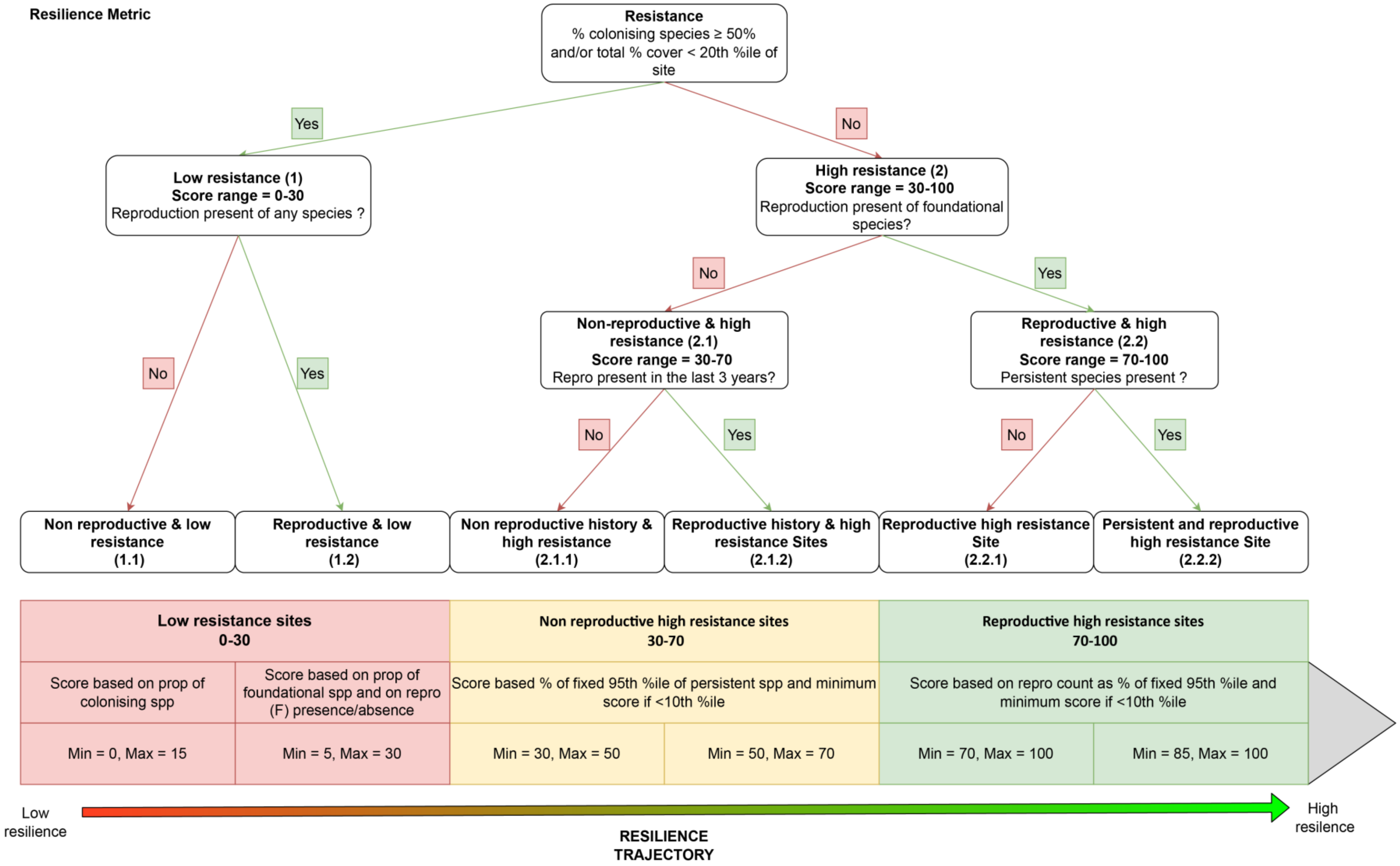


Figure 89. Overall structure of the proposed MMP resilience metric. The score ranges from 0 to 100. Splits in the tree are used to place a site in a grouping (red, yellow, or green), with grading within each grouping based on species composition and reproductive effort. Reproduction refers to sexual 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 (2023) | | | | | | late wet Season (2024) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 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** | 10 | | | | | | | | | | | |
| | | | Piper Reef | **FR1** | 33 | 30 | ✓ | 15 | ✓ | | | | | | | |
| | | | | **FR2** | 33 | 30 | ✓ | 15 | ✓ | ✓ | | | | | | |
| | | Lockhart | Weymouth Bay | **YY1** | | | | | | | | | | | | |
| | | | Lloyd Bay | **LR1^** | 10 | | | | | | | | | | | |
| | | | | **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^** | 10 | | | | | | | | | | | |
| | | 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^** | | | | | | | | | | | | |
| | | | | **MS2^** | 10 | | | | | | | | | | | |
| 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 (2023) | | | | | | late wet Season (2024) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 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 | ✓ | ✓ |
| | | | Cid Harbour | **CH4^** | 10 | | | | | | | | | | | |
| | | | | **CH5^** | 10 | | | | | | | | | | | |
| | | | 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^** | 10 | | | | | | | | | | | |
| | | | | **NB2^** | 10 | | | | | | | | | | | |
| | | Plane | Sarina Inlet | **SI1** | 33 | 30 | ✓ | 15 | ✓ | ✓ | 33 | 30 | ✓ | 15 | ✓ | ✓ |
| | | | | **SI2** | 33 | 30 | ✓ | 15 | ✓ | | 33 | 30 | ✓ | 15 | ✓ | |
| | | | Llewellyn Bay | **LL1** | 33 | | | | | | | | | | | |
| | | | 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 2023–24** (hrs) | **Per cent of annual daylight hours meadow exposed (2023–24)** |
|---|---|---|---|---|---|---|---|---|
| Cape York | AP1 | 0.46 | 1.02 | 0.46 | 49.25 | 1.26 | 36.17 | 0.82 |
| | AP2 | 0.46 | 1.02 | 0.46 | 49.25 | 1.26 | 36.17 | 0.82 |
| Wet Tropics | LI1 | 0.65 | 0.90 | 0.65 | 164.34 | 3.00 | 103.00 | 2.08 |
| | YP1 | 0.64 | 0.94 | 0.64 | 156.75 | 3.00 | 99.67 | 2.08 |
| | YP2 | 0.52 | 1.06 | 0.52 | 87.58 | 3.00 | 55.17 | 2.08 |
| | GI1 | 0.51 | 1.03 | 0.61 | 112.67 | 3.00 | 89.00 | 2.08 |
| | GI2 | 0.57 | 0.97 | 0.67 | 151.17 | 3.00 | 110.83 | 2.08 |
| | DI1 | 0.65 | 1.14 | 0.54 | 73.17 | 0.81 | 45.33 | 0.41 |
| | DI2 | 0.55 | 1.24 | 0.44 | 40.67 | 0.81 | 16.33 | 0.41 |
| | LB1 | 0.42 | 1.37 | 0.31 | 16.00 | 0.81 | 3.33 | 0.41 |
| | LB2 | 0.46 | 1.33 | 0.35 | 18.00 | 0.81 | 6.17 | 0.41 |
| Burdekin | BB1 | 0.58 | 1.30 | 0.58 | 78.83 | 2.08 | 60.83 | 1.30 |
| | SB1 | 0.57 | 1.31 | 0.57 | 63.17 | 2.08 | 56.00 | 1.30 |
| | MI1 | 0.65 | 1.19 | 0.67 | 146.83 | 2.08 | 102.67 | 1.30 |
| | MI2 | 0.54 | 1.30 | 0.56 | 134.33 | 2.08 | 52.50 | 1.30 |
| | JR1 | 0.47 | 1.32 | 0.47 | 53.83 | 2.08 | 35.67 | 1.30 |
| | JR2 | 0.47 | 1.32 | 0.47 | 53.83 | 2.08 | 35.67 | 1.30 |
| Mackay–Whitsunday | PI2* | 0.28 | 1.47 | 0.44 | 80.75 | 1.19 | 10.00 | 0.37 |
| | PI3* | 0.17 | 1.58 | 0.33 | 40.75 | 1.19 | 4.00 | 0.37 |
| | HM1* | 0.68 | 1.52 | 0.38 | 56.67 | 1.19 | 6.17 | 0.37 |
| | HM2* | 0.68 | 1.52 | 0.38 | 56.67 | 1.19 | 6.17 | 0.37 |
| | SI1 | 0.60 | 2.80 | 0.70 | 26.83 | 1.19 | 35.17 | 0.37 |
| | SI2 | 0.60 | 2.80 | 0.70 | 26.83 | 1.19 | 35.17 | 0.37 |
| Fitzroy | RC1 | 2.03 | 1.30 | 1.22 | 173.00 | 2.65 | 177.83 | 2.42 |
| | WH1 | 2.16 | 1.17 | 1.35 | 254.17 | 2.65 | 276.17 | 2.42 |
| | GK1 | 0.52 | 1.93 | 0.59 | 32.67 | 2.65 | 27.33 | 2.42 |
| | GK2 | 0.58 | 1.87 | 0.62 | 48.67 | 2.65 | 36.17 | 2.42 |
| | GH1 | 0.80 | 1.57 | 0.69 | 95.00 | 2.65 | 60.50 | 2.42 |
| | GH2 | 0.80 | 1.57 | 0.69 | 89.50 | 2.65 | 60.50 | 2.42 |
| Burnett–Mary | RD1 | 0.56 | 1.48 | 0.56 | 66.17 | 2.34 | 34.67 | 1.45 |
| | RD2 | 0.63 | 1.41 | 0.63 | 91.83 | 2.34 | 53.83 | 1.45 |
| | UG1 | 0.70 | 1.41 | 0.70 | 141.50 | 2.34 | 95.83 | 1.45 |
| | UG2 | 0.64 | 1.47 | 0.64 | 101.17 | 2.34 | 69.83 | 1.45 |

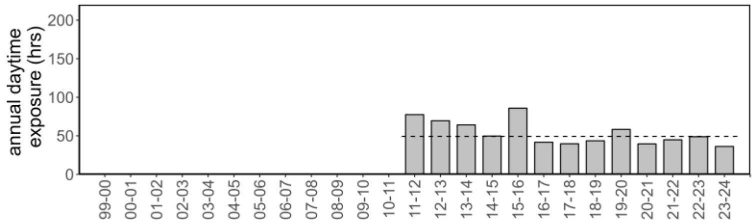


Figure 90. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of reef intertidal seagrass meadows at Archer Point, Cape York NRM region; 2011–2024. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2024. NB: Meadow heights have not yet been determined in the far northern Cape York sites.

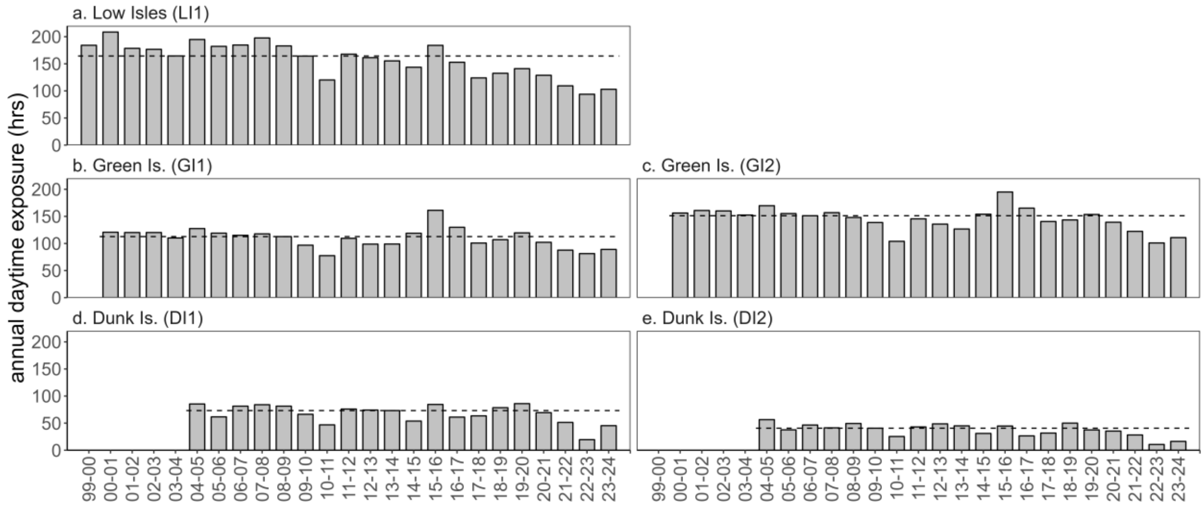


Figure 91. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of reef intertidal seagrass meadows in the Wet Tropics NRM region; 1999–2024. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2024.

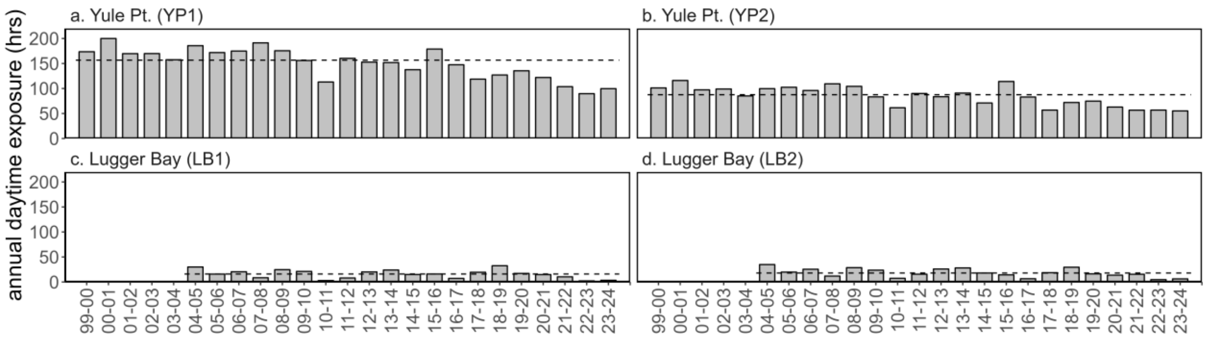


Figure 92. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of coastal intertidal seagrass meadows in Wet Tropics NRM region; 1999–2024. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2024.

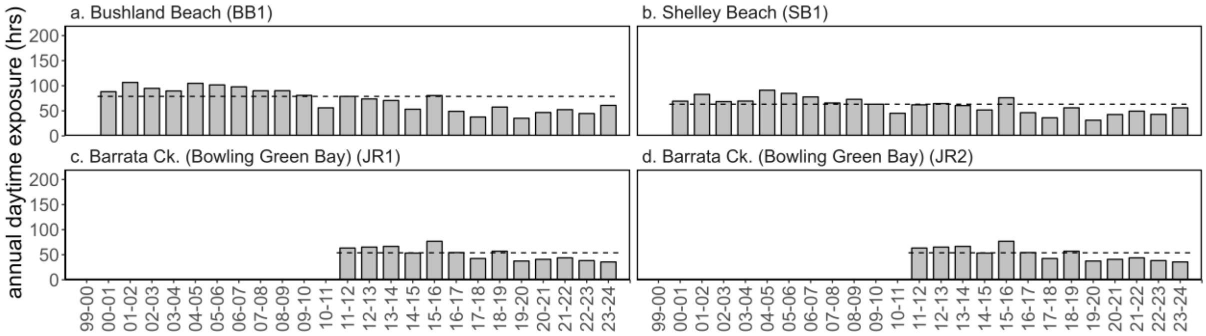


Figure 93. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of coastal intertidal seagrass meadows in Burdekin NRM region; 2000–2024. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2024.

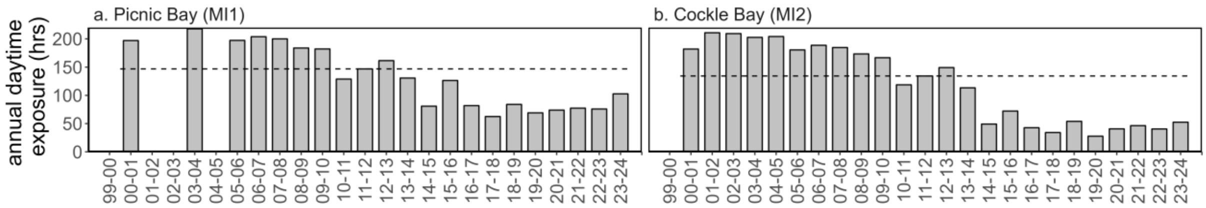


Figure 94. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of reef intertidal seagrass meadows in Burdekin NRM region; 2000–2024. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2024.

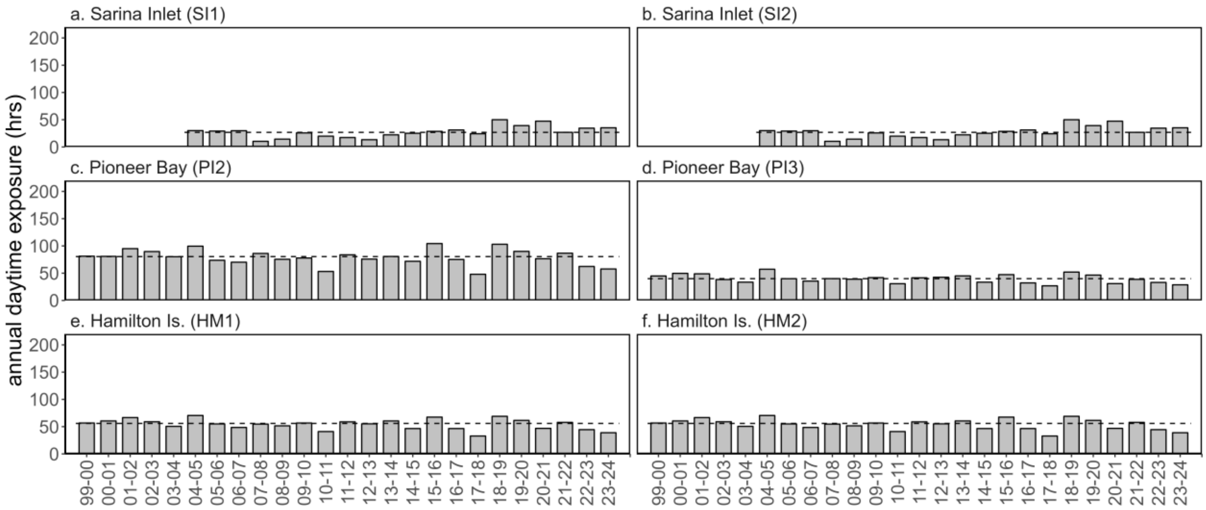


Figure 95. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of estuarine intertidal (a, b) coastal intertidal (c, d) and reef intertidal (e, f) seagrass meadows in Mackay–Whitsunday NRM region; 1999–2024. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2024.

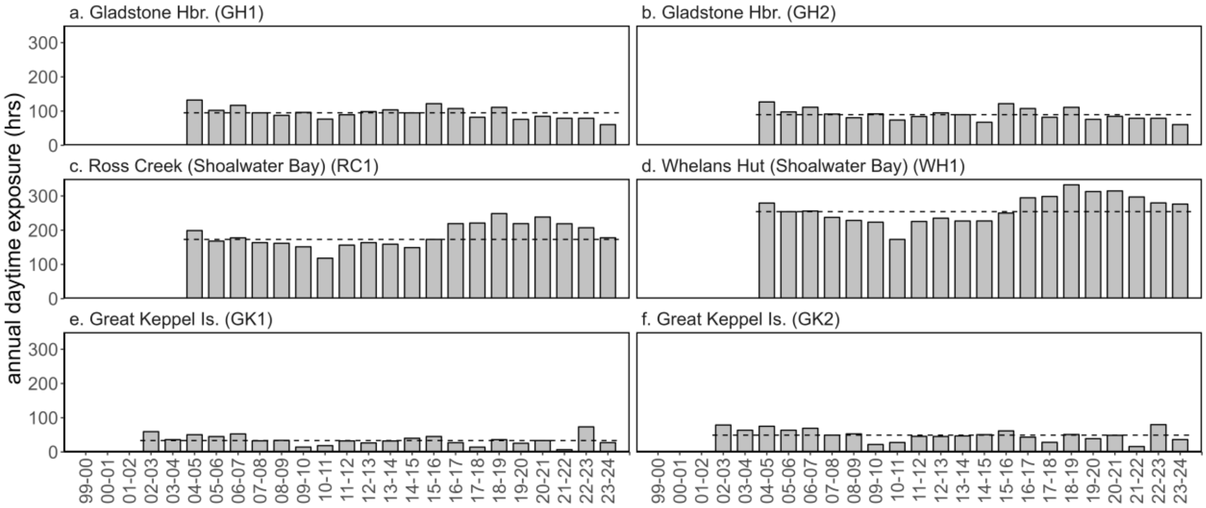


Figure 96. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of estuarine intertidal (a, b) coastal intertidal (c, d) and reef intertidal (e, f) seagrass meadows in the Fitzroy NRM region; 1999–2024. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2024.

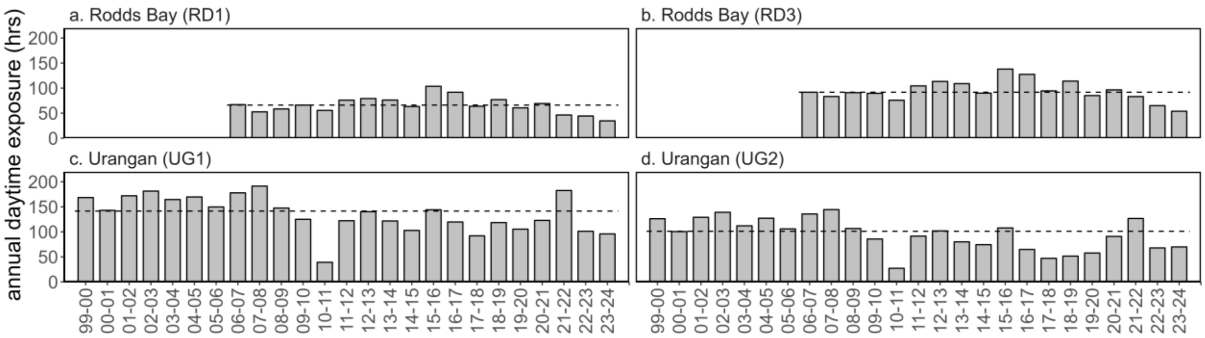


Figure 97. Annual daytime tidal exposure (total hours) and long-term median (dashed line) of estuarine intertidal seagrass meadows in the Burnett–Mary NRM region; 1999–2024. Year is June–May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 21. Observed tidal heights courtesy Maritime Safety Queensland, 2024.

## A2.1.2 Light at seagrass canopy

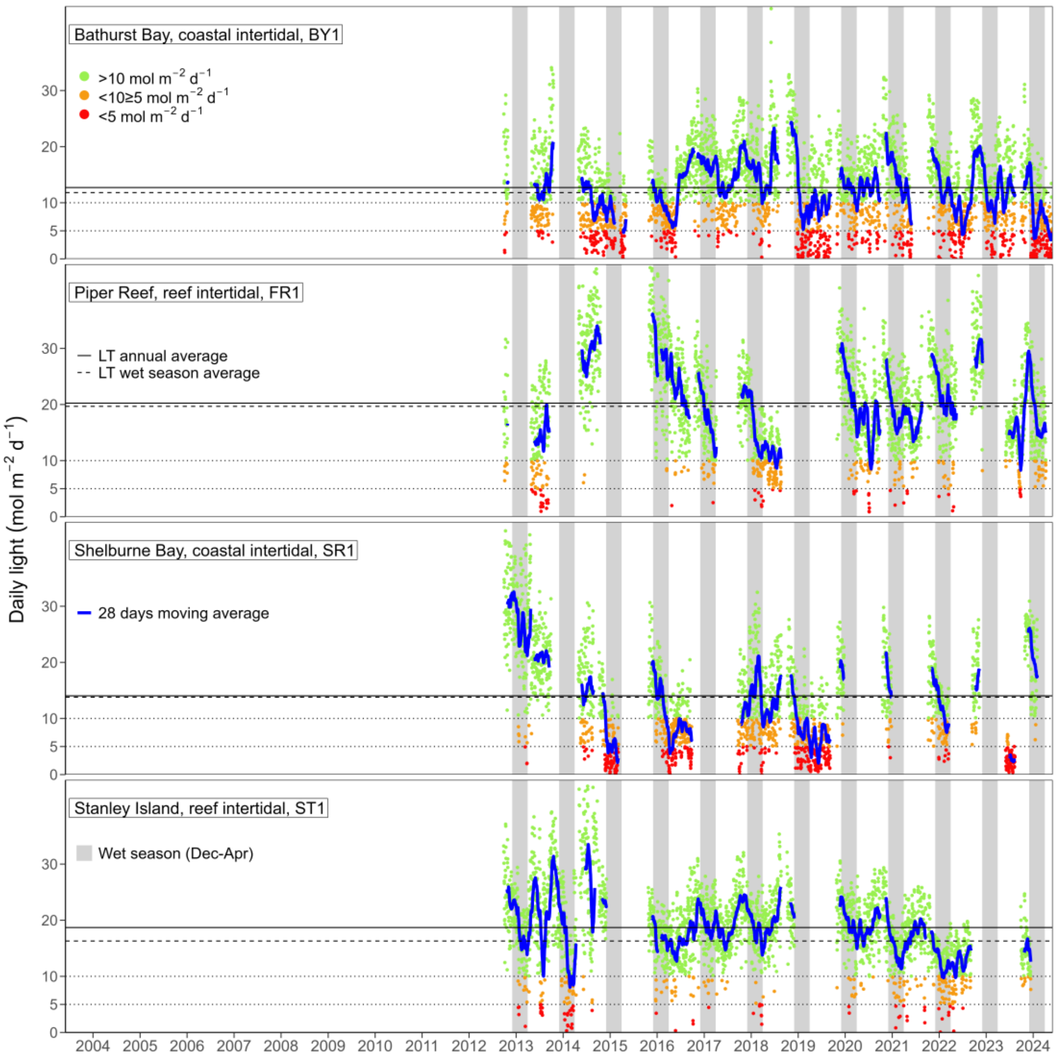


Figure 98. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in the Cape York NRM region.

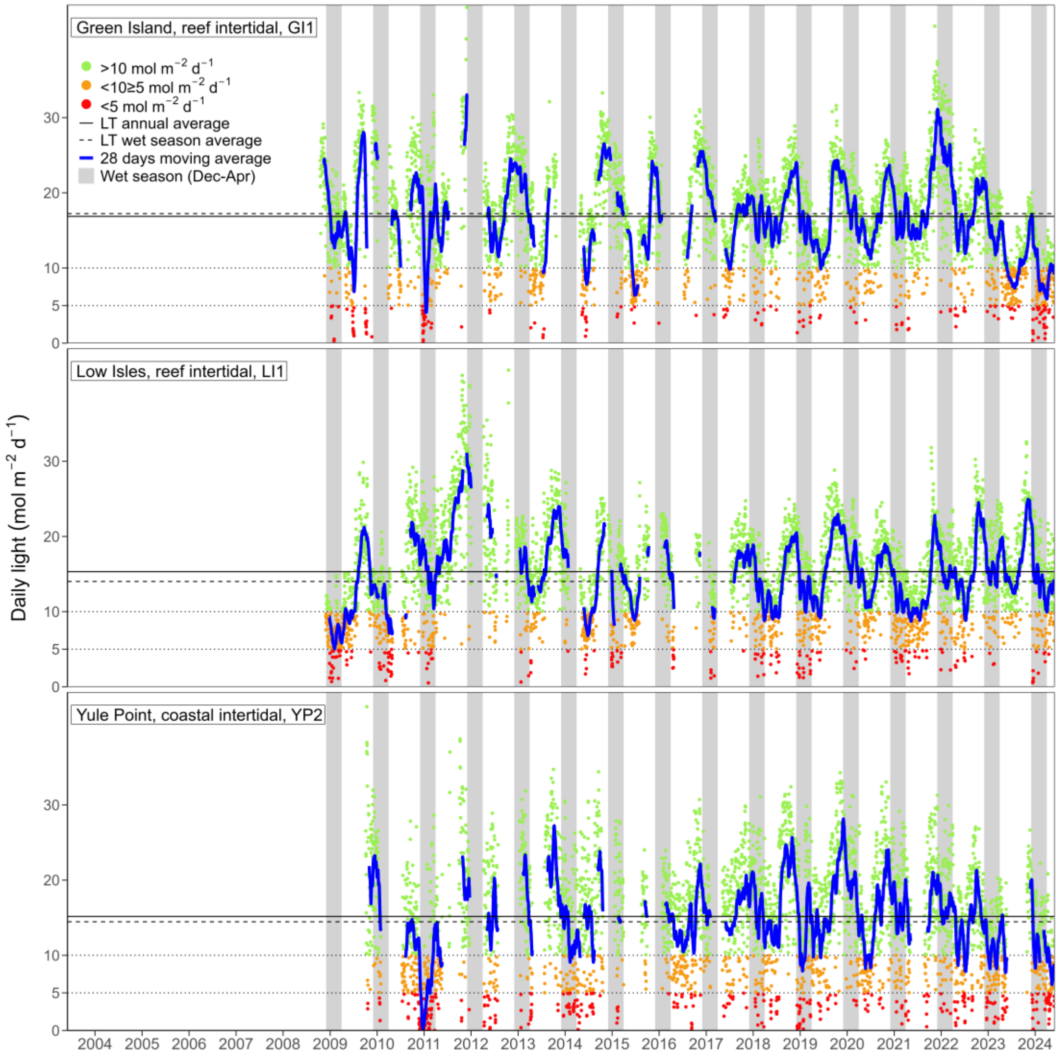


Figure 99. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in northern Wet Tropics region.

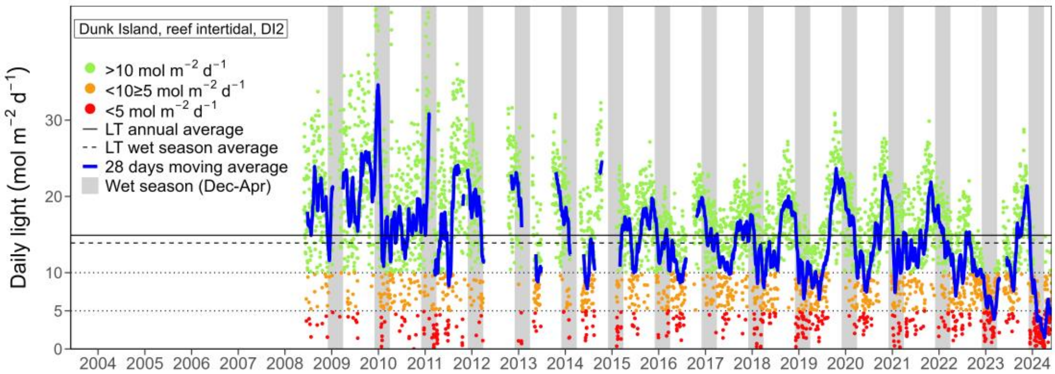


Figure 100. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in the southern Wet Tropics region.

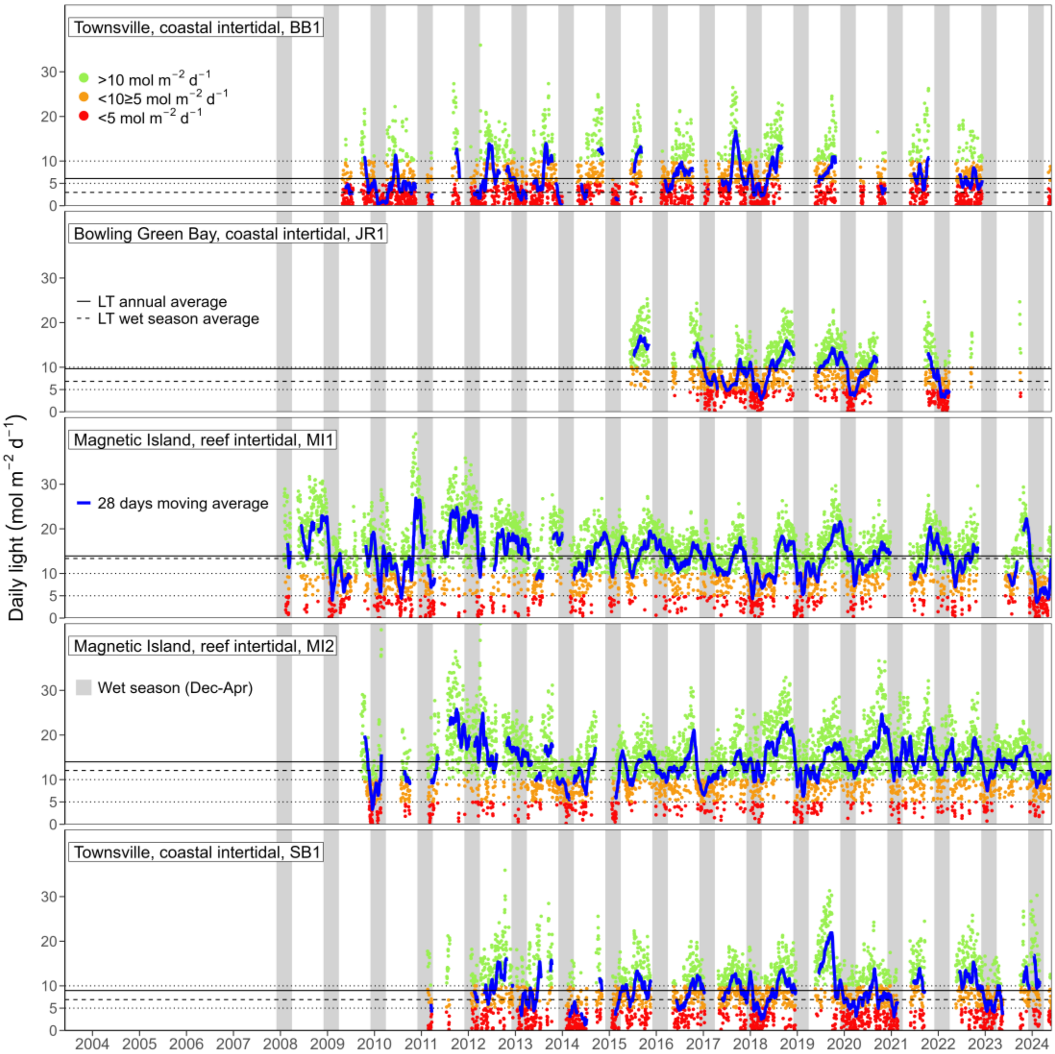


Figure 101. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in the Burdekin region.

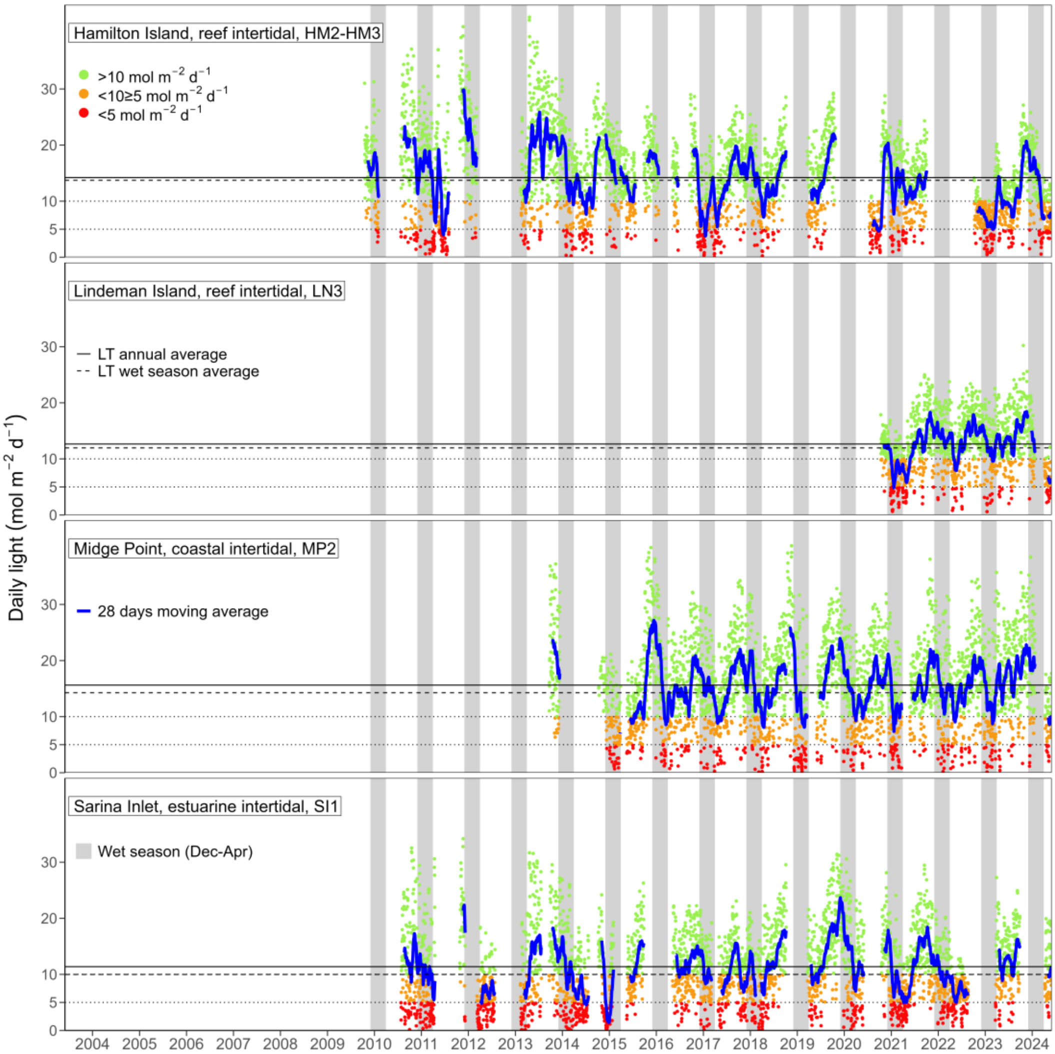
Hamilton Island, reef intertidal, HM2-HM3
>10 mol m−2 d−1
<10≥5 mol m−2 d−1
<5 mol m−2 d−1
Lindeman Island, reef intertidal, LN3
LT annual average
LT wet season average
Midge Point, coastal intertidal, MP2
28 days moving average
Sarina Inlet, estuarine intertidal, SI1
Wet season (Dec-Apr)
Daily light (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
2024

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.

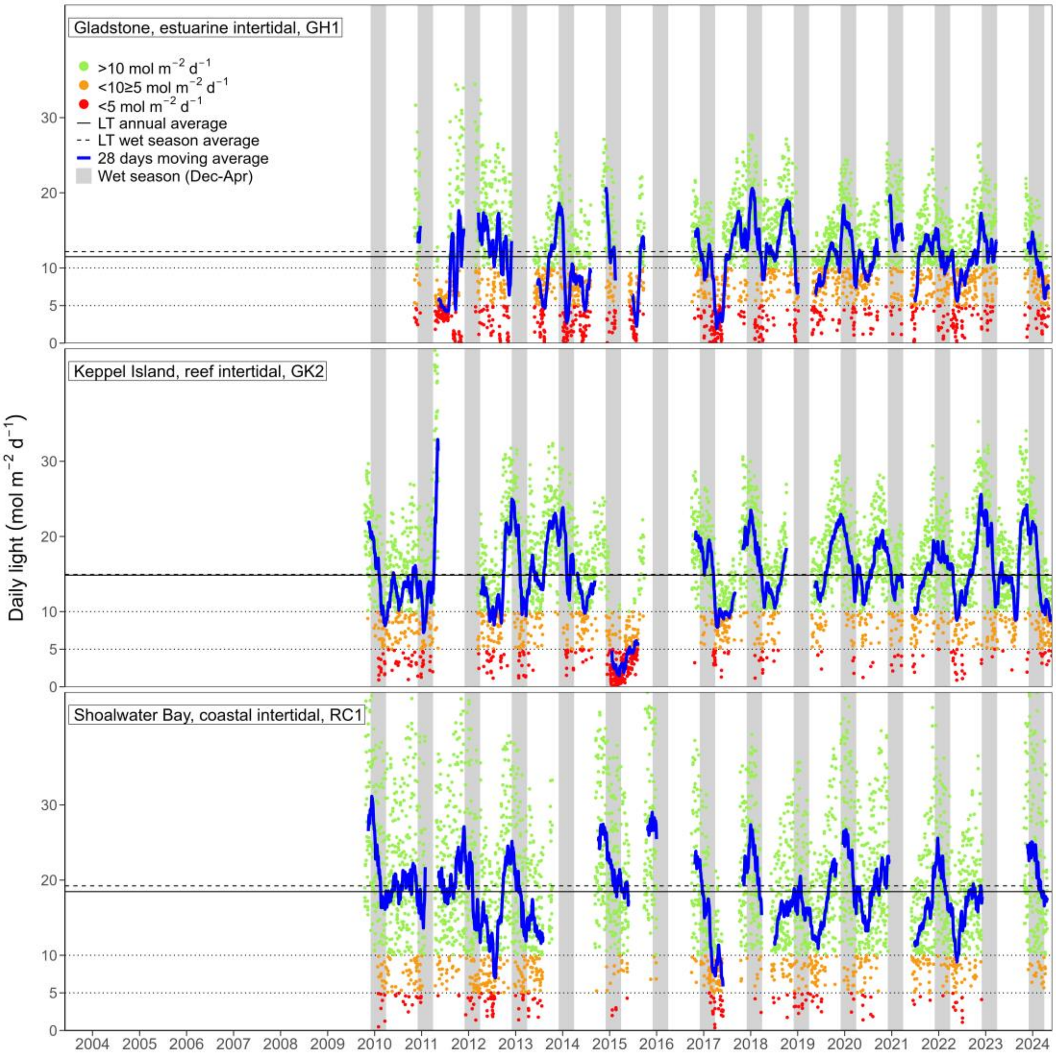


Figure 103. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in the Fitzroy NRM region.

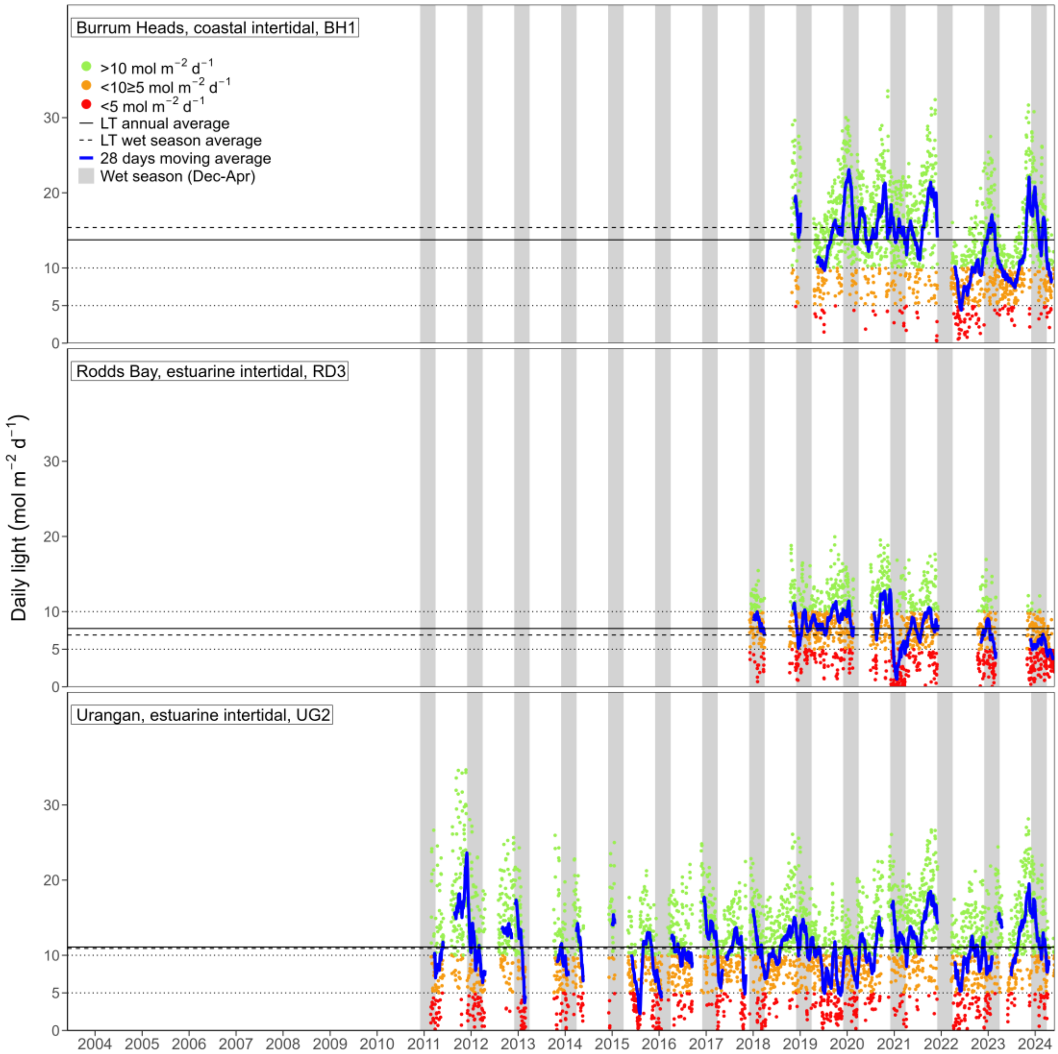


Figure 104. Daily light (coloured points), 28-day rolling average (blue, bold line) and long-term average (annual and wet season, solid and dashed lines) at monitoring locations in the Burnett–Mary NRM region.

## A2.2 Seagrass habitat condition: Sediments composition

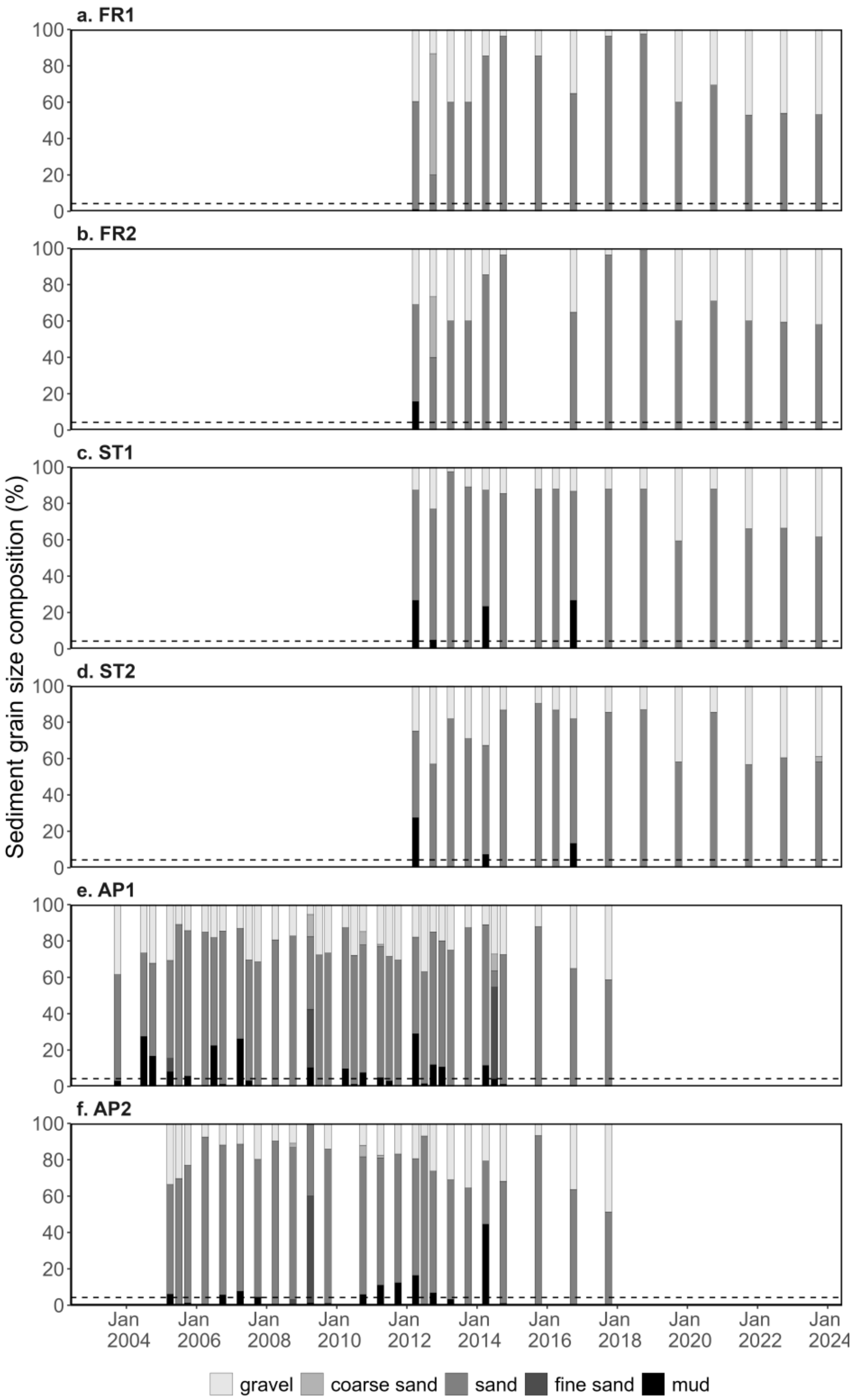


Figure 105. Sediment grain size composition at intertidal reef habitat monitoring sites in the Cape York region, 2003–2024. Dashed line is the Reef long-term average proportion of mud.

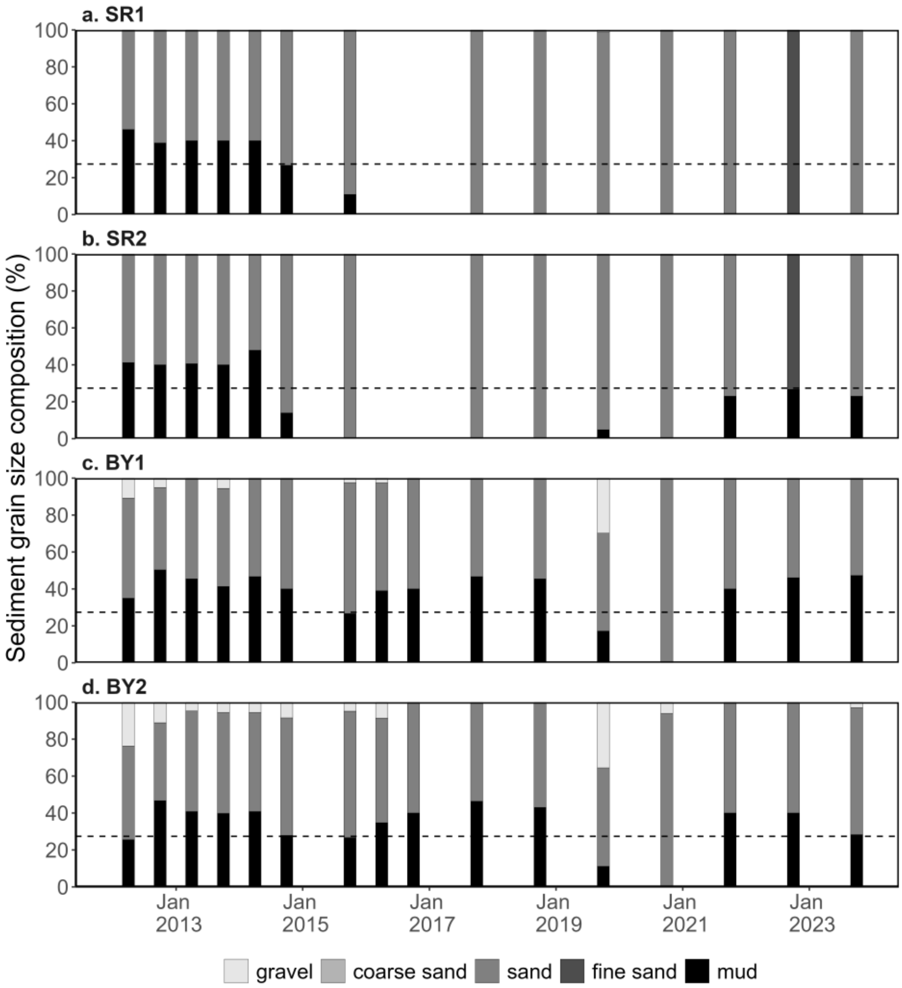


Figure 106. Sediment grain size composition at intertidal coastal habitat monitoring sites in the Cape York region, 2012–-2024. Dashed line is the Reef long-term average proportion of mud.

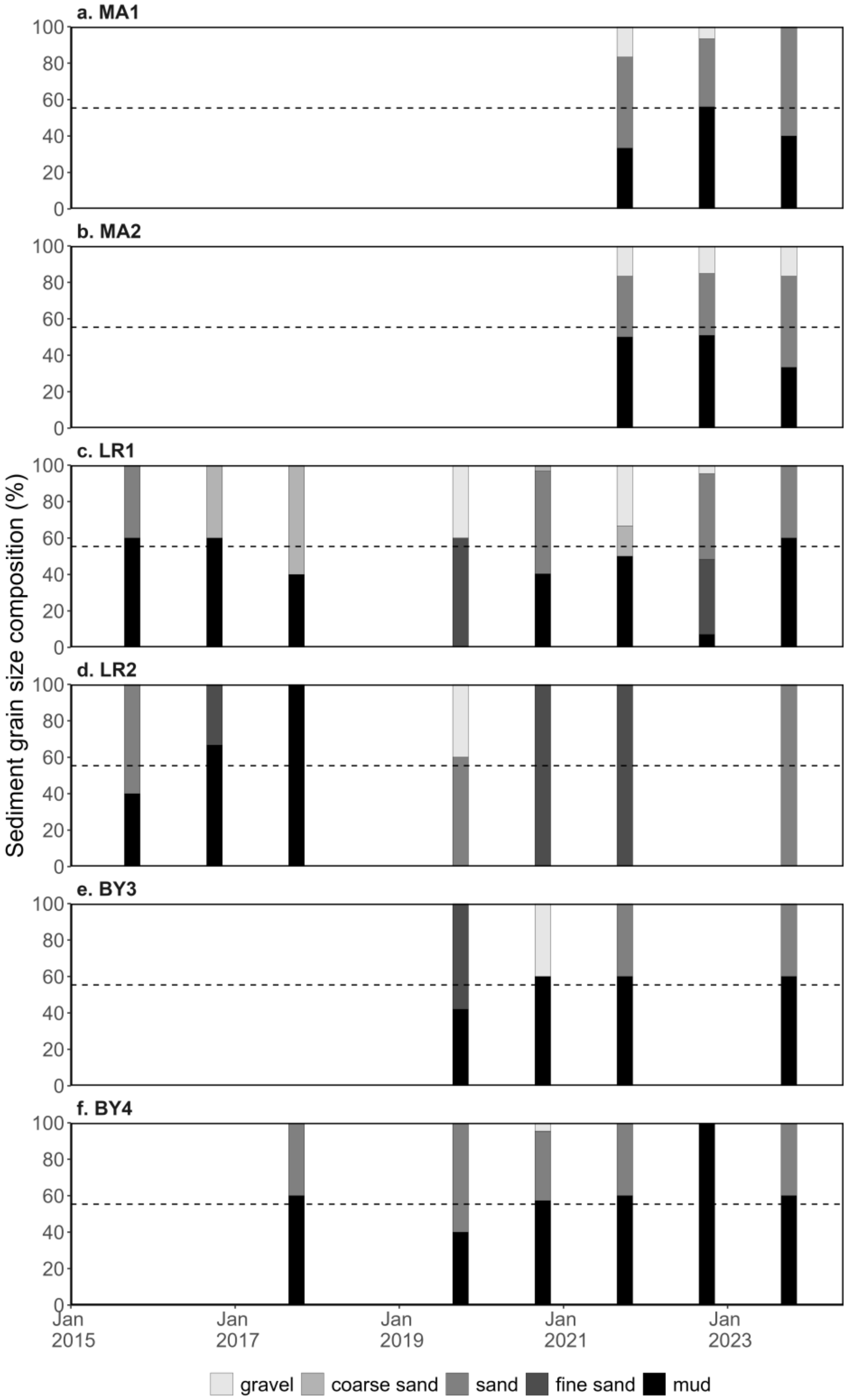


Figure 107. Sediment grain size composition at subtidal coastal habitat monitoring sites in the Cape York region, 2015–-2024. Dashed line is the Reef long-term average proportion of mud.

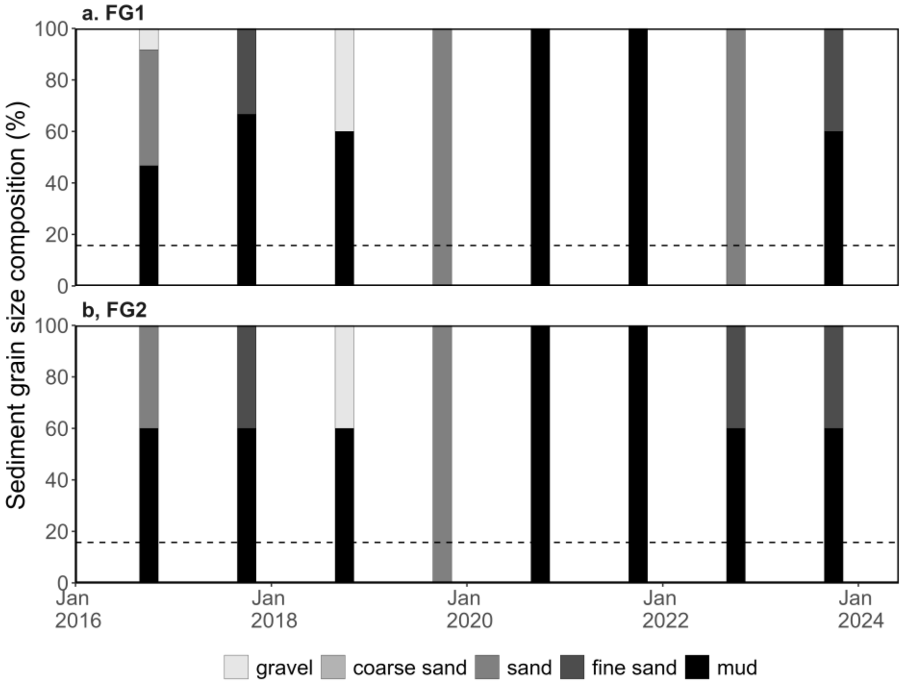


Figure 108. Sediment grain size composition at subtidal reef habitat monitoring sites in the Cape York region, 2016–-2024. Dashed line is the Reef long-term average proportion of mud.

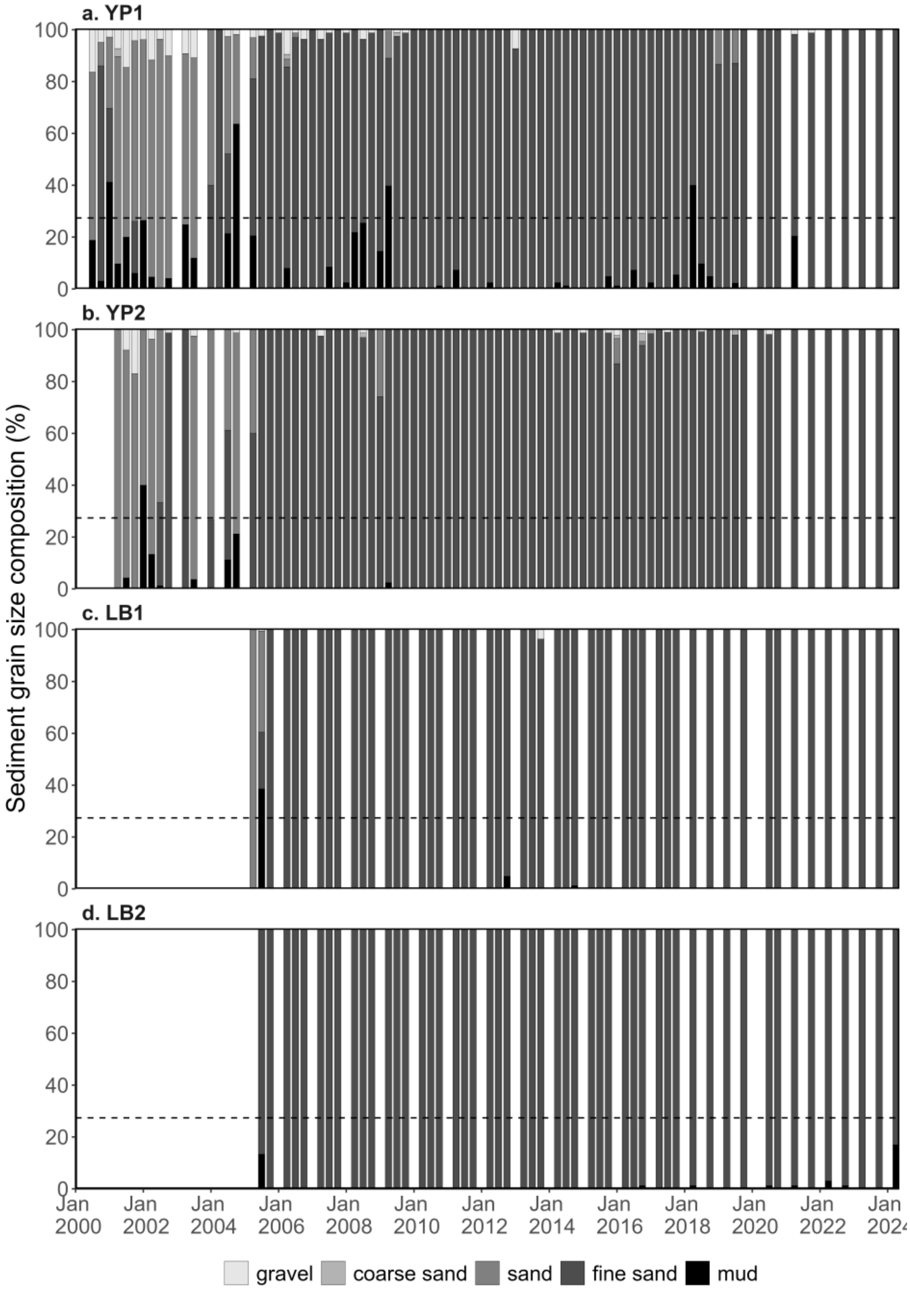


Figure 109. Sediment grain size composition at intertidal coastal habitat monitoring sites in the Wet Tropics region, 2001–2024. Dashed line is the Reef long-term average proportion of mud.

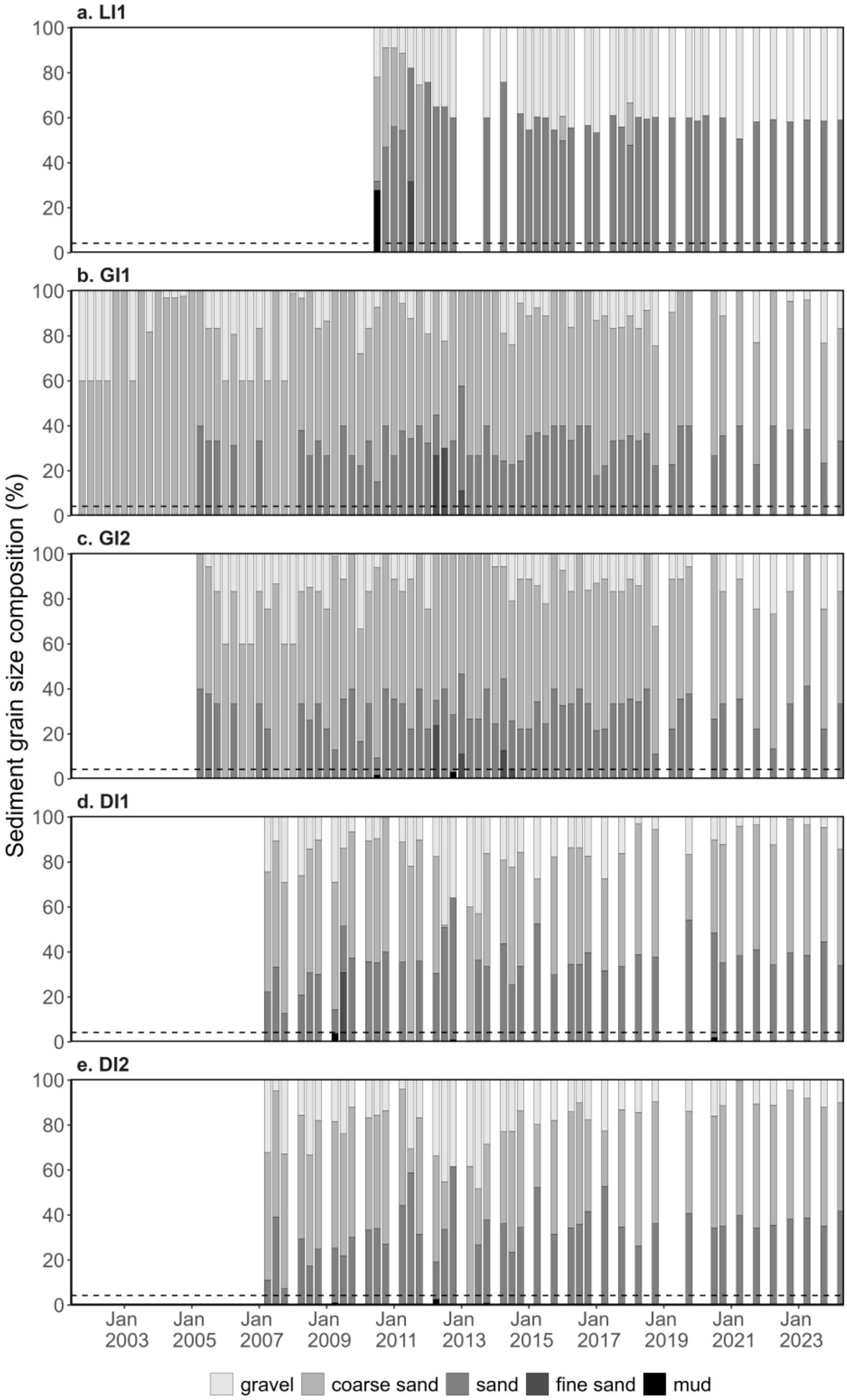


Figure 110. Sediment grain size composition at intertidal reef habitat monitoring sites in the Wet Tropics region, 2001–2023. Dashed line is the Reef long-term average proportion of mud.

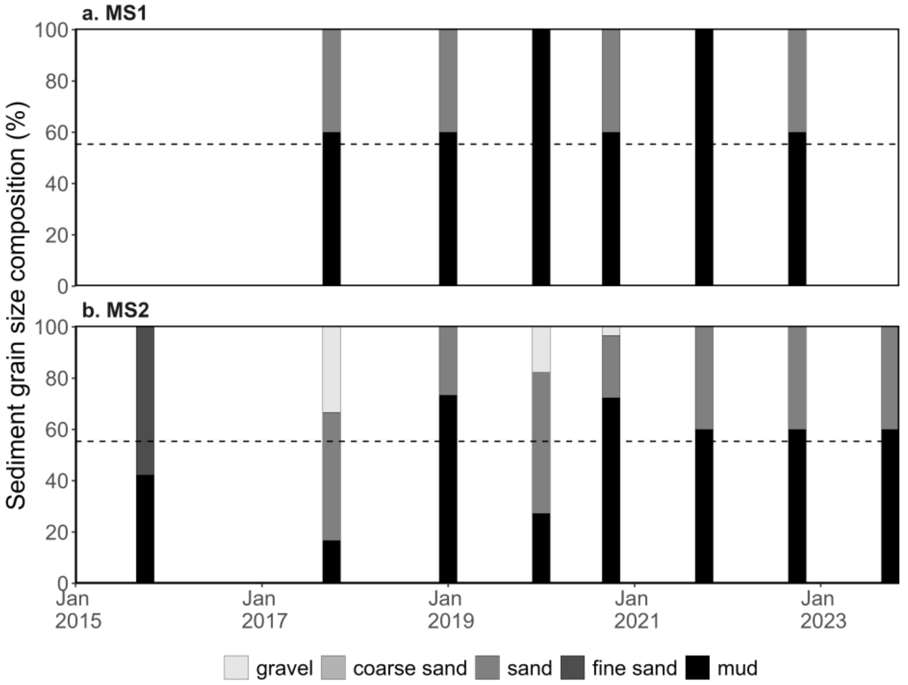


Figure 111. Sediment grain size composition at subtidal coastal habitat monitoring sites in the Wet Tropics region, 2015–2024. Dashed line is the Reef long-term average proportion of mud.

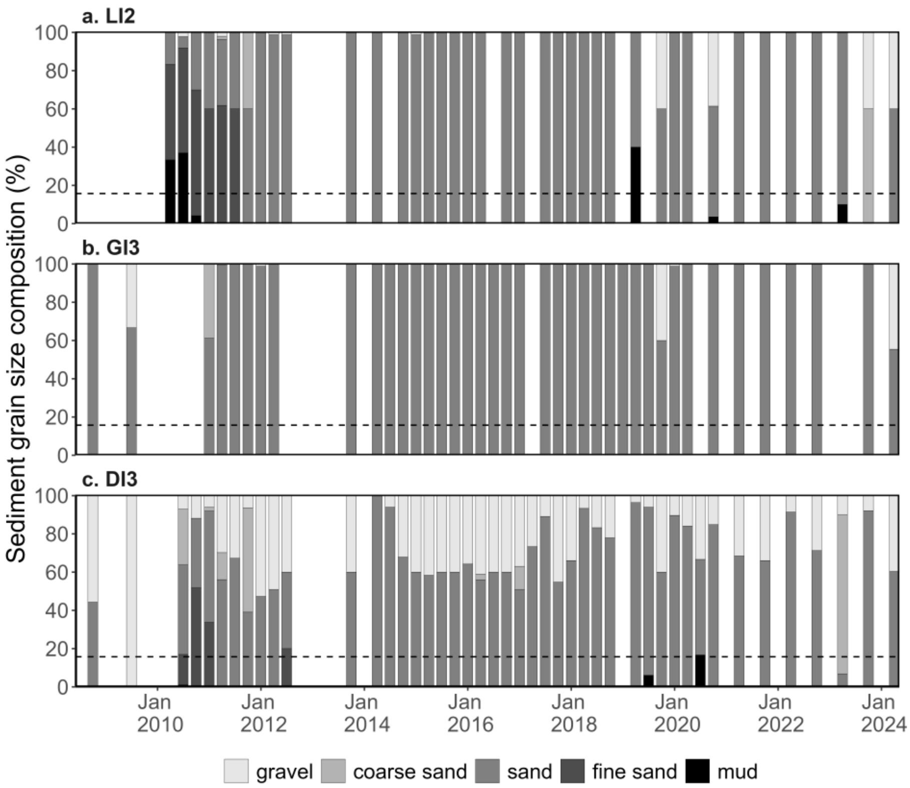


Figure 112. Sediment grain size composition at subtidal reef habitat monitoring sites in the Wet Tropics region, 2008–2024. Dashed line is the Reef long-term average proportion of mud.

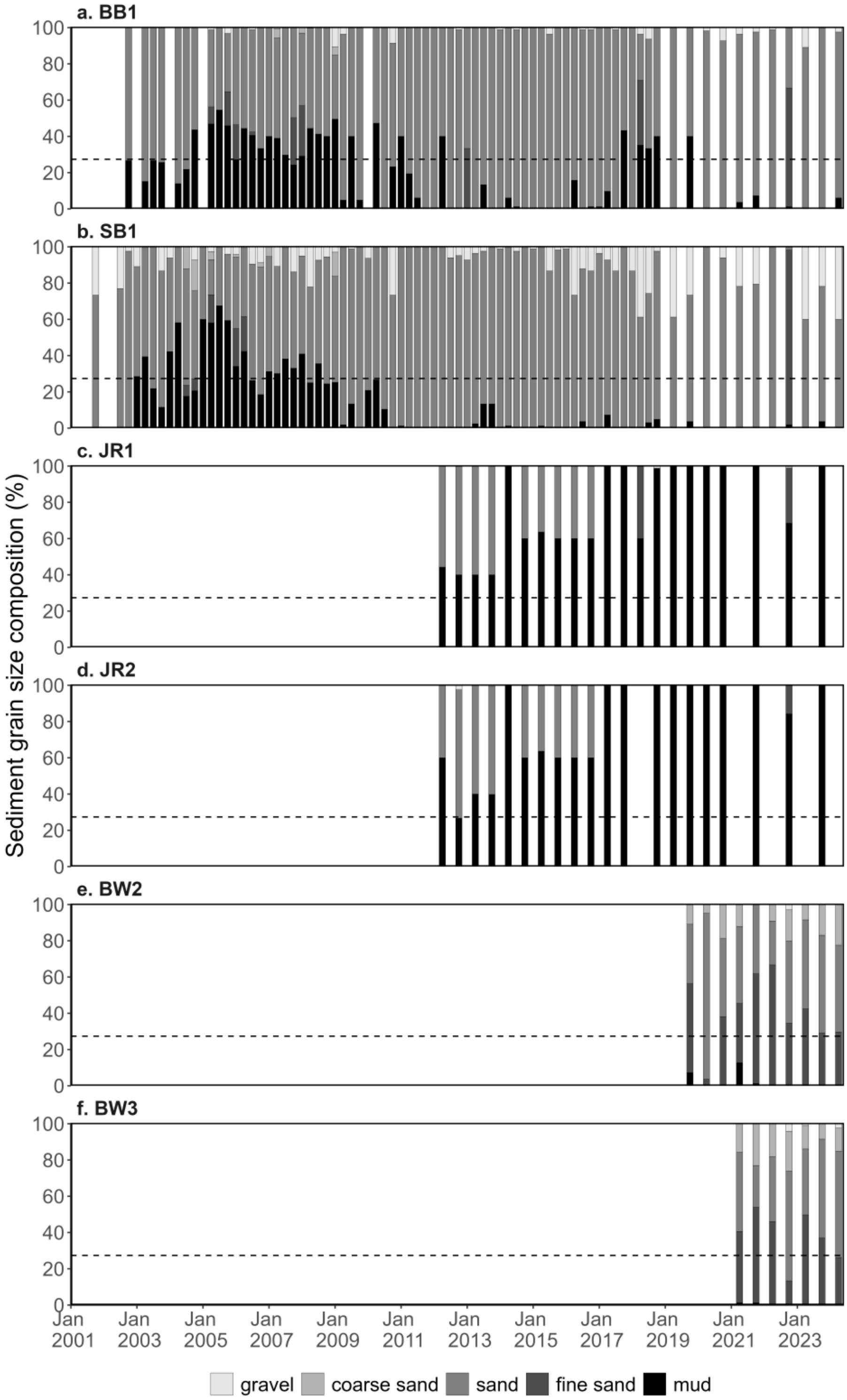


Figure 113. Sediment grain size composition at coastal intertidal habitat monitoring sites in the Burdekin region, 2001–2024. Dashed line is the Reef long-term average proportion of mud.

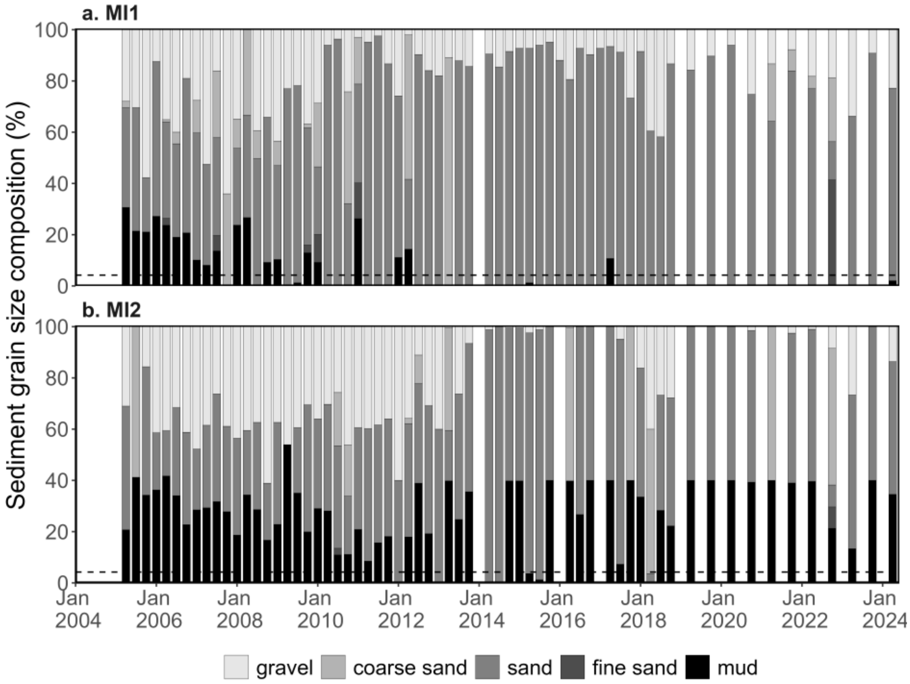


Figure 114. Sediment grain size composition at intertidal reef habitat monitoring sites in the Burdekin region, 2004–2024. Dashed line is the Reef long-term average proportion of mud.

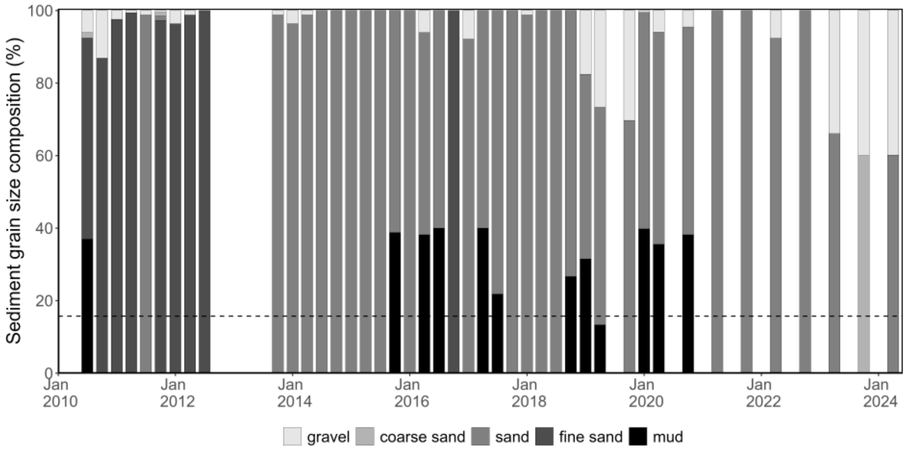


Figure 115. Sediment grain size composition at subtidal reef habitat monitoring site (MI3) in the Burdekin region, 2010–2024. Dashed line is the Reef long-term average proportion of mud.

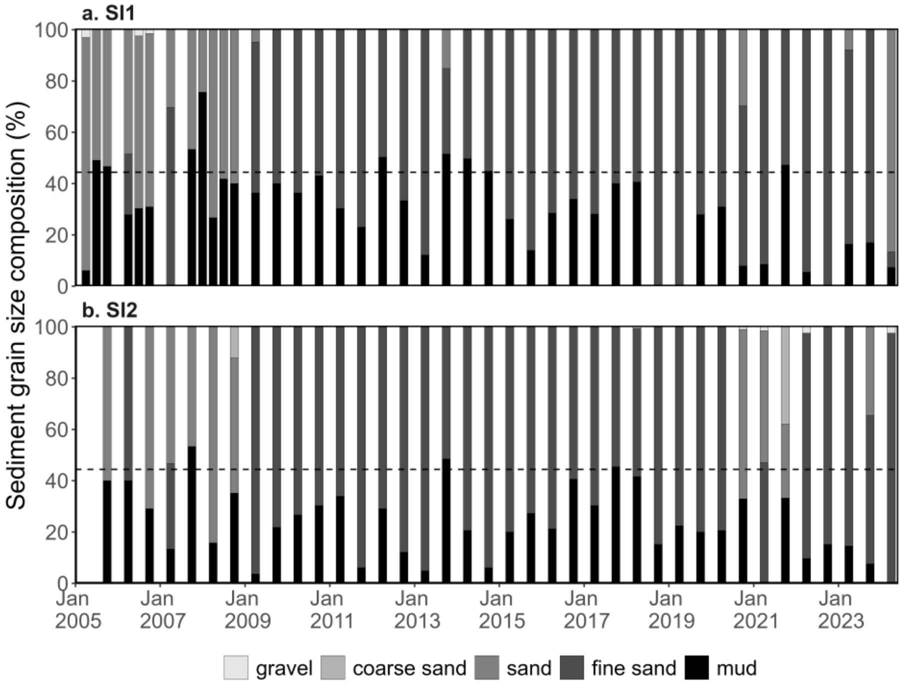


Figure 116. Sediment grain size composition at intertidal estuarine habitat monitoring sites in the Mackay–Whitsunday region, 2005–2024. Dashed line is the Reef long-term average proportion of mud.

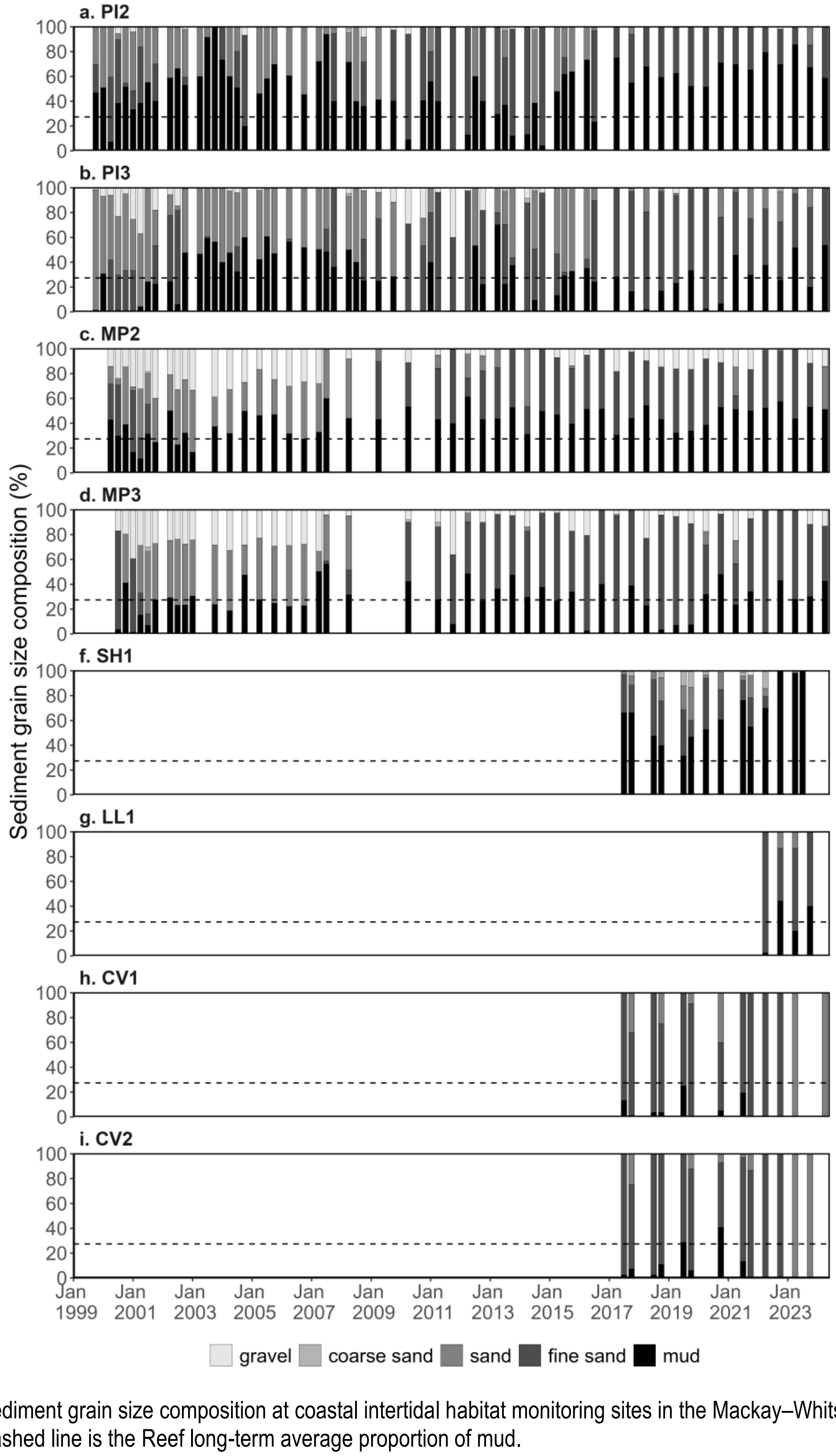


Figure 117. Sediment grain size composition at coastal intertidal habitat monitoring sites in the Mackay–Whitsunday region, 1999–2024. Dashed line is the Reef long-term average proportion of mud.

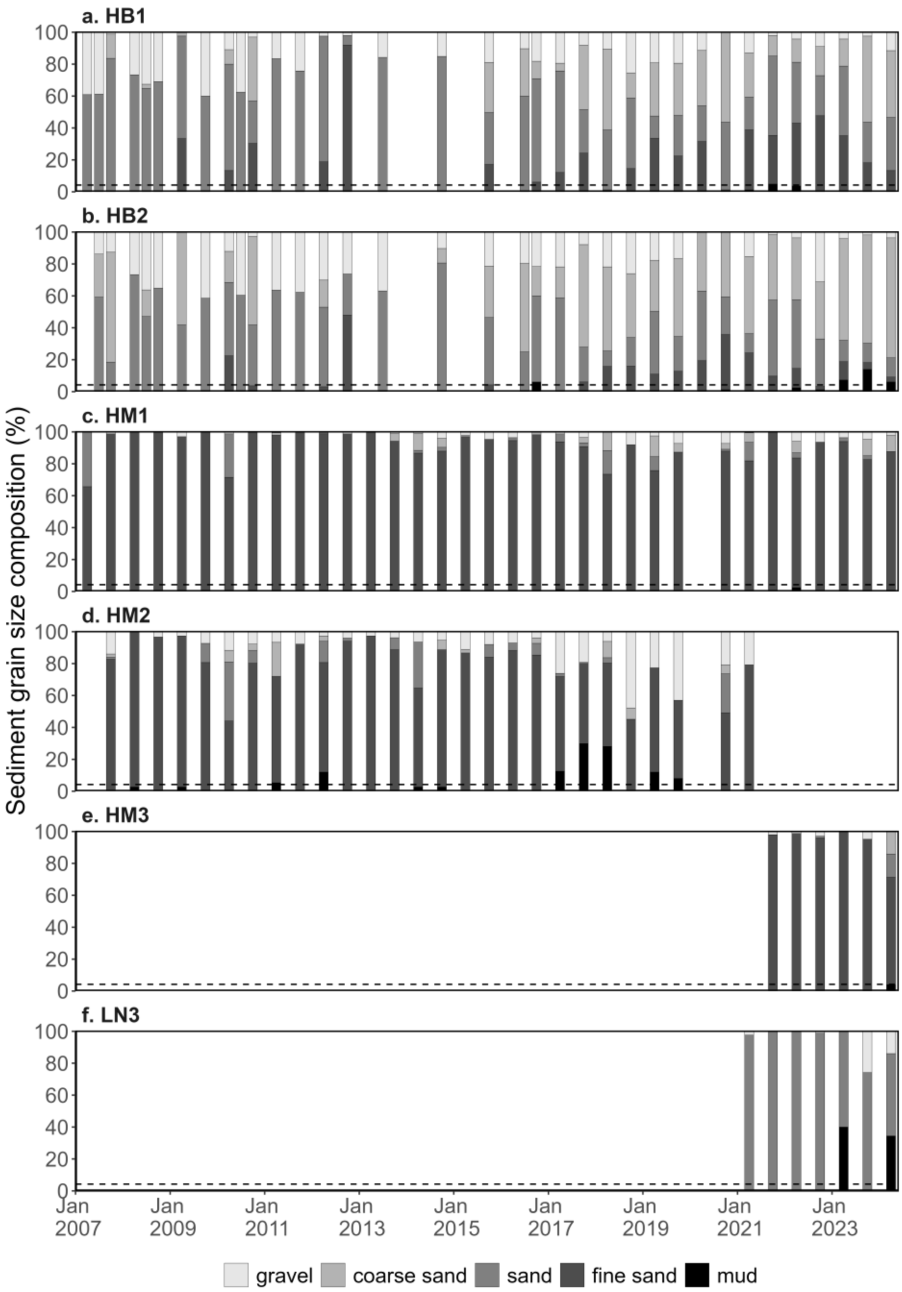


Figure 118. Sediment grain size composition at reef intertidal habitat monitoring sites in the Mackay–Whitsunday region, 2007–2024. Dashed line is the Reef long-term average proportion of mud.

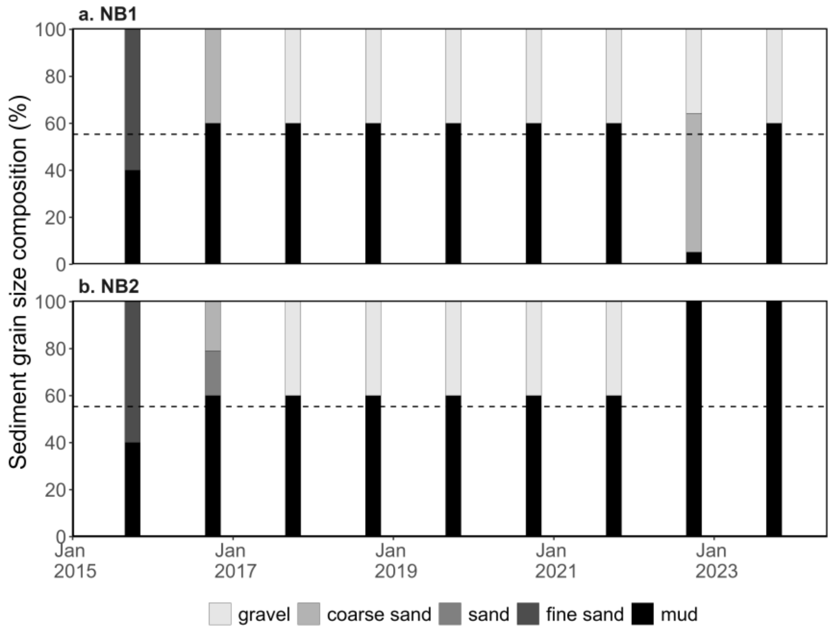


Figure 119. Sediment grain size composition at subtidal coastal habitat monitoring sites in the Mackay–Whitsunday region, 2015–2024. Dashed line is the Reef long-term average proportion of mud.

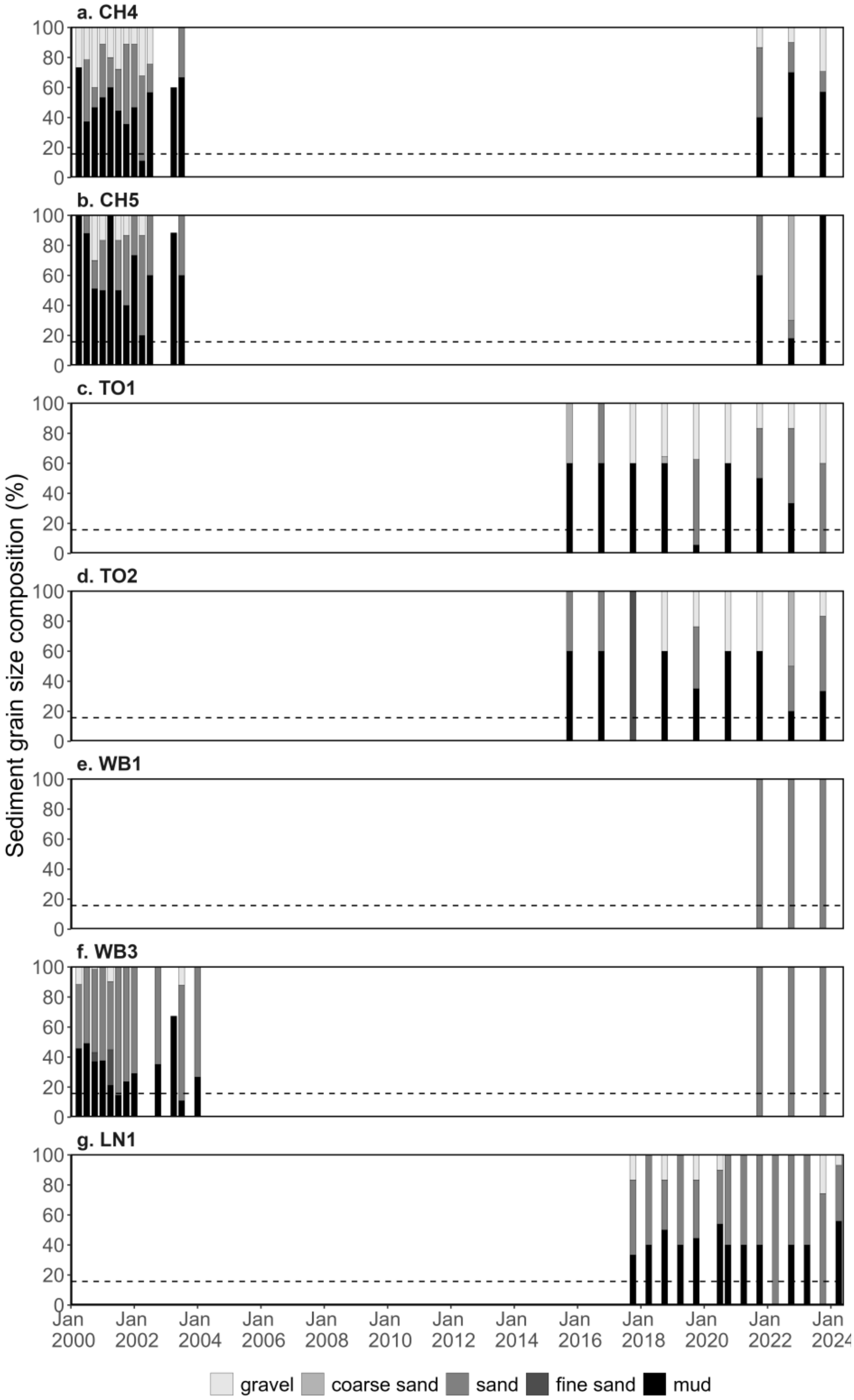


Figure 120. Sediment grain size composition at reef subtidal habitat monitoring sites in the Mackay–Whitsunday region, 2000–2024. Dashed line is the Reef long-term average proportion of mud.

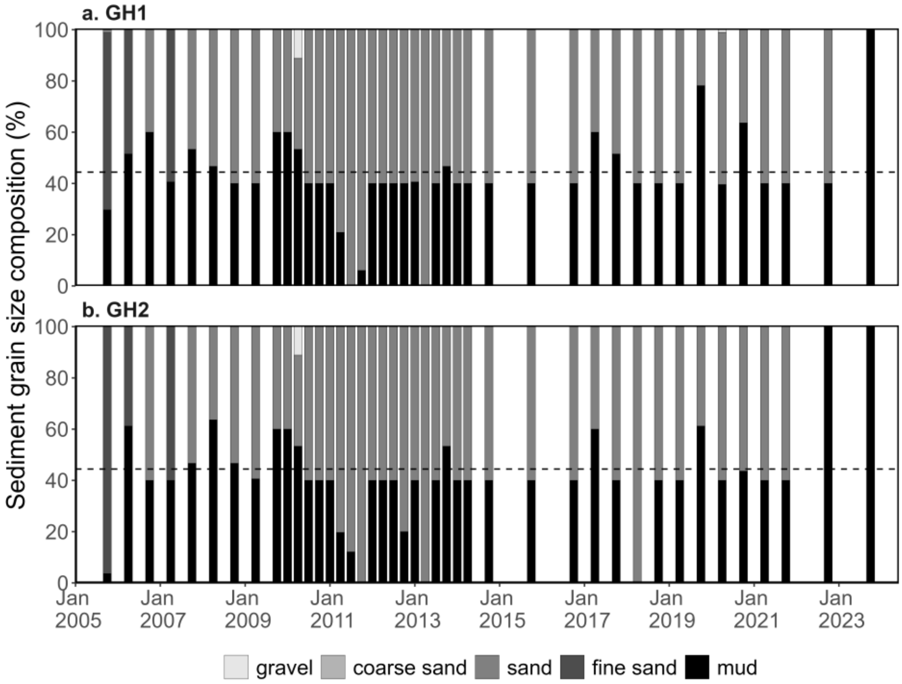


Figure 121. Sediment grain size composition at estuarine intertidal habitat monitoring sites in the Fitzroy region, 2005–2024. Dashed line is the Reef long-term average proportion of mud.

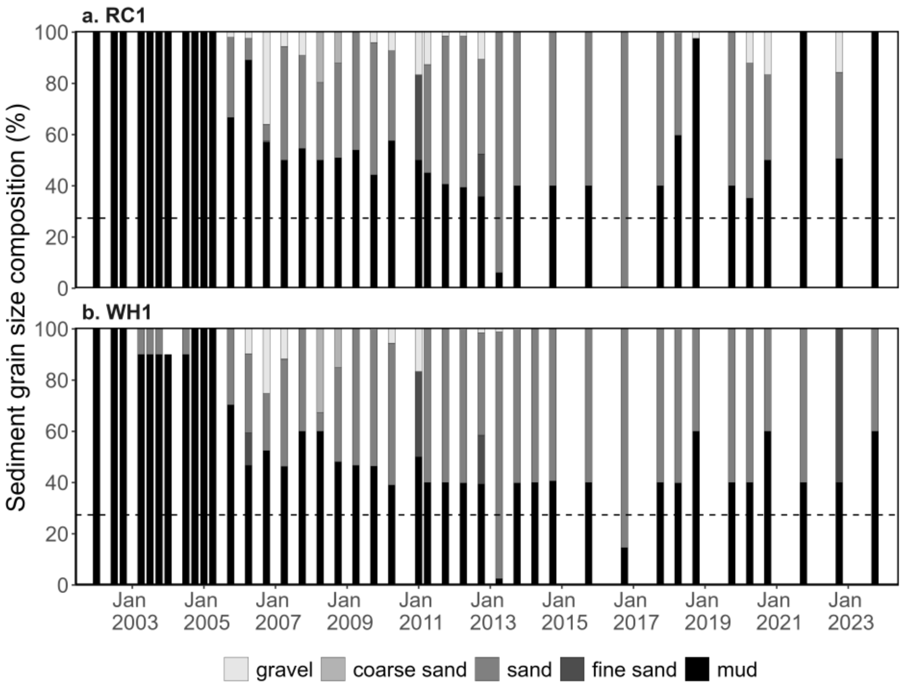


Figure 122. Sediment grain size composition at coastal intertidal habitat monitoring sites in the Fitzroy region, 2002–2024. Dashed line is the Reef long-term average proportion of mud.

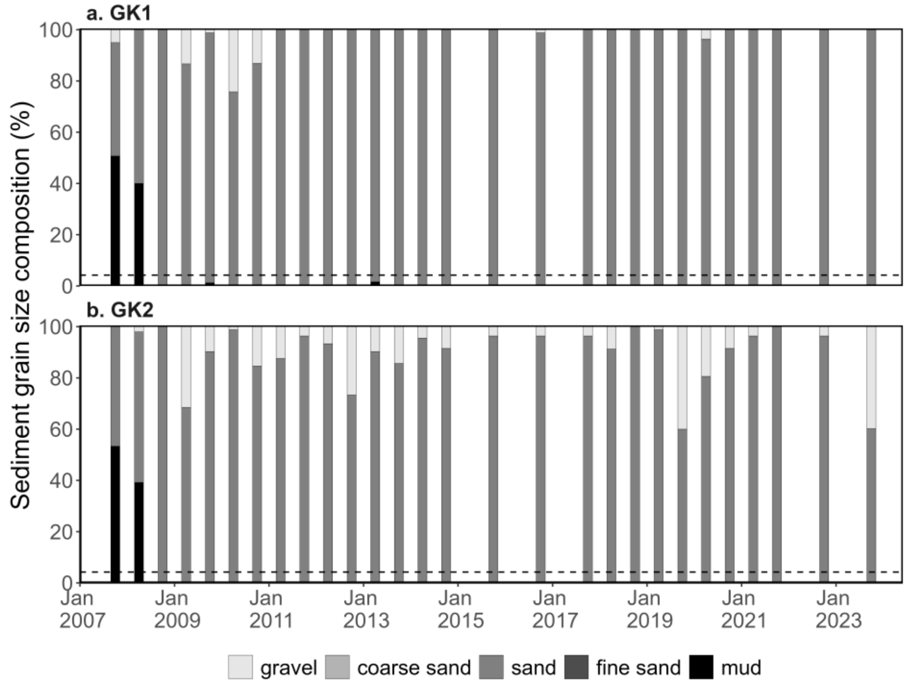


Figure 123. Sediment grain size composition at reef intertidal habitat monitoring sites in the Fitzroy region, 2007–2024. Dashed line is the Reef long-term average proportion of mud.

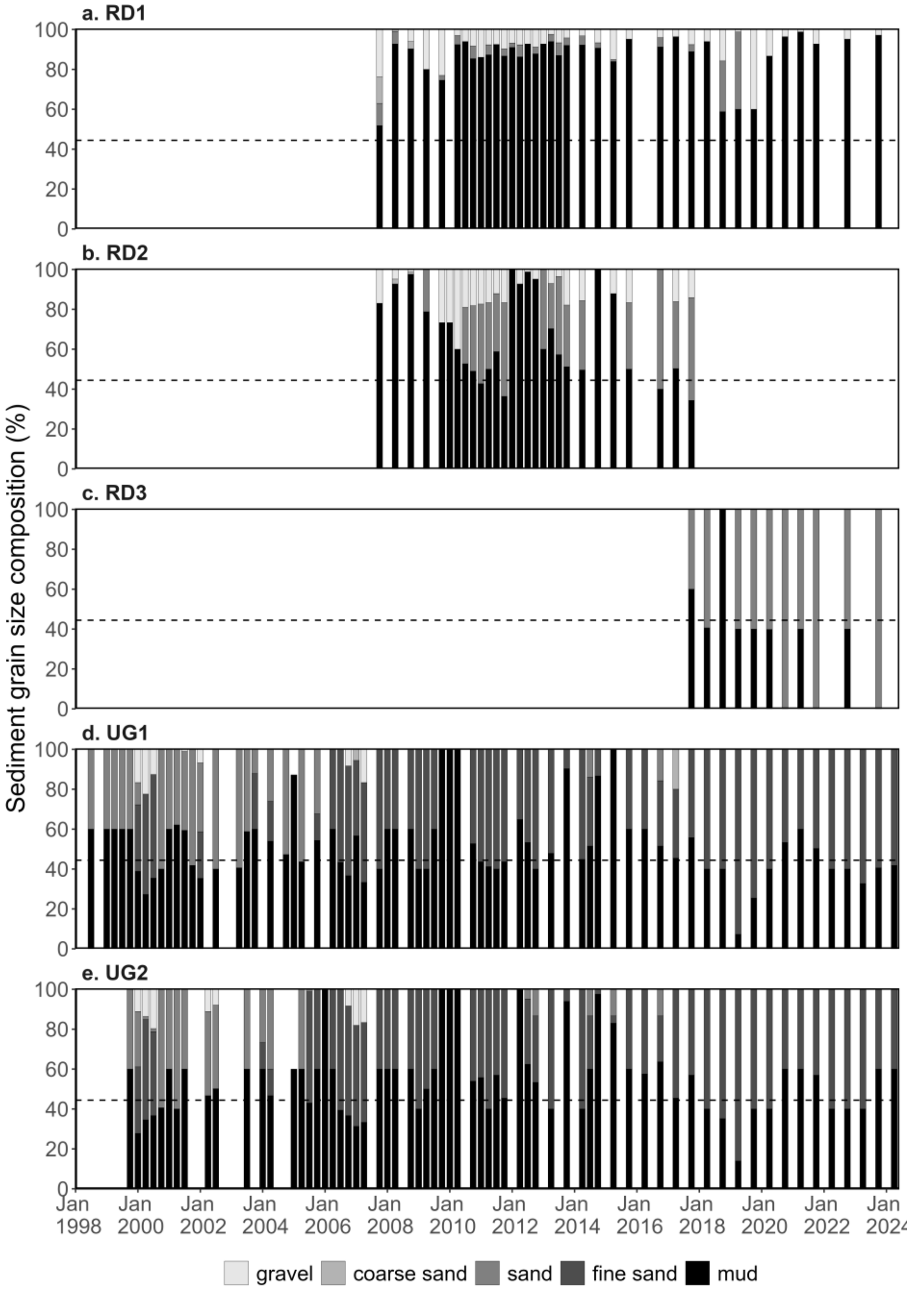


Figure 124. Sediment grain size composition at estuarine intertidal habitat monitoring sites in the Burnett–Mary region, 1999–2024. Dashed line is the Reef long-term average proportion of mud.

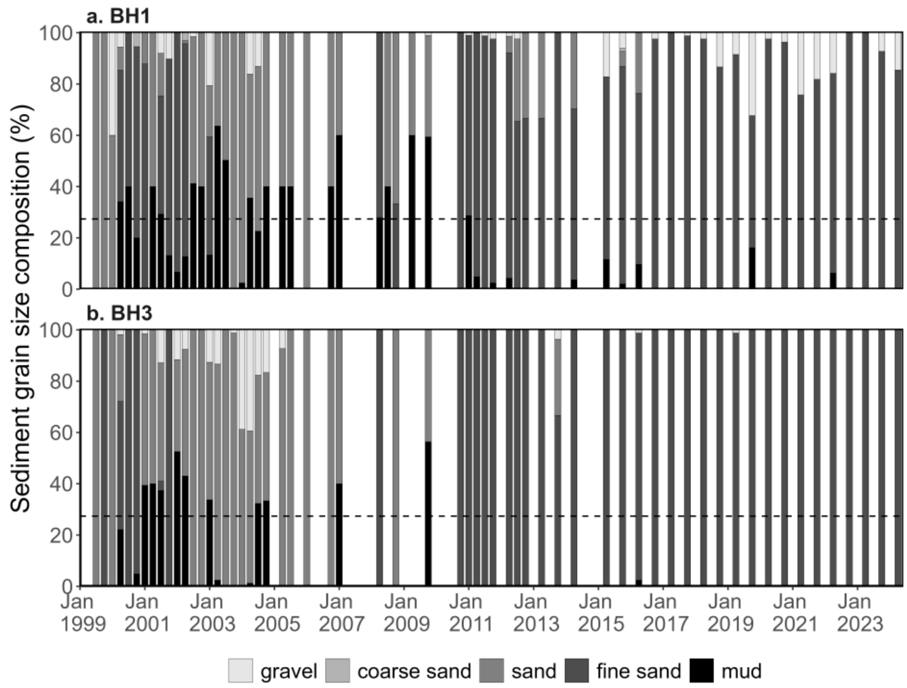


Figure 125. Sediment grain size composition at coastal intertidal habitat monitoring sites in the Burnett–Mary region, 1999–2024. Dashed line is the Reef long-term average proportion of mud.

# 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 | 2023 | 16 | -0.042 | 0.857 | -0.063 | no trend |
| | | BY2 | 2012 | 2023 | 16 | 0.05 | 0.822 | 0.118 | no trend |
| | | SR1 | 2012 | 2023 | 14 | -0.363 | 0.08 | -0.399 | no trend |
| | | SR2 | 2012 | 2023 | 14 | 0.11 | 0.622 | 0.187 | no trend |
| | coastal subtidal | BY3 | 2019 | 2023 | 4 | 0 | 1 | 0.207 | no trend |
| | | BY4 | 2017 | 2023 | 6 | -0.552 | 0.181 | -3.767 | no trend |
| | | LR1 | 2015 | 2023 | 8 | 0.429 | 0.174 | 1.943 | no trend |
| | | LR2 | 2015 | 2023 | 7 | -0.143 | 0.764 | -2.53 | no trend |
| | | MA1 | 2021 | 2023 | 3 | 0.333 | 1 | 3.212 | no trend |
| | | MA2 | 2021 | 2023 | 3 | 0.333 | 1 | 4.703 | 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 | -0.03 | no trend |
| | | FR1 | 2012 | 2023 | 15 | -0.345 | 0.083 | -0.331 | no trend |
| | | **FR2** | **2012** | **2023** | **14** | **-0.56** | **0.006** | **-1.116 (-1.672 to -0.655)** | **decrease** |
| | | ST1 | 2012 | 2023 | 16 | 0.35 | 0.065 | 0.426 | no trend |
| | | **ST2** | **2012** | **2023** | **16** | **0.494** | **0.009** | **0.626 (0.412 to 0.859)** | **increase** |
| | | YY1 | 2012 | 2014 | 3 | 0.333 | 1 | 1.045 | no trend |
| | reef subtidal | FG1 | 2016 | 2023 | 8 | -0.5 | 0.108 | -1.92 | no trend |
| | | FG2 | 2016 | 2023 | 8 | -0.357 | 0.266 | -1.533 | no trend |
| | pooled | | 2003 | 2023 | 42 | **-0.382** | **<0.001** | **-0.236 (-0.361 to -0.088)** | **decrease** |
| Wet Tropics | coastal intertidal | **LB1** | **2005** | **2024** | **52** | **-0.311** | **0.002** | **-0.015 (-0.053 to 0)** | **decrease** |
| | | LB2 | 2005 | 2024 | 51 | -0.139 | 0.169 | -0.002 | no trend |
| | | **YP1** | **2000** | **2024** | **85** | **0.197** | **0.008** | **0.124 (0.033 to 0.215)** | **increase** |

| NRM region | Habitat | Site | First Year | Last Year | *n* | *Kendall -τ* | *p* (2-sided) | Sen's slope (confidence interval) | trend |
|---|---|---|---|---|---|---|---|---|---|
| | | **YP2** | **2001** | **2024** | **81** | **0.161** | **0.033** | **0.068 (0.006 to 0.135)** | **increase** |
| | coastal subtidal | MS1 | 2017 | 2022 | 6 | -0.333 | 0.452 | -1.824 | no trend |
| | | MS2 | 2015 | 2023 | 8 | 0.071 | 0.902 | 0.282 | no trend |
| | reef intertidal | DI1 | 2007 | 2024 | 43 | 0.161 | 0.132 | 0.065 | no trend |
| | | DI2 | 2007 | 2024 | 43 | 0.153 | 0.152 | 0.107 | no trend |
| | | GI1 | 2001 | 2024 | 81 | -0.065 | 0.396 | -0.031 | no trend |
| | | GI2 | 2005 | 2024 | 67 | 0.049 | 0.563 | 0.03 | no trend |
| | | GO1 | 2008 | 2016 | 7 | -0.429 | 0.23 | -1.682 | no trend |
| | | LI1 | 2008 | 2024 | 49 | -0.117 | 0.238 | -0.05 | no trend |
| | reef subtidal | DI3 | 2008 | 2024 | 55 | 0.03 | 0.755 | 0.002 | no trend |
| | | **GI3** | **2008** | **2024** | **51** | **-0.228** | **0.019** | **-0.303 (-0.538 to -0.066)** | **decrease** |
| | | LI2 | **2005** | **2024** | **52** | **-0.311** | **0.002** | **-0.015 (-0.053 to 0)** | **decrease** |
| | pooled | | 2000 | 2024 | 94 | -0.122 | 0.082 | -0.049 | no trend |
| Burdekin | coastal intertidal | BB1 | 2002 | 2024 | 72 | -0.049 | 0.543 | -0.037 | no trend |
| | | SB1 | 2001 | 2024 | 78 | -0.027 | 0.733 | -0.014 | no trend |
| | | **SB2** | **2001** | **2024** | **76** | **-0.195** | **0.013** | **-0.162 (-0.296 to -0.032)** | **decrease** |
| | | JR1 | 2012 | 2023 | 21 | 0.162 | 0.319 | 0.476 | no trend |
| | | **JR2** | **2012** | **2023** | **20** | **0.337** | **0.041** | **1.367 (0.019 to 2.7)** | **increase** |
| | | BW2 | 2019 | 2024 | 10 | 0.333 | 0.21 | 0.707 | no trend |
| | | BW3 | 2021 | 2024 | 7 | 0.524 | 0.133 | 1.485 | no trend |
| | reef intertidal | MI1 | 2005 | 2024 | 65 | -0.079 | 0.353 | -0.083 | no trend |
| | | **MI2** | **2005** | **2024** | **63** | **-0.26** | **0.003** | **-0.41 (-0.639 to -0.141)** | **decrease** |
| | reef subtidal | MI3 | 2008 | 2024 | 56 | -0.091 | 0.326 | -0.187 | no trend |
| | pooled | | 2001 | 2024 | 85 | -0.096 | 0.196 | -0.064 | no trend |
| Mackay Whitsunday | estuarine intertidal | SI1 | 2005 | 2024 | 43 | -0.107 | 0.315 | -0.098 | no trend |
| | | SI2 | 2005 | 2024 | 38 | 0.124 | 0.28 | 0.071 | no trend |
| | coastal intertidal | CV1 | 2017 | 2024 | 13 | 0.026 | 0.951 | 0.077 | no trend |

| NRM region | Habitat | Site | First Year | Last Year | n | Kendall -τ | p (2-sided) | Sen's slope (confidence interval) | trend |
|---|---|---|---|---|---|---|---|---|---|
| | | CV2 | 2017 | 2023 | 13 | 0.154 | 0.502 | 0.119 | no trend |
| | | LL1 | 2022 | 2023 | 4 | 0.333 | 0.734 | 5.22 | no trend |
| | | **MP2** | **2000** | **2024** | **50** | **0.346** | **<0.001** | **0.23 (0.112 to 0.333)** | **increase** |
| | | **MP3** | **2000** | **2024** | **48** | **0.236** | **0.019** | **0.151 (0.028 to 0.262)** | **increase** |
| | | **PI2** | **1999** | **2024** | **66** | **-0.345** | **<0.001** | **-0.268 (-0.383 to -0.157)** | **decrease** |
| | | PI3 | 1999 | 2024 | 66 | -0.08 | 0.344 | -0.052 | no trend |
| | | SH1 | 2017 | 2023 | 14 | 0.385 | 0.063 | 1.251 | no trend |
| | coastal subtidal | NB1 | 2015 | 2023 | 9 | -0.333 | 0.251 | -3.422 | no trend |
| | | NB2 | 2015 | 2023 | 9 | 0.389 | 0.175 | 1.834 | no trend |
| | reef intertidal | HB1 | 2000 | 2024 | 52 | -0.081 | 0.398 | -0.042 | no trend |
| | | HB2 | 2000 | 2024 | 51 | 0.125 | 0.199 | 0.066 | no trend |
| | | **HM1** | **2007** | **2024** | **34** | **-0.34** | **0.005** | **-0.13 (-0.226 to -0.039)** | **decrease** |
| | | **HM2** | **2007** | **2021** | **27** | **-0.448** | **0.001** | **-0.141 (-0.282 to -0.054)** | **decrease** |
| | | HM3 | 2021 | 2024 | 6 | -0.067 | 1 | -0.086 | no trend |
| | | LN3 | 2021 | 2024 | 7 | 0.238 | 0.548 | 1.704 | no trend |
| | reef subtidal | **CH4** | **2000** | **2023** | **16** | **-0.567** | **0.003** | **-2.711 (-3.464 to -0.801)** | **decrease** |
| | | **CH5** | **2000** | **2023** | **16** | **-0.55** | **0.003** | **-1.635 (-2.867 to -0.285)** | **decrease** |
| | | LN1 | 2017 | 2024 | 14 | -0.077 | 0.743 | -0.194 | no trend |
| | | LN2 | 2017 | 2020 | 6 | 0.333 | 0.452 | 0.313 | no trend |
| | | TO1 | 2015 | 2023 | 9 | 0.278 | 0.348 | 1.029 | no trend |
| | | TO2 | 2015 | 2023 | 9 | 0.333 | 0.251 | 0.81 | no trend |
| | | WB1 | 1999 | 2023 | 4 | -1 | 0.089 | -6.034 | no trend |
| | | WB3 | 2000 | 2023 | 17 | -0.214 | 0.248 | -0.221 | no trend |
| | pooled | | **1999** | **2024** | **81** | **-0.253** | **<0.001** | **-0.094 (-0.15 to -0.045)** | **decrease** |
| Fitzroy | estuarine intertidal | **GH1** | **2005** | **2023** | **42** | **-0.41** | **<0.001** | **-0.613 (-0.917 to -0.299)** | **decrease** |
| | | GH2 | 2005 | 2023 | 42 | -0.198 | 0.067 | -0.292 | no trend |
| | coastal intertidal | RC1 | 2002 | 2023 | 41 | -0.121 | 0.271 | -0.179 | no trend |

| NRM region | Habitat | Site | First Year | Last Year | *n* | Kendall -τ | *p* (2-sided) | Sen's slope (confidence interval) | trend |
|---|---|---|---|---|---|---|---|---|---|
| | | WH1 | 2002 | 2023 | 42 | 0.14 | 0.197 | 0.098 | no trend |
| | reef intertidal | **GK1** | **2007** | **2023** | **28** | **-0.517** | **<0.001** | **-0.09 (-0.144 to -0.05)** | **decrease** |
| | | GK2 | 2007 | 2023 | 28 | -0.066 | 0.635 | -0.007 | no trend |
| | pooled | | **2002** | **2023** | **54** | **-0.394** | **<0.001** | **-0.221 (-0.319 to -0.13)** | **decrease** |
| Burnett Mary | estuarine intertidal | RD1 | 2007 | 2023 | 37 | 0.136 | 0.244 | 0.009 | no trend |
| | | **RD2** | **2007** | **2017** | **28** | **-0.409** | **0.003** | **-0.009 (-0.096 to -0.001)** | **decrease** |
| | | RD3 | 2017 | 2023 | 11 | -0.164 | 0.533 | -0.437 | no trend |
| | | UG1 | 1998 | 2024 | 71 | 0.025 | 0.761 | 0 | no trend |
| | | UG2 | 1999 | 2024 | 67 | 0.142 | 0.092 | 0.015 | no trend |
| | coastal intertidal | BH1 | 1999 | 2024 | 62 | -0.001 | 1 | 0 | no trend |
| | | **BH3** | **1999** | **2024** | **60** | **0.299** | **<0.001** | **0.13 (0.064 to 0.182)** | **increase** |
| | pooled | | 1998 | 2024 | 84 | -0.005 | 0.951 | 0.056 | no trend |

Table 23. Resilience score and resilience score category for each site in 2023–24.

| **MMP Site** | **Score** | **Score category** | **% colonising species > 50%** | **% cover < low cover threshold** | **Repro structures present** (all species) | **Repro structures present** (foundational species) | **Repro history** (last 3 years) | **Persistent species present** |
|---|---|---|---|---|---|---|---|---|
| **Cape York** | | | | | | | | |
| BY1 | 85 | 2.2.2 | FALSE | FALSE | TRUE | TRUE | 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 | 1.1 | FALSE | TRUE | FALSE | FALSE | FALSE | TRUE |
| SR1 | 12 | 1.1 | FALSE | TRUE | FALSE | FALSE | FALSE | TRUE |
| SR2 | 100 | 2.2.2 | FALSE | FALSE | TRUE | TRUE | FALSE | TRUE |
| ST1 | 14 | 1.1 | FALSE | TRUE | FALSE | FALSE | TRUE | TRUE |
| ST2 | 15 | 1.1 | FALSE | TRUE | FALSE | FALSE | FALSE | TRUE |
| **Northern Wet Tropics** | | | | | | | | |
| GI1 | 30 | 2.1.1 | FALSE | FALSE | TRUE | FALSE | FALSE | TRUE |
| GI2 | 100 | 2.2.2 | FALSE | FALSE | TRUE | FALSE | TRUE | TRUE |
| GI3 | 100 | 2.2.2 | FALSE | FALSE | TRUE | FALSE | 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 | TRUE | FALSE |
| YP2 | 78 | 2.2.1 | FALSE | FALSE | TRUE | TRUE | TRUE | FALSE |
| **Southern Wet Tropics** | | | | | | | | |
| DI1 | 50 | 2.1.2 | FALSE | FALSE | TRUE | FALSE | TRUE | TRUE |
| DI2 | 70 | 2.1.2 | FALSE | FALSE | FALSE | FALSE | TRUE | TRUE |
| DI3 | 33 | 2.1.1 | FALSE | FALSE | FALSE | FALSE | FALSE | TRUE |
| LB1 | 30 | 2.1.1 | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE |
| LB2 | 30 | 2.1.1 | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE |
| **Burdekin** | | | | | | | | |
| BB1 | 30 | 1.2 | FALSE | TRUE | TRUE | TRUE | TRUE | FALSE |
| JR1 | 50 | 2.1.2 | FALSE | FALSE | TRUE | FALSE | TRUE | FALSE |
| JR2 | 50 | 2.1.2 | FALSE | FALSE | TRUE | FALSE | TRUE | FALSE |
| MI1 | 85 | 2.2.2 | FALSE | FALSE | TRUE | TRUE | TRUE | TRUE |
| MI2 | 5 | 1.2 | TRUE | FALSE | TRUE | FALSE | FALSE | TRUE |
| MI3 | 14 | 1.2 | FALSE | TRUE | TRUE | FALSE | FALSE | TRUE |
| SB1 | 15 | 1.2 | FALSE | TRUE | TRUE | FALSE | TRUE | FALSE |
| **Mackay-Whitsunday** | | | | | | | | |
| HM1 | 30 | 2.1.1 | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE |
| HM3 | 7 | 1.1 | TRUE | TRUE | FALSE | FALSE | FALSE | FALSE |
| LN1 | 50 | 2.1.2 | FALSE | FALSE | TRUE | FALSE | TRUE | FALSE |
| LN3 | 50 | 2.1.2 | FALSE | FALSE | TRUE | FALSE | TRUE | FALSE |
| MP2 | 70 | 2.2.1 | FALSE | FALSE | TRUE | TRUE | TRUE | FALSE |

| **MMP Site** | **Score** | **Score category** | **% colonising species > 50%** | **% cover < low cover threshold** | **Repro structures present** (all species) | **Repro structures present** (foundational species) | **Repro history** (last 3 years) | **Persistent species present** |
|---|---|---|---|---|---|---|---|---|
| MP3 | 70 | 2.2.1 | FALSE | FALSE | TRUE | TRUE | TRUE | FALSE |
| SI1 | 73 | 2.2.1 | FALSE | FALSE | TRUE | TRUE | TRUE | FALSE |
| SI2 | 70 | 2.2.1 | FALSE | FALSE | TRUE | TRUE | TRUE | FALSE |
| **Fitzroy** | | | | | | | | |
| GH1 | 71 | 2.2.1 | FALSE | FALSE | TRUE | TRUE | TRUE | FALSE |
| GH2 | 28 | 1.2 | FALSE | TRUE | TRUE | TRUE | TRUE | FALSE |
| GK1 | 0 | 1.1 | TRUE | FALSE | FALSE | FALSE | FALSE | FALSE |
| GK2 | 2 | 1.1 | TRUE | FALSE | FALSE | FALSE | TRUE | FALSE |
| RC1 | 50 | 2.1.2 | FALSE | FALSE | FALSE | FALSE | TRUE | FALSE |
| WH1 | 75 | 2.2.1 | FALSE | FALSE | TRUE | TRUE | TRUE | FALSE |
| **Burnett-Mary** | | | | | | | | |
| BH1 | 50 | 2.1.2 | FALSE | FALSE | FALSE | FALSE | TRUE | FALSE |
| BH3 | 30 | 2.1.1 | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE |
| RD1 | 72 | 2.2.1 | FALSE | FALSE | TRUE | TRUE | TRUE | FALSE |
| RD3 | 30 | 2.1.1 | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE |
| UG1 | 5 | 1.1 | TRUE | FALSE | FALSE | FALSE | FALSE | FALSE |
| UG2 | 7 | 1.2 | TRUE | FALSE | TRUE | 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)** | 94 | 23.161 | 5425.47 | <2e-16 | 0.542 | 0.722 |
| **% cover = s(date) + Habitat** | 344 | | | | 0.489 | 0.811 |
| Estuarine intertidal | | 2.616 | 13.266 | 0.003 | | |
| Coastal intertidal | | 23.344 | 1441.35 | <2e-16 | | |
| Coastal subtidal | | 21.029 | 1012.518 | <2e-16 | | |
| Reef intertidal | | 15.093 | 1018.337 | <2e-16 | | |
| Reef subtidal | | 17.805 | 545.857 | <2e-16 | | |
| **% cover = s(date) + NRM** | 424 | | | | 0.581 | 0.798 |
| Cape York | | 20.251 | 1335.475 | <2e-16 | | |
| Wet Tropics | | 23.261 | 1276.286 | <2e-16 | | |
| Burdekin | | 6.076 | 63.318 | <2e-16 | | |
| Mackay Whitsunday | | 16.803 | 273.501 | <2e-16 | | |
| Fitzroy | | 20.654 | 590.899 | <2e-16 | | |
| Burnett Mary | | 17.759 | 772.504 | <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)** | 42 | 9.416 | 226.002 | <0.001 | 0.397 | 0.481 |
| **% cover = s(date) + Habitat** | 74 | | | | 0.599 | 0.804 |
| Coastal intertidal | | 3.575 | 22.686 | <0.001 | | |
| Coastal subtidal | | 2.841 | 32.2 | <0.001 | | |
| Reef intertidal | | 6.801 | 183.89 | <0.001 | | |
| Reef subtidal | | 2.943 | 108.307 | <0.001 | | |
| **% cover = s(date) + Location** | 124 | | | | 0.679 | 0.96 |
| Coastal intertidal [BY] | | 3.319 | 14.236 | 0.007 | | |
| Coastal intertidal [SR] | | 1.458 | 0.516 | 0.796 | | |
| Coastal subtidal [BY] | | 2.973 | 108.705 | <0.001 | | |
| Coastal subtidal [LR] | | 2.833 | 42.254 | <0.001 | | |
| Coastal subtidal [MA] | | 1.965 | 4.124 | 0.121 | | |
| Reef intertidal [AP] | | 6.358 | 102.934 | <0.001 | | |
| Reef intertidal [FR] | | 1 | 17.616 | <0.001 | | |
| Reef intertidal [ST] | | 2.88 | 30.391 | <0.001 | | |
| Reef intertidal [YY] | | 1.633 | 0.344 | 0.776 | | |
| Reef subtidal [FG] | | 2.92 | 79.106 | <0.001 | | |
| **% cover = s(date) + Site** | | | | | | |
| **AP1** | 35 | 5.154 | 46.91 | <0.001 | 0.602 | 0.687 |
| **AP2** | 24 | 2.655 | 8.655 | 0.041 | 0.272 | 0.342 |
| **BY1** | 16 | 1 | 0.02 | 0.888 | -0.07 | 0.002 |
| **BY2** | 16 | 2.786 | 3.926 | 0.372 | 0.147 | 0.34 |
| **BY3** | 4 | 1.971 | 30.76 | <0.001 | 0.77 | 0.993 |
| **BY4** | 6 | 2.03 | 15.213 | 0.001 | -0.211 | 6.341 |
| **FG1** | 8 | 4.582 | 99.671 | <0.001 | 0.948 | 0.996 |
| **FG2** | 8 | 3.292 | 20.319 | <0.001 | 0.606 | 0.891 |
| **FR1** | 15 | 1 | 4.573 | 0.032 | 0.19 | 0.27 |
| **FR2** | 14 | 1 | 32.969 | <0.001 | 0.731 | 0.75 |
| **LR1** | 8 | 1.001 | 3.894 | 0.048 | 0.315 | 0.345 |
| **LR2** | 7 | 3.296 | 10.282 | 0.037 | -0.171 | 0.87 |
| **MA1** | | | | | | |
| **MA2** | | | | | | |
| **SR1** | 14 | 1.592 | 3.901 | 0.167 | 0.204 | 0.265 |
| **SR2** | 14 | 2.897 | 10.44 | 0.021 | 0.445 | 0.536 |
| **ST1** | 16 | 3.723 | 38.116 | <0.001 | 0.705 | 0.781 |
| **ST2** | 16 | 4.242 | 42.927 | <0.001 | 0.747 | 0.829 |
| **YY1** | | | | | | |
| **Northern Wet Tropics** | | | | | | |
| **% cover = s(date)** | 89 | 16.751 | 403.435 | <0.001 | 0.352 | 0.519 |
| **% cover = s(date) + Habitat** | 221 | | | | 0.695 | 0.748 |
| Coastal intertidal | | 13.418 | 211.635 | <0.001 | | |
| Reef intertidal | | 10.93 | 215.32 | <0.001 | | |
| Reef subtidal | | 7.823 | 44.451 | <0.001 | | |
| **% cover = s(date) + Location** | 315 | | | | 0.826 | 0.91 |
| Coastal intertidal [YP] | | 13.005 | 192.355 | <0.001 | | |
| Reef intertidal [GI] | | 5.55 | 47.022 | <0.001 | | |
| Reef intertidal [LI1] | | 3.316 | 30.051 | <0.001 | | |
| Reef subtidal [GI3] | | 6.528 | 63.12 | <0.001 | | |
| Reef subtidal [LI2] | | 7.606 | 139.126 | <0.001 | | |

| MODELS PER NRM REGIONS | N | EDF | CHI-SQ | *P*-VALUE | R-SQ (ADJ) | DEVIANCE EXPLAINED |
|---|---|---|---|---|---|---|
| **% cover = s(date) + Site** | | | | | | |
| GI1 | 81 | 3.197 | 11.146 | 0.025 | 0.114 | 0.152 |
| GI2 | 67 | 4.584 | 23.35 | 0.001 | 0.267 | 0.322 |
| GI3 | 51 | 6.167 | 54.028 | <0.001 | 0.523 | 0.602 |
| LI1 | 49 | 3.722 | 40.104 | <0.001 | 0.453 | 0.495 |
| LI2 | 49 | 5.541 | 62.373 | <0.001 | 0.329 | 0.636 |
| YP1 | 85 | 10.636 | 94.447 | <0.001 | 0.521 | 0.685 |
| YP2 | 81 | 8.943 | 46.449 | <0.001 | 0.328 | 0.472 |
| **Southern Wet Tropics** | | | | | | |
| **% cover = s(date)** | 66 | 16.21 | 1323.044 | <0.001 | 0.712 | 0.917 |
| **% cover = s(date) + Habitat** | 158 | | | | 0.909 | 0.981 |
| Coastal intertidal | | 12.948 | 923.893 | <0.001 | | |
| Coastal subtidal | | 2.322 | 4.165 | 0.316 | | |
| Reef intertidal | | 12.127 | 678.077 | <0.001 | | |
| Reef subtidal | | 12.376 | 235.854 | <0.001 | | |
| **% cover = s(date) + Location** | 165 | | | | 0.914 | 0.986 |
| Coastal intertidal [LB] | | 13.238 | 1049.634 | <0.001 | | |
| Coastal subtidal [MS] | | 2.294 | 3.955 | 0.346 | | |
| Reef intertidal [DI] | | 12.713 | 532.571 | <0.001 | | |
| Reef intertidal [GO] | | 5.427 | 162.378 | <0.001 | | |
| Reef subtidal [DI3] | | 12.651 | 256.026 | <0.001 | | |
| **% cover = s(date) + Site** | | | | | | |
| DI1 | 43 | 10.845 | 284.487 | <0.001 | 0.909 | 0.968 |
| DI2 | 43 | 10.169 | 222.893 | <0.001 | 0.801 | 0.957 |
| DI3 | 55 | 11.65 | 210.687 | <0.001 | 0.674 | 0.947 |
| GO1 | 7 | 2.943 | 42.146 | <0.001 | 0.923 | 0.905 |
| LB1 | 52 | 10.563 | 488.903 | <0.001 | 0.901 | 0.978 |
| LB2 | 51 | 9.105 | 237.682 | <0.001 | 0.737 | 0.943 |
| MS1 | 6 | 1 | 1.235 | 0.266 | 0.016 | 0.223 |
| MS2 | 8 | 1.75 | 1.467 | 0.472 | 0.026 | 0.334 |
| **Burdekin** | | | | | | |
| **% cover = s(date)** | 83 | 20.162 | 1847.031 | <0.001 | 0.775 | 0.906 |
| **% cover = s(date) + Habitat** | 202 | | | | 0.782 | 0.909 |
| Coastal intertidal | | 19.637 | 790.965 | <0.001 | | |
| Reef intertidal | | 14.16 | 474.142 | <0.001 | | |
| Reef subtidal | | 12.65 | 503.366 | <0.001 | | |
| **% cover = s(date) + Location** | 233 | | | | 0.752 | 0.897 |
| Coastal intertidal [BW] | | 1 | 10.826 | 0.001 | | |
| Coastal intertidal [JR] | | 8.217 | 178.448 | <0.001 | | |
| Coastal intertidal [TSV] | | 19.03 | 573.392 | <0.001 | | |
| Reef intertidal [MI] | | 13.403 | 368.137 | <0.001 | | |
| Reef subtidal [MI3] | | 12.073 | 402.583 | <0.001 | | |
| **% cover = s(date) + Site** | | | | | | |
| BB1 | 72 | 14.094 | 226.039 | <0.001 | 0.718 | 0.935 |
| BW1 | | | | | | |
| BW2 | 10 | 3.679 | 43.472 | <0.001 | 0.828 | 0.895 |
| BW3 | 7 | 1.885 | 18.47 | <0.001 | 0.758 | 0.833 |
| JR1 | 21 | 2.639 | 6.807 | 0.11 | 0.215 | 0.356 |
| JR2 | 20 | 3.562 | 15.851 | 0.005 | 0.412 | 0.62 |
| MI1 | 65 | 11.055 | 192.034 | <0.001 | 0.762 | 0.858 |
| MI2 | 63 | 11.278 | 159.54 | <0.001 | 0.73 | 0.837 |
| MI3 | 56 | 11.303 | 311.037 | <0.001 | 0.868 | 0.935 |

| MODELS PER NRM REGIONS | N | EDF | CHI-SQ | *P*-VALUE | R-SQ (ADJ) | DEVIANCE EXPLAINED |
|---|---|---|---|---|---|---|
| SB1 | 78 | 17.543 | 236.351 | <0.001 | 0.741 | 0.919 |
| SB2 | 75 | 14.301 | 147.033 | <0.001 | 0.636 | 0.843 |
| **Mackay Whitsunday** | | | | | | |
| **% cover = s(date)** | 78 | 22.128 | 969.521 | <0.001 | 0.455 | 0.696 |
| **% cover = s(date) + Habitat** | 198 | | | | 0.667 | 0.872 |
| Estuarine intertidal | | 7.192 | 66.161 | <0.001 | | |
| Coastal intertidal | | 17.053 | 307.51 | <0.001 | | |
| Coastal subtidal | | 20.692 | 315.638 | <0.001 | | |
| Reef intertidal | | 8.096 | 173.254 | <0.001 | | |
| Reef subtidal | | 5.023 | 23.12 | <0.001 | | |
| **% cover = s(date) + Location** | 321 | | | | 0.656 | 0.821 |
| Estuarine intertidal [SI] | | 6.885 | 123.16 | <0.001 | | |
| Coastal intertidal [CV] | | 1 | 0.254 | 0.614 | | |
| Coastal intertidal [LL] | | 1 | 0.98 | 0.321 | | |
| Coastal intertidal [MP] | | 1.589 | 13.19 | 0.001 | | |
| Coastal intertidal [PI] | | 8.607 | 146.5 | <0.001 | | |
| Coastal intertidal [SH1] | | 2.819 | 18.229 | 0.001 | | |
| Coastal subtidal [NB] | | 2.887 | 22.299 | 0.003 | | |
| Reef intertidal [HB] | | 6.474 | 45.343 | <0.001 | | |
| Reef intertidal [HM] | | 1.896 | 19.084 | <0.001 | | |
| Reef intertidal [LN3] | | 1.503 | 2.961 | 0.244 | | |
| Reef subtidal [CH] | | 1 | 0.154 | 0.694 | | |
| Reef subtidal [LN] | | 1.502 | 0.525 | 0.64 | | |
| Reef subtidal [TO] | | 3.191 | 26.426 | <0.001 | | |
| Reef subtidal [WB] | | 1 | 0.651 | 0.42 | | |
| **% cover = s(date) + Site** | | | | | | |
| CH4 | | | | | | |
| CH5 | | | | | | |
| CV1 | 13 | 1.129 | 0.06 | 0.953 | -0.076 | 0.026 |
| CV2 | 13 | 1.145 | 0.896 | 0.358 | 0.039 | 0.111 |
| HB1 | 52 | 7.123 | 58.552 | <0.001 | 0.515 | 0.671 |
| HB2 | 51 | 10.011 | 111.175 | <0.001 | 0.709 | 0.793 |
| HM1 | 34 | 1.922 | 16.476 | 0.001 | 0.332 | 0.337 |
| HM2 | 27 | 4.506 | 56.476 | <0.001 | 0.412 | 0.838 |
| HM3 | 6 | 1 | 0.123 | 0.726 | -0.239 | 0.028 |
| **LL1** | 4 | 1 | 0.313 | 0.576 | -0.26 | 0.121 |
| LN1 | 14 | 1.118 | 0.101 | 0.803 | -0.078 | 0.035 |
| LN2 | 6 | 1.285 | 2.419 | 0.281 | -0.049 | 0.423 |
| LN3 | 7 | 1.771 | 7.871 | 0.012 | 0.545 | 0.702 |
| MP2 | 50 | 1.369 | 12.64 | 0.001 | 0.241 | 0.238 |
| MP3 | 48 | 1.756 | 5.989 | 0.053 | 0.112 | 0.134 |
| NB1 | 9 | 1.118 | 5.392 | 0.024 | 0.334 | 0.433 |
| NB2 | 9 | 2.625 | 4.573 | 0.269 | -0.441 | 0.502 |
| PI2 | 66 | 7.591 | 50.708 | <0.001 | 0.373 | 0.577 |
| PI3 | 66 | 11.864 | 68.049 | <0.001 | 0.469 | 0.683 |
| SH1 | 14 | 3.318 | 20.076 | 0.001 | 0.613 | 0.708 |
| SI1 | 43 | 10.041 | 62.775 | <0.001 | 0.446 | 0.79 |
| SI2 | 38 | 3.837 | 7.555 | 0.163 | 0.013 | 0.304 |
| TO1 | 9 | 3.648 | 12.517 | 0.019 | 0.117 | 0.857 |
| TO2 | 9 | 5.522 | 104.947 | <0.001 | 0.974 | 0.992 |
| WB1 | | | | | | |
| WB3 | | | | | | |

| MODELS PER NRM REGIONS | N | EDF | CHI-SQ | *P*-VALUE | R-SQ (ADJ) | DEVIANCE EXPLAINED |
|---|---|---|---|---|---|---|
| **Fitzroy** | | | | | | |
| **% cover = s(date)** | 53 | 11.704 | 193.163 | <0.001 | 0.341 | 0.563 |
| **% cover = s(date) + Habitat** | 111 | | | | 0.795 | 0.918 |
| Estuarine intertidal | | 9.603 | 119.708 | <0.001 | | |
| Coastal intertidal | | 15.235 | 231.048 | <0.001 | | |
| Reef intertidal | | 1 | 7.517 | 0.006 | | |
| **% cover = s(date) + Location** | 111 | | | | 0.795 | 0.918 |
| Estuarine intertidal [GH] | | 9.6 | 119.57 | <0.001 | | |
| Coastal intertidal [SWB] | | 15.234 | 231.198 | <0.001 | | |
| Reef intertidal [GK] | | 1 | 7.64 | 0.006 | | |
| **% cover = s(date) + Site** | | | | | | |
| GH1 | 42 | 6.262 | 75.215 | <0.001 | 0.548 | 0.83 |
| GH2 | 42 | 3.395 | 27.475 | <0.001 | 0.226 | 0.527 |
| GK1 | 28 | 1 | 21.514 | <0.001 | 0.213 | 0.499 |
| GK2 | 28 | 1 | 0.181 | 0.671 | -0.026 | 0.006 |
| RC1 | 40 | 9.409 | 84.27 | <0.001 | 0.699 | 0.776 |
| WH1 | 42 | 6.262 | 75.215 | <0.001 | 0.548 | 0.83 |
| **Burnett Mary** | | | | | | |
| **% cover = s(date)** | 79 | 22.196 | 678.426 | <0.001 | 0.501 | 0.737 |
| **% cover = s(date) + Habitat** | 137 | | | | 0.527 | 0.867 |
| Estuarine intertidal | | 6.603 | 42.493 | <0.001 | | |
| Coastal intertidal | | 21.013 | 718.885 | <0.001 | | |
| **% cover = s(date) + Location** | 171 | | | | 0.598 | 0.889 |
| Estuarine intertidal [RD] | | 6.55 | 41.795 | <0.001 | | |
| Estuarine intertidal [UG] | | 8.577 | 219.086 | <0.001 | | |
| Coastal intertidal [BH] | | 20.724 | 703.763 | <0.001 | | |
| **% cover = s(date) + Site** | | | | | | |
| BH1 | 62 | 7.079 | 47.71 | <0.001 | 0.434 | 0.524 |
| BH3 | 60 | 5.222 | 32.28 | <0.001 | 0.337 | 0.439 |
| RD1 | 37 | 1 | 1.383 | 0.24 | -0.014 | 0.035 |
| RD2 | 28 | 3.793 | 52.445 | <0.001 | 0.55 | 0.755 |
| RD3 | 11 | 1.7 | 1.821 | 0.461 | 0.04 | 0.237 |
| UG1 | 67 | 11.956 | 157.855 | <0.001 | 0.537 | 0.862 |
| UG2 | 65 | 11.491 | 128.215 | <0.001 | 0.541 | 0.836 |

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** | 160 | | | | 0.428 | 0.78 |
| Mackay Whitsunday | | 6.743 | 53.172 | <0.001 | | |
| Fitzroy | | 3.712 | 47.686 | <0.001 | | |
| Burnett Mary | | 8.782 | 403.068 | <0.001 | | |
| **Coastal intertidal** | | | | | | |
| **% cover = s(date) + NRM** | 358 | | | | 0.551 | 0.725 |
| Cape York | | 2.835 | 2.282 | 0.588 | | |
| Wet Tropics | | 8.58 | 235.176 | <0.001 | | |
| Burdekin | | 8.314 | 536.498 | <0.001 | | |
| Mackay Whitsunday | | 8.644 | 139.723 | <0.001 | | |
| Fitzroy | | 7.177 | 73.888 | <0.001 | | |
| Burnett Mary | | 6.258 | 73.169 | <0.001 | | |
| **Coastal subtidal** | | | | | | |
| **% cover = s(date) + NRM** | 25 | | | | 0.212 | 0.615 |
| Cape York | | 3.234 | 18.392 | 0.001 | | |
| Wet Tropics | | 1.236 | 0.271 | 0.859 | | |
| Mackay Whitsunday | | 3.643 | 36.023 | <0.001 | | |
| **Reef intertidal** | | | | | | |
| **% cover = s(date) + NRM** | 275 | | | | 0.77 | 0.858 |
| Cape York | | 5.406 | 77.584 | <0.001 | | |
| Wet Tropics | | 7.583 | 610.744 | <0.001 | | |
| Burdekin | | 7.732 | 471.941 | <0.001 | | |
| Mackay Whitsunday | | 6.621 | 153.058 | <0.001 | | |
| Fitzroy | | 1.002 | 7.907 | 0.005 | | |
| **Reef subtidal** | | | | | | |
| **% cover = s(date) + NRM** | 136 | | | | 0.759 | 0.767 |
| Cape York | | 8.383 | 343.732 | <0.001 | | |
| Wet Tropics | | 3.562 | 39.145 | <0.001 | | |
| Burdekin | | 3.435 | 7.905 | 0.085 | | |
| Mackay Whitsunday | | 6.489 | 46.83 | <0.001 | | |