# Port of Townsville Seagrass Monitoring Program 2025

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# Port of Townsville Seagrass Monitoring Program 2025

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# 1 KEY FINDINGS

**Seagrass Condition 2025**

**Poor**

The Port of Townsville Long Term Seagrass Monitoring Program (LTSMP) was established in 2007, with seagrass in the region monitored annually since. This report presents the results from the 19th year of the LTSMP.

At the end of 2025, seagrass in the Townsville region remained in an overall poor condition for the second consecutive year. Although seagrass spatial extent remained in satisfactory or better condition across most monitoring meadows, above-ground biomass remained low for most meadows (Figure 1). Despite this, seagrass remained widespread across the monitoring region, species composition was relatively stable and continued use by turtles and dugongs indicates that seagrass meadows remain ecologically important.

The observed decline in seagrass condition over recent years is likely due to cumulative, climate-driven pressures affecting the Townsville region, rather than localised anthropogenic activity. Limited recovery windows between successive climate disturbances, including high rainfall, flooding, and wind- and wave-driven resuspension, have likely further constrained the recovery of seagrass meadows in the region.

Key findings of the 2025 seagrass monitoring include:

- Overall, meadow condition remained poor at the end of 2025.
  - Most monitoring meadows were classified as poor or very poor, with only three meadows in satisfactory or better condition (Figure 1), compared with four meadows in 2024.
  - Overall meadow area remained relatively stable across most locations between 2024 and 2025, with most meadows maintaining satisfactory or better spatial extent despite low biomass (Figure 1).
  - The species composition indicator remained relatively stable, and eight seagrass species were recorded during 2025 surveys, similar to the 2024 surveys.
- The widespread seagrass decline observed in recent years is consistent with cumulative, system-wide climatic pressures rather than localised anthropogenic related impacts.
- Key drivers of seagrass change have included:
  - Elevated rainfall and river discharge: Above-average rainfall during the 2018/19, 2021/22, 2022/23 and 2024/25 wet seasons, including record flooding in January–February 2019 and exceptionally high discharge during February–March 2025, resulted in sustained freshwater input, sediment delivery and reduced light availability across the region.
  - Prolonged low-light conditions as evidenced through the Marine Water Quality Monitoring Program: Widespread climate-linked low-light conditions across multiple years, leading to limited photosynthetic productivity and seagrass biomass accumulation.
  - Tropical cyclones and intense weather systems: Tropical Cyclone Jasper (December 2023), Tropical Cyclone Kirrily (January 2024), and a strong low-pressure system in January–February 2025 generated wind driven elevated turbidity, sediment resuspension and physical disturbance.
  - Extreme temperature events and marine heatwaves between 2019 and 2024: 2019 (Australia's hottest year on record (GBRMPA)), record-high sea surface temperatures in February 2020 (GBR Outlook Report 2024), and above-average summer sea temperatures in 2021/22 and 2023/24 contributed to physiological stress in seagrass meadows (GBR Outlook Report 2024).

Despite declines in seagrass biomass, several indicators remain positive. Spatial coverage of seagrass remained relatively extensive, species composition was largely intact, and higher light-requiring species persisted in subtidal meadows. Provided favourable environmental conditions return, these factors offer a foundation for recovery. In response to current meadow conditions, the Port of Townsville (PoTL) has commissioned an additional post-wet season survey in 2026 to reassess meadow status and recovery trajectory. A post-wet season survey was also completed in May 2025 (see McKenna et al. 2025a).

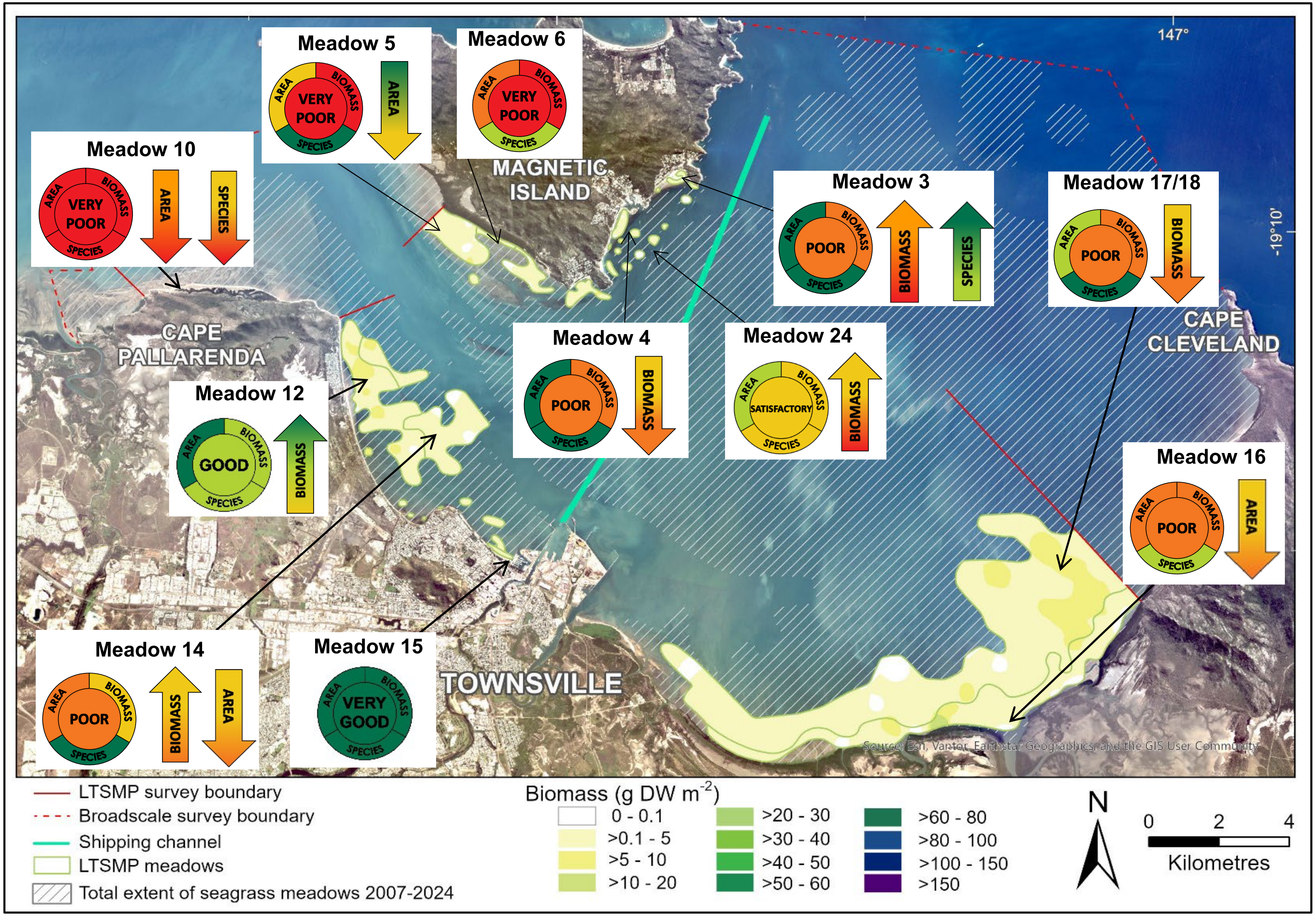



**Figure 1.** Seagrass condition for meadows monitored as part of the Townsville Long-Term Seagrass Monitoring Program (LTSMP), September/October 2025. Lack of arrows indicates no change in condition index from the previous year.

= very good condition = good condition = satisfactory condition = poor condition = very poor condition

# 2 INTRODUCTION

Seagrasses are among the most productive marine habitats and provide a variety of important ecosystem services (Costanza et al. 2014; do Amaral Camara Lima et al. 2023; Duarte et al. 2025). These services include providing nursery habitats for economically significant fish and crustaceans (Coles et al. 1993; Whitfield 2017), as well as serving as food for grazing marine megaherbivores such as dugongs and sea turtles (Tol et al. 2016; Scott et al. 2018; Cleguer et al. 2026). Seagrasses also play a key role in nutrient cycling and improving water quality (De Boer 2007; Azizova et al. 2025), carbon sequestration (Fourqurean et al. 2012; York et al. 2018), and sediment stabilisation (James et al. 2019; Infantes et al. 2022). Increasingly, seagrass ecosystems are recognised as critical to achieving global biodiversity and climate goals, supporting complex food webs while contributing to climate mitigation and coastal resilience (Duarte et al. 2025).

Globally, seagrasses have been declining due to natural and anthropogenic causes (Waycott et al. 2009; Dunic et al. 2021). This decline is driven by a combination of natural disturbances and anthropogenic pressures. Natural drivers include storms and cyclones, disease, and overgrazing by herbivores. Anthropogenic stressors include direct disturbance from coastal development, dredging and trawling; indirect effects through changes in water quality due to sedimentation, resuspension, pollution and eutrophication; and climate change, including ocean warming, marine heatwaves, sea-level rise and frequency and severity of tropical storms, which can interact with other stressors and exacerbate declines (Waycott et al. 2009; Dunic et al. 2021; Turschwell et al. 2021; Duarte et al. 2025). Global seagrass extent declined at rates of approximately 1-2 % per year during the twentieth century; however, improved management – particularly reductions in coastal water pollution – has led to stabilisation or recovery in some regions (Duarte et al. 2025). In the Great Barrier Reef (GBR) coastal region, hotspots with the highest threat exposure for seagrasses are located in the southern two-thirds of the GBR, where multiple threats accumulate, including urban, port, industrial, and agricultural runoff (Grech et al. 2011). These hotspots arise as seagrasses occur in the same sheltered coastal locations where ports and urban centres are established (Coles et al. 2015). In Queensland, this has been recognised, and a strategic monitoring program of these high-risk areas has been established to aid in their management (Coles et al. 2015).


**Figure 2.** Location of Queensland port seagrass monitoring sites.

Despite growing recognition of their ecological and socio-economic importance, substantial knowledge gaps remain, including uncertainties in seagrass distribution, long-term trends, and the effectiveness of conservation and restoration strategies (Duarte et al. 2025). Continued monitoring and targeted research are therefore essential to support evidence-based management to ensure the resilience of seagrass ecosystems under increasing environmental pressure.

## 2.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program has been established in most Queensland commercial ports. The program was developed by James Cook University's Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) in partnership with various Queensland port authorities. Although each location is funded separately, a common methodology and rationale are applied, creating a network of seagrass monitoring sites across Queensland (Figure 2).

This long-term strategic assessment and monitoring program for seagrasses offers port managers and regulators essential information on seagrass habitat and ecosystem function. This data is often vital for planning and executing port development and maintenance activities that minimise impact on seagrass.

The program offers ongoing assessments of many vulnerable seagrass communities in Queensland and contributes to regional evaluations of seagrass habitat conditions. It has also significantly advanced the science and understanding of tropical seagrass and habitat ecology. This includes developing tools, indicators, and thresholds for seagrass protection and management, as well as understanding the factors influencing seagrass change.

For more information on the program and reports from the other monitoring locations, see: https://www.tropwater.com/themes/seagrass-habitats.

## 2.2 Port of Townsville Seagrass Monitoring Program

The Townsville port is managed by Port of Townsville Limited (PoTL). The port is located in the Great Barrier Reef World Heritage Area, outside the Great Barrier Reef Marine Park. The area supports a diverse range of habitats, including important and productive seagrass meadows and reefs that start in the intertidal zone and extend into the deeper waters of Cleveland Bay. Townsville's seagrass meadows are a connectivity hotspot in the central GBR (Grech et al. 2016; Grech et al. 2018).

As part of its commitment to the environmental health of the port and surrounding areas, PoTL, in partnership with TropWATER's Seagrass Ecology Group, established the Long-term Seagrass Monitoring Program (LTSMP) in 2007 to assess and monitor seagrass habitat surrounding Townsville and Magnetic Island. Detailed baseline surveys conducted in 2007 and 2008 documented the distribution and abundance of seagrasses within the broader port limits (Rasheed and Taylor 2008). From these baseline surveys, representative monitoring meadows (Figure 3) were selected for annual monitoring. Broadscale mapping was undertaken in 2007, 2008, 2013, 2016, and annually from 2019 to 2024 (as part of the Channel Upgrade Seagrass Program). The selected monitoring areas represent the range of seagrass communities within the port and include meadows considered most likely to be influenced by port activity and development, as well as reference areas. At its largest extent, the program has mapped approximately 25,000 ha of coastal and deepwater seagrass in the broader Townsville region (2007; Figure 8).

Between 2019 and 2024, the LTSMP was expanded into a fit-for-purpose monitoring framework to meet regulatory requirements associated with the Channel Upgrade Project (CU Project), forming the Channel Upgrade Seagrass Program (CUSP). This CUSP incorporated the existing long-term monitoring framework while increasing survey frequency to biannual monitoring before, during, and after capital dredging works. With the completion of the CU Project, monitoring has now returned to the standard annual LTSMP.

The LTSMP regularly assesses seagrass condition in the area, providing an annual update on the marine environmental health of Cleveland Bay to support port management. The monitoring initiative is part of TropWATER's Queensland network of long-term sites that track significant seagrass habitats in high-risk zones. Information from the program also helps inform the condition and trends of habitats for the Healthy Waters Partnership Dry Tropics reporting (www.drytropicshealthywaters.org).

All seagrass reports from the Townsville seagrass monitoring programs can be found on the TropWATER website https://www.tropwater.com/reports-and-publications and the Port of Townsville website https://www.townsville-port.com.au/projects-development/channel-upgrade/environmental-monitoring/

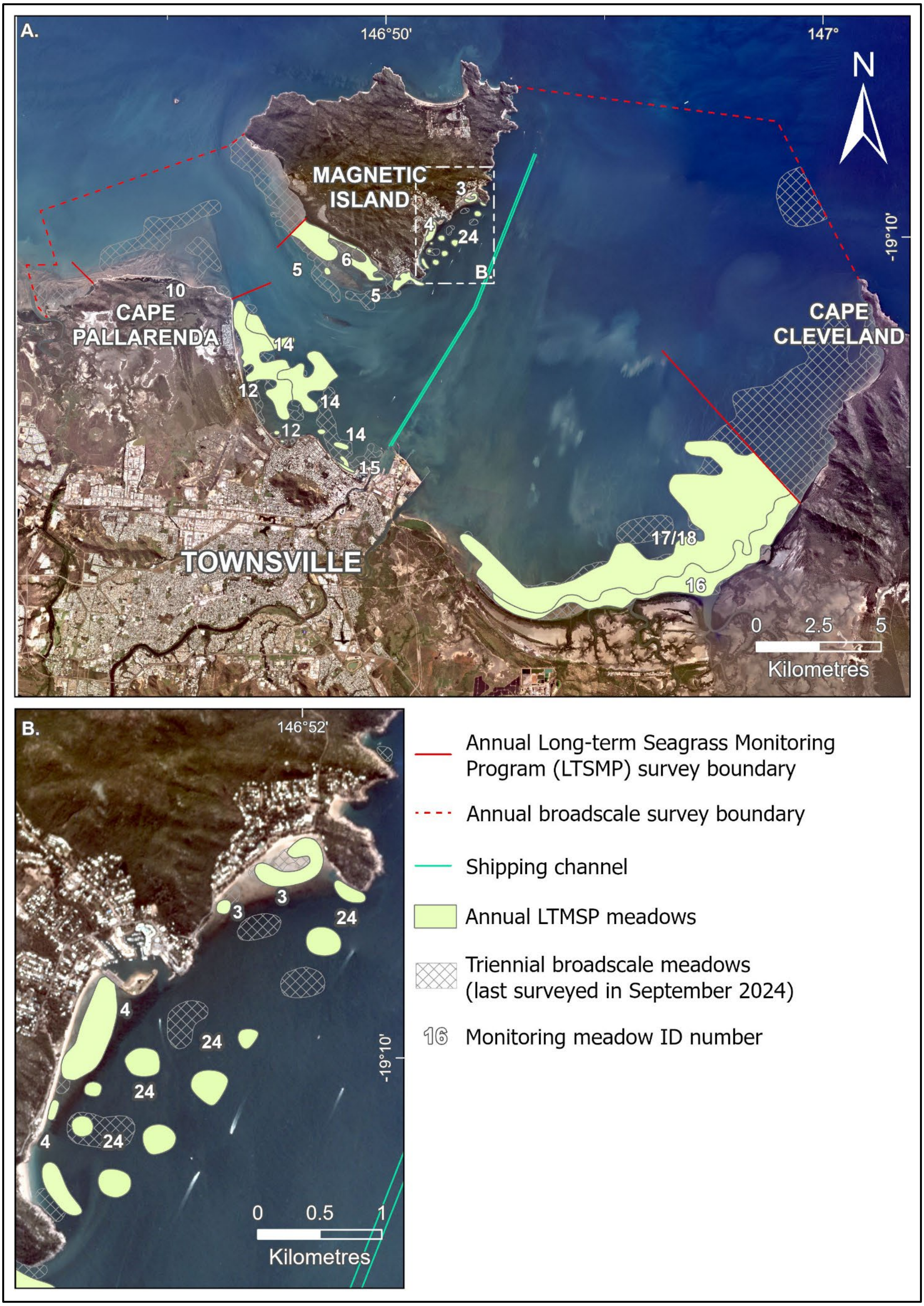



**Figure 3**. Location and survey extent of the annual LTSMP meadows (meadows shown are mapped from the September-October 2025 survey) and triennial broadscale survey extent (last mapped in 2024).

# 3 METHODS

## 3.1 Sampling approach

Survey and monitoring methods for assessing seagrass in the Townsville region follow the established techniques used for Townsville and JCU TropWATER's Queensland-wide seagrass monitoring programs. Using standardised methods across Townsville and Queensland enables direct comparison of local seagrass dynamics with other monitoring programs in the wider Queensland region.

Detailed methods and sampling approach for the program are in previous reports (Wells and Rasheed 2017; McKenna et al. 2022). The Townsville LTSMP has been assessing and monitoring 10 seagrass meadows in the region annually since 2007 (Table 1). In 2025, Meadow 24 (a subtidal meadow that spans Geoffrey Bay to Nelly Bay at Magnetic Island; assessed in 3-yearly broadscale surveys then annually as part of the CUSP) was included in the annual survey (Figure 5). It was included for additional representation of subtidal *Halophila* meadows in the region.

Seagrass assessments for the LTSMP take place each year between September and November, with broadscale surveys of the wider Townsville survey area (Figure 3) conducted every three years. Broadscale surveys were conducted in 2007, 2013 and 2016, before being undertaken annually from 2019–2024 as part of the CUSP. The next broadscale survey is scheduled to occur in 2027. Conducting assessments across the broadscale survey area ensures that trends observed in the annual monitoring meadows reflect the broader Townsville region and, conversely, changes in seagrasses across this larger area provide valuable context and confidence in the observed trends within the monitoring meadows. Within this broadscale survey extent, the highly variable deeper water seagrasses (>8 m) between Cleveland Bay and Magnetic Island (Meadow 19) are also assessed (Figure 3). Details on the LTSMP meadows are provided in Table 1.

**Table 1**. The seagrass meadows that make up the LTSMP, their monitoring location type, survey frequency, and the species present in the meadows.

| Monitoring location (Meadow ID) | Seagrass Meadow Depth | Dominant species of meadow | Seagrass species found within the meadow* | Monitoring History |
|---|---|---|---|---|
| **Yunbenun - Magnetic Island** | | | | |
| Geoffrey Bay (3) | Intertidal | *Halodule uninervis* | HU, HO, CS | Detailed Annual >10 years |
| Geoffrey Bay (24) | Subtidal | *Halophila spinulosa* | HS, HD, HO | 6 years biannual surveys |
| Nelly Bay (4) | Intertidal/shallow subtidal | *Halodule uninervis* | HU, HO, CS | Detailed Annual >10 years |
| Cockle/Picnic Bay (5) | Intertidal/shallow subtidal | *Halodule uninervis* | CS, HU, HO, HS, HD, SI | Detailed Annual >10 years |
| Cockle Bay (6) | Intertidal | *Zostera muelleri* | ZM, HU, HO | Detailed Annual >10 years |
| **The Strand to Cape Pallarenda / Shelley Beach** | | | | |
| Shelly Beach (10) | Intertidal | *Zostera muelleri* | ZM, HU, HO | Detailed Annual >10 years |
| Rowes Bay (12) | Intertidal/shallow subtidal | *Halodule uninervis* | HU, HO, HD, ZM, HS, CS | Detailed Annual >10 years |
| Pallarenda (inc. Virago Shoal) (14) | Shallow subtidal | *Halophila spinulosa* | HS, HU, HO, HD, CS | Detailed Annual >10 years |
| Strand (15) | Intertidal/shallow subtidal | *Halodule uninervis* | HU, HO, HD, ZM, HS | Detailed Annual >10 years |
| **Cleveland Bay (east side of Bay)** | | | | |
| Cleveland Bay (16) | Intertidal | *Zostera muelleri* | ZM, HU, CS | Detailed Annual >10 years |
| Cleveland Bay (17/18) | Subtidal | *Halodule uninervis* | HU, CS, HD, HS | Detailed Annual >10 years |

*HU – *Halodule uninervis*, HO - *Halophila ovalis*, HD - *Halophila decipiens*, HS – *Halophila spinulosa*, HT – *Halophila tricostata*, ZM – *Zostera muelleri*, CS – *Cymodocea serrulata,* SI – *Syringodium isoetifolium*

## 3.2 Seagrass indicators and sampling methods

Three principal indicators of seagrass condition are assessed at each survey: seagrass above-ground biomass (grams dry weight per metre square, g DW $m^{-2}$), species composition, and meadow area (ha). These are fundamental indicators used to answer questions about seagrass condition, such as whether seagrass is present, the spatial extent of the meadow, its density, and the species that define it (Carter et al. 2023).

Sampling methods include (Figure 4):

1. *Intertidal seagrass:* helicopter survey of exposed banks during spring low tide: sites were spread across the seagrass meadow and sampled by a trained observer when the helicopter hovered close to the substrate (<1 m above the ground).
2. *Shallow subtidal seagrass:* boat-based video camera vertical drops: A high-definition camera with a wide-angle lens was attached to a 'drop' frame. Footage was relayed to a screen on the vessel for real-time data analysis and recorded as needed. Assessment sites were sampled randomly within survey boundaries, approximately every 50-200 m or where significant changes in the bottom topography and seagrass community occurred. Assessment sites extended to the offshore edge of seagrass meadows or 'hard' survey boundaries.
3. *Deep-water seagrass:* boat-based towed video camera transects: Towed video transects employed a high-definition camera with a wide-angle lens. The camera and a net were attached to a sled and then towed approximately 100 m at drift speed. Footage was relayed to a screen on the vessel for real-time data analysis, and footage was recorded when necessary. Surface benthos collected with a towed net helped confirm the seagrass species observed on the real-time screen. This technique ensured that a large area of the seafloor was surveyed at each site, enabling the detection of patchily distributed seagrass and benthic life typically present in deep-water habitats.

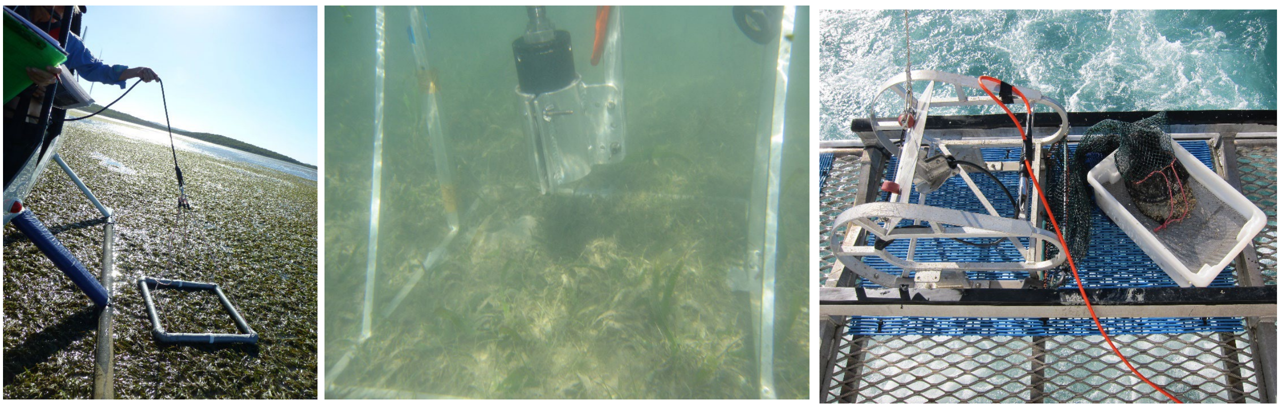


**Figure 4.** Different seagrass monitoring techniques include helicopter aerial surveillance, boat-based digital systems, and live feed camera systems.

Seagrass above-ground biomass was determined using a visual estimate of biomass technique (Mellors 1991; Kirkman 1996). Seagrass percentage cover was estimated using internationally recognised cover standards (www.seagrasswatch.org/manuals).

For consistency with the long-term monitoring approach, *Cymodocea serrulata* is excluded from calculations of mean meadow above-ground biomass and species composition for Meadows 3 and 4 on Magnetic Island. These meadows are characterised by *Halodule uninervis*, while the much larger and higher-biomass *C. serrulata* occurs in isolated patches. As assessment sites are distributed haphazardly throughout the meadows, occasional sampling of these patches can disproportionately influence mean meadow biomass and species composition and potentially mask year-to-year changes in the more widespread *H. uninervis*. Similarly, *Enhalus acoroides*, which has a substantially greater biomass than the smaller seagrass species that characterise Meadows 5 and 6 at Cockle Bay, is excluded from these calculations where it occurs as isolated plants or patches. The presence and abundance of *C. serrulata* and *E. acoroides* are still recorded at all survey sites; they are only excluded from the calculation of these meadow-level indicators. This analytical treatment has been applied consistently through the long-term monitoring program, and in other port programs, to enable comparable assessment of temporal changes in the seagrass communities that characterise these meadows.

## 3.3 Seagrass condition assessments, index, and meadow baselines

A condition index was developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area, and species composition relative to a 10-year baseline (Carter et al. 2023). Seagrass condition for each indicator in each meadow is rated from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor), and E (very poor). The overall meadow condition is determined by the lowest indicator score, whether it was above-ground biomass or area. When species composition scored the lowest, it contributes 50% to the total meadow score, with the next lowest indicator (area or above-ground biomass) contributing the remaining 50% (Carter et al. 2023).

We have previously established baseline conditions for seagrass meadow above-ground biomass, area, and species composition at the original ten LTSMP meadows. The baseline for Meadow 24 (Geoffrey Bay subtidal meadow) currently includes nine years of historical data as of this report. Baseline conditions for Meadow 24 will continue to be updated with additional years of monitoring data as appropriate until a total of 10 years of data are incorporated into the baseline analysis.

## 3.4 Habitat mapping and Geographic Information System

All survey data were entered into the Port of Townsville Limited Geographic Information System (GIS) database using ArcPro®. GIS layers were created to describe the region's spatial features: a site layer, seagrass meadow layers, and seagrass above-ground biomass interpolation layers.

- *Site Layer:* The site (point) layer contains data collected at each site, including:
  - Unique site number.
  - Temporal details – survey date and time.
  - Spatial details – latitude and longitude, depth below mean sea level (dbMSL; metres) for subtidal sites.
  - Habitat information – sediment type; seagrass information including presence/absence, above-ground biomass (total and for each species) and above-ground biomass standard error (SE); percentage cover of seagrass, algae, and open substrate; presence/absence of dugong feeding trails (DFTs).
  - Sampling method and any relevant comments.
- *Meadow layers:* The meadow (polygon) layer provides summary information for all sites within each meadow, including:
  - Temporal details – survey date.
  - Habitat information – depth category (intertidal/subtidal), mean meadow above-ground biomass + standard error (SE), meadow area (hectares) + reliability estimate (R), number of sites within the meadow, seagrass species present, meadow density and community type, meadow landscape category.
  - Meadow identification number – a unique number assigned to each monitoring meadow to allow comparisons among surveys.
  - Sampling method and any relevant comments.
- *Interpolation layers*: The interpolation (raster) layer describes spatial variation in seagrass above-ground biomass across each meadow and was created using an inverse distance weighted (IDW) interpolation of seagrass site data within each meadow.

Seagrass meadow community type, meadow density (light, moderate, dense), and meadow landscape categories (isolated seagrass patches, aggregated patches, and continuous cover) were described using a standard nomenclature system developed for Queensland's seagrass meadows. Details of this approach are in previous reports (McKenna et al. 2022).

Seagrass meadow boundaries were established using GPS-marked boundaries where available, alongside site data on seagrass presence or absence, field notes, colour satellite imagery of the survey region (Source: ESRI), depth contours, and aerial photographs taken during helicopter surveys. The meadow area was calculated using the calculate geometry function in ArcPro®. Meadows were given a mapping precision estimate (in metres) based on the mapping methods used for each meadow (Table 2). This precision estimate was utilised to create a buffer around each meadow, representing potential error; the area of this buffer is expressed as a meadow reliability estimate (R) in hectares.

**Table 2.** Mapping precision and methodology for mapping the monitoring meadows in Townsville, 2025.

| Mapping precision | Mapping methodology |
|---|---|
| 3-20 m | Intertidal meadows completely exposed or visible at low tide.<br>Inshore meadow boundaries determined from helicopter.<br>Offshore meadow boundaries determined from helicopter and/or camera.<br>Relatively high density of mapping and survey sites.<br>Recent aerial imagery aided in mapping. |
| 20-50 m | Meadow boundary interpreted from free camera surveys.<br>Most meadows are partially or completely subtidal.<br>Moderate density of survey sites.<br>Recent aerial imagery aided in mapping. |
| 100 m | Subtidal meadow boundaries determined from camera/van veen grab/distance between survey sites/presence/absence of seagrass.<br>Meadows subtidal.<br>Moderate – sparse density of survey sites.<br>Deepwater meadows determined from camera tows. |

## 3.5 Environmental data

Data for time-series plots of rainfall (mm), air temperature (°C), and wind speed (km/hr) are publicly available on the Australian Bureau of Meteorology website (http://www.bom.gov.au/climate/data/), sourced from the Townsville Airport weather station (#032040), and are presented in Section 4.4. Wind speed data (km/hr) was also obtained from the Australian Institute of Marine Science (AIMS) Cleveland Bay weather station (-19.4 S, 146.9 E). River flow data for the time series plots were sourced from the Queensland Government's Water Monitoring Information Portal (https://water-monitoring.information.qld.gov.au/). Tidal data used in tidal exposure time series plots were provided by Maritime Safety Queensland (MSQ) for Townsville Berth 1 Pumphouse (MSQ station #100447).

Photosynthetically Active Radiation (PAR) and seabed temperature data were provided by the Port of Townsville from seabed loggers deployed at Cleveland Bay (subtidal), Cockle Bay (intertidal), Florence Bay (subtidal), Geoffrey Bay (subtidal), The Strand (subtidal), and Virago Shoals (subtidal).

## 3.6 Statistical analysis

Seasonal (post-wet and pre-wet/dry season) differences in mean above-ground biomass and meadow area were assessed using linear mixed-effects models in R (R Core Team 2020) using the packages lme4 (Bates et al. 2009) and lmerTest (Kuznetsova et al. 2017).

Biomass and area data were log-transformed (log(x + 0.001)) to improve normality and homogeneity of variance. Models were fitted with Season (post-wet season: May-June; pre-wet/dry season: September-November) and Meadow ID as fixed effects, including their interaction, and Year included as a random intercept to account for repeated measures through time.

Type III Analysis of Variance with Satterthwaite's approximation was used to evaluate fixed effects. Where appropriate, estimated marginal means and pairwise seasonal contrasts within meadows were calculated using the emmeans package (Lenth 2020), with Holm-adjusted p-values applied for multiple comparisons. All graphs were visualised using the ggplot2 package (Wickham 2016).

Seasonal comparisons used the standardised biannual survey boundaries applied between 2019 and 2024 (McKenna et al. 2025b) to ensure spatial consistency among survey periods.

# 4 RESULTS

## 4.1 Seagrass in the Townsville long-term monitoring areas

In 2025, two monitoring surveys were conducted in the Townsville region, one in May and the other between September and October. Both surveys were completed at the LTSMP survey scope (Figures 3, 5).

Key findings of the 2025 surveys include:

- May 2025; post-wet season survey:
  - A total of 826 sites were assessed for seagrass condition, with seagrass present at 33% of sites (McKenna et al. 2025a).
  - The seagrass meadow footprint covered ~3,482 ha. This was a 23% decrease from the September/October 2024 meadow extent (McKenna et al. 2025b).

- September–October 2025; pre-wet/dry season survey (this survey):
  - A total of 652 sites were assessed for seagrass condition (Figure 5), with seagrass present at 42% of sites.
  - The seagrass meadow footprint covered ~4,254 ha. This was an 18% increase in footprint from the May 2025 survey (McKenna et al. 2025a), and a 7% decrease from the September/October survey in 2024 (McKenna et al. 2025b; Figure 8).
  - The Shelley Beach *Zostera muelleri* meadow was absent in this survey period.

Eleven seagrass species have been historically identified in the monitoring program (Figure 7). Except for *Syringodium isoetifolium*, *C. rotundata*, and *Halophila tricostata*, all other species (eight) were present at assessment sites or recorded in the area during the 2025 surveys. *S. isoetifolium* was last recorded in 2015, while *C. rotundata* was last observed in 2021. *H. tricostata* was last found in the deepwater meadow (Meadow 19) in 2022.

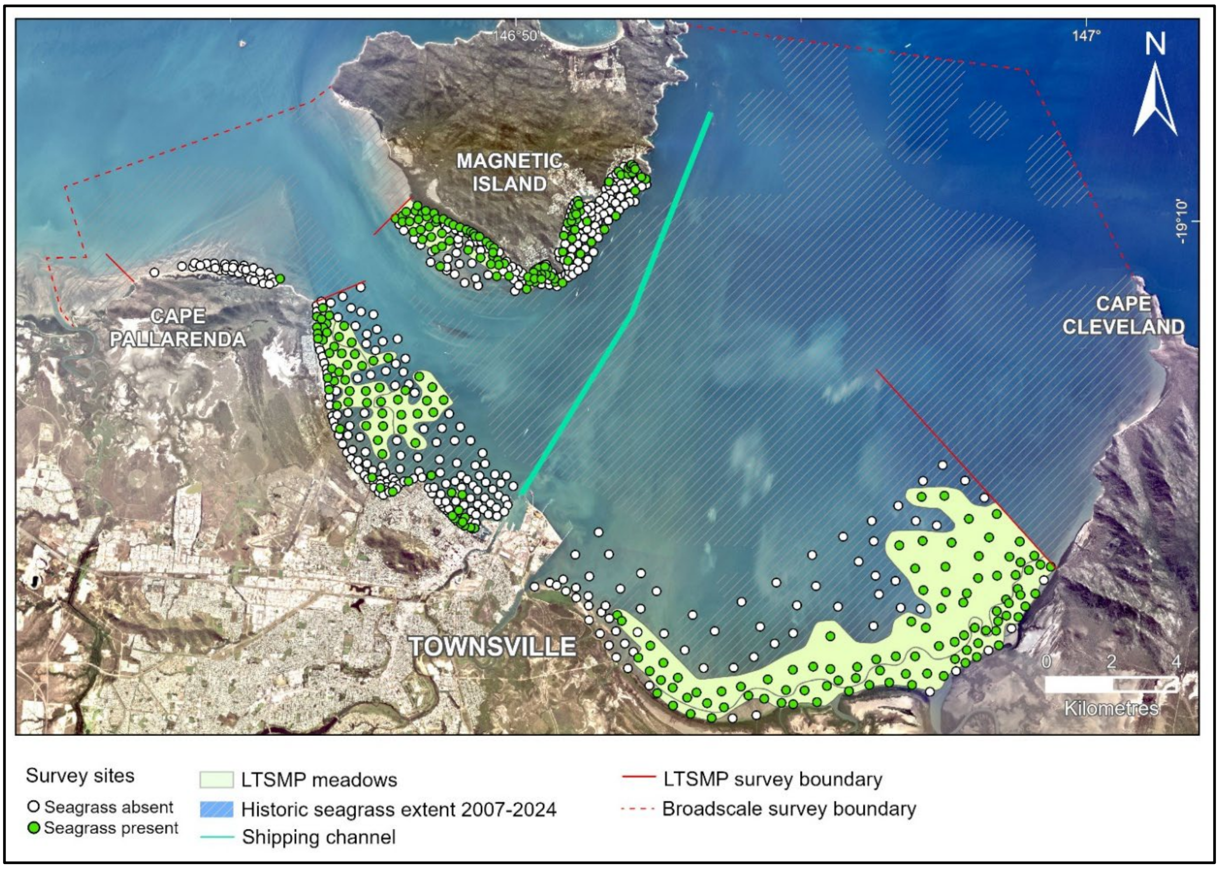



**Figure 5:** Location of benthic habitat assessment sites showing seagrass presence/absence, and extent of mapped seagrass meadows in the September/October 2025 Townsville Long-Term Seagrass Monitoring Program.

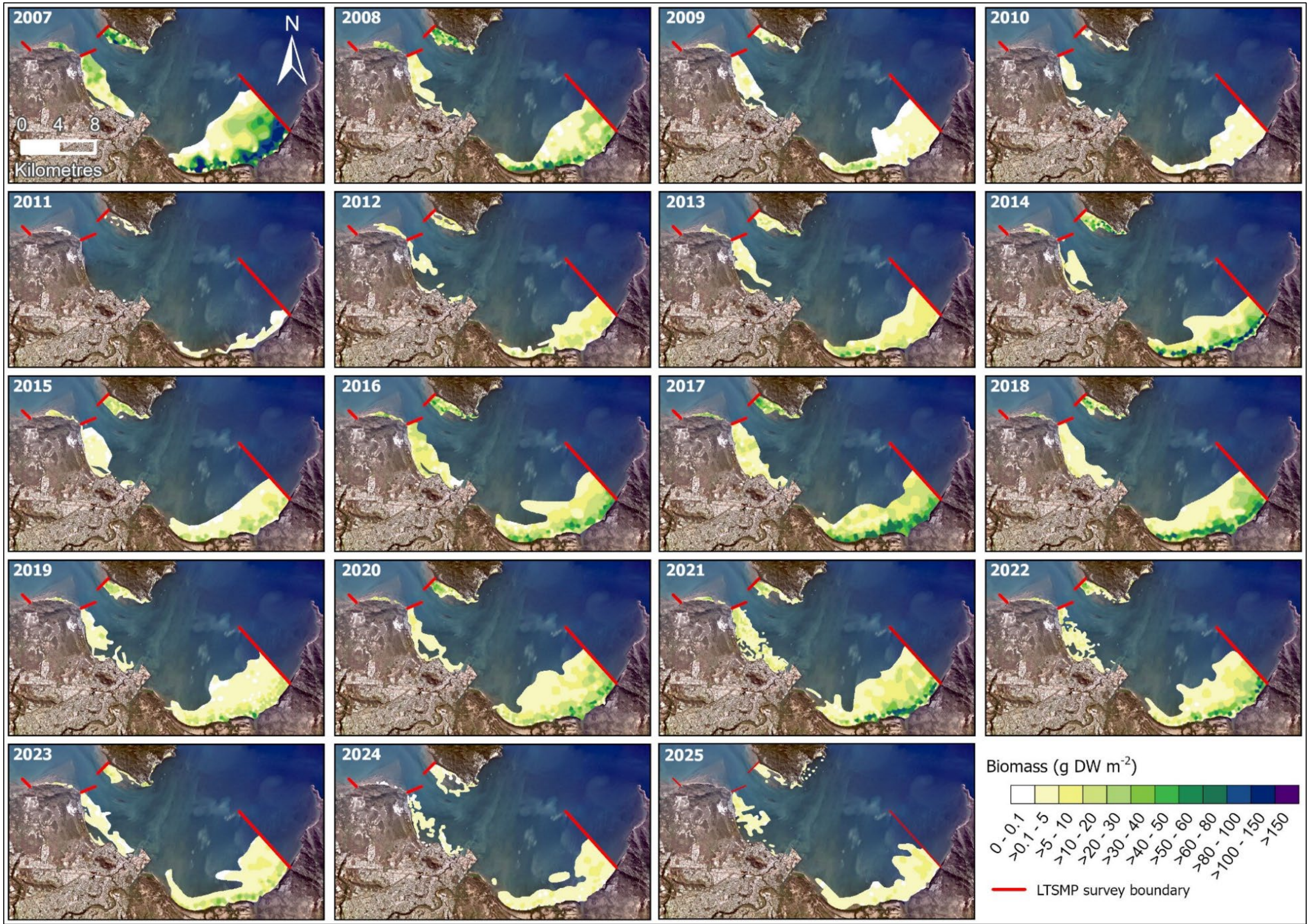



**Figure 6.** Long-Term Seagrass Monitoring Program (LTSMP) meadow above-ground biomass (g DW $m^{-2}$), location, and spatial extent of meadows from 2007 – 2025. Note: deepwater meadow (19) in the middle of Cleveland Bay is not displayed and the Geoffrey Bay subtidal meadow (24) is displayed for the first time in the LTSMP.

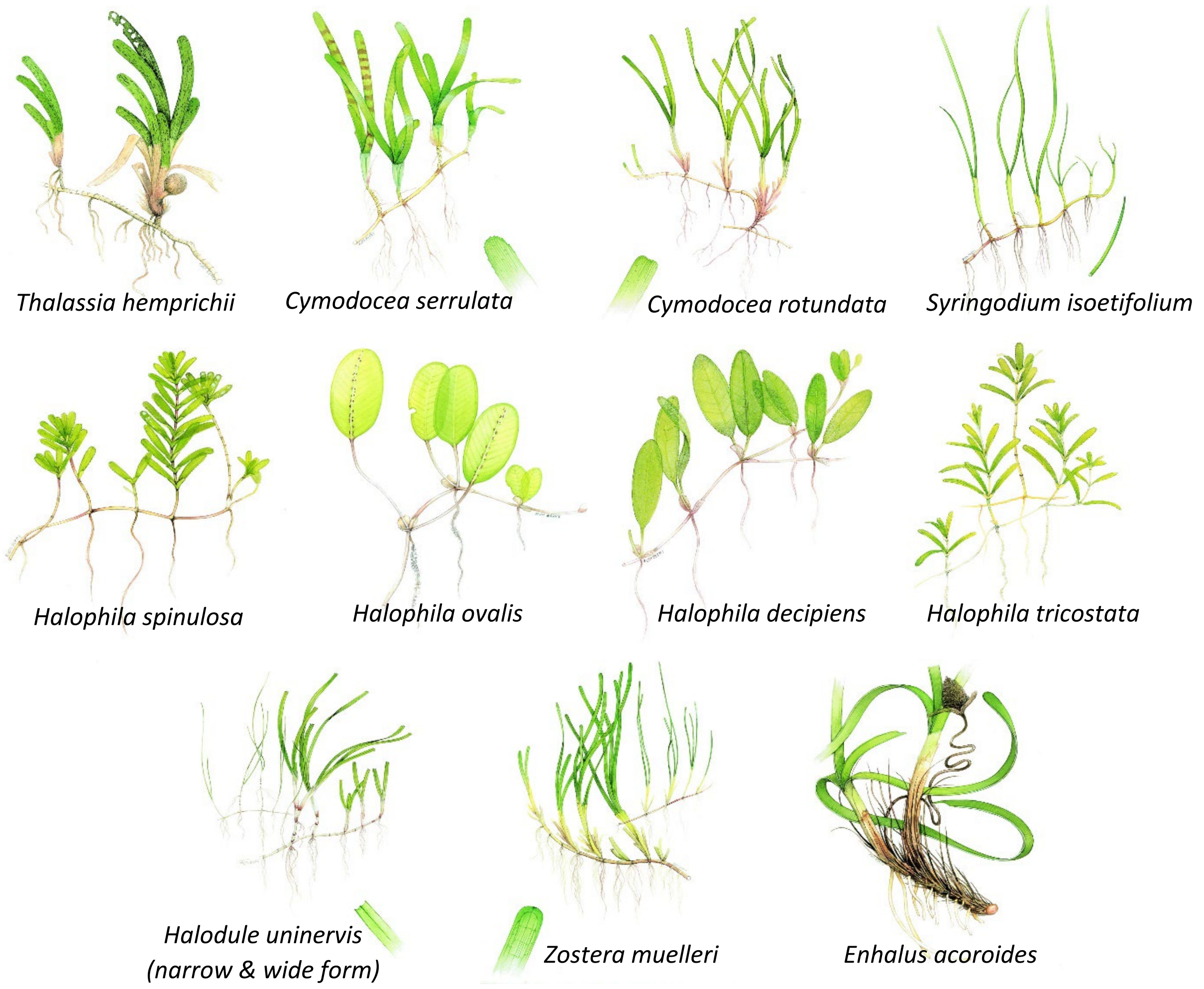



**Figure 7**. Seagrass species that have been identified in the Townsville seagrass monitoring program since 2007. Pictures are not to scale.

## 4.2 Seagrass condition in Townsville long-term monitoring areas

Townsville seagrass meadows were in an overall poor condition at the end of 2025 (Table 3). The poor condition was primarily driven by low above-ground biomass across most long-term monitoring meadows (64%) and the absence of the Shelley Beach *Z. muelleri* monitoring meadow. Of all meadows, three were classified as being in satisfactory or better condition, while eight were in poor or very poor condition (Table 3). The inshore meadow along the Strand (Meadow 15) was the only meadow in very good condition across all indicators at the end of 2025 (Table 3).

Mean meadow biomass was the poorest-performing condition indicator, with only two meadows in the Cape Pallarenda/Strand area (Meadows 12 and 15) recording biomass levels above their long-term baselines during the 2025 survey (Figures 17, 19). In contrast, the area of long-term monitoring meadows remained relatively stable, with most meadows classified as being in good or very good condition for this indicator. Meadow area represented the largest overall indicator increase during this survey period. Species composition was also comparatively stable, with all but two monitoring meadows having satisfactory or better species composition condition (Table 3).

Individual monitoring meadow areas ranged from being absent in the intertidal *Z. muelleri* meadow at Shelly Beach, Cape Pallarenda (Meadow 10; Figure 16) to 2,469 ha for the subtidal *H. uninervis* meadow at Cleveland Bay (Meadow 17/18; Figure 21). Over the same survey period, above-ground biomass across individual monitoring meadows ranged from absent in Meadow 10 to 2.40 g DW m$^{-2}$ in Meadow 17/18 (Figures 16 and 21).

**Table 3.** Grades and scores for seagrass indicators (above-ground biomass (gDWm$^2$), area (ha), and species composition for the Long-Term Seagrass Monitoring Program (LTSMP) meadows in Townsville; September–October 2025 survey.

| Meadow | Region | Above-ground Biomass score | Area score | Species Composition | LTSMP Overall Meadow Score |
|---|---|---|---|---|---|
| 3 | Magnetic Island | 0.43 | 0.87 | 1.00 | 0.43 |
| 4 | | 0.36 | 1.00 | 0.98 | 0.36 |
| 5 | | 0.23 | 0.60 | 0.96 | 0.23 |
| 6 | | 0.14 | 0.32 | 0.74 | 0.14 |
| 24 | | 0.56 | 0.66 | 0.63 | 0.56 |
| 10 | Cape Pallarenda - Strand | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | | 0.79 | 1.00 | 0.75 | 0.77 |
| 14 | | 0.52 | 0.49 | 0.92 | 0.49 |
| 15 | | 0.87 | 0.92 | 0.99 | 0.87 |
| 16 | Cleveland Bay | 0.25 | 0.47 | 0.75 | 0.25 |
| 17/18 | | 0.46 | 0.73 | 0.99 | 0.46 |
| **Overall Score for the Port of Townsville 2025** | | | | | **0.41** |

= very good condition = good condition = satisfactory condition

= poor condition = very poor condition

### 4.2.1 Magnetic Island seagrass meadows

Five monitoring meadows occur around Magnetic Island (Meadows 3, 4, 5, 6 and 24 (Figures 11–15), spanning intertidal to deeper-water habitats (>8 m below MSL). At the end of 2025, only one meadow (meadow 24) was in satisfactory condition, while the remaining four meadows were in poor or very poor condition relative to their long-term baselines (Table 3). Across all meadows, individual condition indicators (above-ground biomass, area, and species composition) ranged from very poor to very good (Table 3).

***Eastern Magnetic Island***

The Geoffrey Bay intertidal *H. uninervis* meadow (3) improved from very poor to poor, while the subtidal *H. spinulosa* meadow that spans Geoffrey Bay to Nelly Bay (24) improved from very poor to satisfactory. In both meadows, improvements were driven primarily by increases in above-ground biomass (Table 3; Figures 11 and 12). This survey marks the first time since 2021 that biomass and area have increased concurrently in these two meadows, a positive sign of some recovery. The remaining eastern monitoring meadow, the intertidal-shallow subtidal *H. uninervis* meadow in Nelly Bay (4), declined from overall satisfactory to poor condition during the current survey period (Table 3; Figure 13).

Increases in biomass for the Geoffrey Bay meadows were associated with increases in the dominance of *H. uninervis* in Meadow 3 and *H. spinulosa* in Meadow 24. However, the proportion of *H. spinulosa* in Meadow 24 remains below baseline levels. Despite these gains, seagrass biomass in both meadows remains low, with all but one assessment site recording less than 10 % cover and seagrass shoots remaining very short (Figure 8).

For the Nelly Bay intertidal meadow (4), seagrass above-ground biomass was the fourth-lowest recorded for the program, resulting in a poor condition score for this indicator (Figure 13). This was despite an increase in the presence of *H. uninervis* with wide-leaf morphology. Previously, this meadow had meadow biomass hotspots within its footprint that drove up overall biomass, and these were yet to return in 2025. The proportion of *H. uninervis* in the meadow declined from 2024 and was below baseline levels for the first time in seven years. While biomass had yet to return to baseline levels, there was expansion in meadow extent, particularly in the northern section of the meadow, reaching the highest area recorded historically.

For the Geoffrey Bay meadows, meadow area remained relatively stable, with area indicators very good or good. The subtidal Geoffrey Bay meadow (24) was more fragmented than in the previous survey, potentially increasing the risk of future area decline (Gera et al. 2013; Taylor et al. 2025).

Species composition remained in satisfactory condition for the subtidal Geoffrey Bay meadow (24) and was in very good condition in the two intertidal meadows; Geoffrey Bay (3) and Nelly Bay (4), recording both thin and wide *H. uninervis* morphologies.

Despite the low biomass and limited area of Meadow 3, a small number of dugong feeding trails were observed during this survey.

Seagrass was recorded to 9.6 m below MSL in Geoffrey Bay, consistent with observations from the previous year. Seagrass has previously been recorded at depths of up to 11.2 m below MSL in this meadow.

Baseline values for all condition indicators in the Geoffrey Bay subtidal meadow (24) are still being established because fewer than 10 years of data are currently available. Consequently, some condition scores may continue to vary as the baseline is refined.

**Figure 8:** the intertidal monitoring meadow at Geoffrey Bay, Magnetic Island (Meadow 3), recorded low mean meadow above-ground biomass of *H. uninervis*, with percent cover not exceeding 10 % at most assessment sites.

***Cockle Bay***

The two Cockle Bay monitoring meadows (located between Picnic Bay and Bolger Bay); the intertidal to shallow subtidal *H. uninervis* meadow (Meadow 5; Figure 14) and the intertidal *Z. muelleri* meadow (Meadow 6; Figure 15), remained in very poor condition at the end of 2025. This was principally due to low biomass, with both meadows having similar above-ground biomass to that observed in 2011 (following TC Yasi) and showing no change from the previous survey.

Meadow 5 declined substantially in area, from very good to poor. There was a substantial reduction and increased fragmentation along the seaward edge of the meadow (Table 3; Figure 14). This *H. uninervis* monitoring meadow is now at its lowest recorded area and biomass since the TC Yasi period. Despite declines in area and biomass, the meadow maintained a very good species composition.

The intertidal *Z. muelleri* meadow that runs adjacent to the mangroves in Cockle Bay (6) continued to be in very poor condition due to its low biomass, with limited *Z. muelleri* recorded across this section of Magnetic Island (Table 3; Figure 15). Meadow extent has varied throughout the monitoring program (Figure 15), largely reflecting the variable presence or absence of isolated *Z. muelleri* patches during aerial mapping of the meadow's seaward boundary.

Dugong feeding trails were not observed within the Meadow 5 survey boundary, however, feeding trails were observed further northwest near Bolger Bay (pers. comm., McKenna 2026).

### 4.2.2 Cape Pallarenda–Strand seagrass meadows

Four monitoring meadows are assessed in the Cape Pallarenda–Strand/Breakwater Marina region (Meadows 10, 12, 14 and 15; Figures 16–19). At the end of 2025, meadow condition ranged from very poor (Shelley Beach Meadow 10) to very good (The Strand Meadow 15) (Table 3). Across the region, individual condition indicators (above-ground biomass, area, and species composition) also spanned the full range from very poor to very good at individual meadows (Table 3; Figures 16-19).

The most notable decline in this region occurred in the intertidal Shelley Beach *Z. muelleri* meadow (10). This monitoring meadow was completely absent in 2025 for the first time in the monitoring program, continuing the downward trend observed over recent years (Table 3; Figures 9, 16). The presence of *Z. muelleri* in this section of the coast has been declining since 2017. Broader aerial reconnaissance assessments from Cape Pallarenda to the northern side of the Bohle River and across the entire breadth of the exposed sandbanks only found one small patch of *H. uninervis* at the Cape Pallarenda end (Figure 9; fluorescent green polygon) and a few small patches of *Z. muelleri* on the northern side of the Bohle River. None of the 31 assessment sites contained *Z. muelleri* during this survey (Figure 16), and only one site recorded the presence of seagrass (*H. uninervis*).

In contrast, the intertidal-shallow subtidal *H. uninervis* meadow between Rowes Bay and Cape Pallarenda (12) was in an overall good condition, with an improvement in biomass in 2025 (Table 3; Figure 17). Meadow area reached its highest recorded level in the monitoring program, maintaining a very good condition, with reduced fragmentation across the northern section contributing to this increase. There was however, increased fragmentation of the meadow in Rowes Bay (Figure 17). The mean biomass of the meadow improved from satisfactory to good condition in this survey. Species composition remained in good condition, with minimal change in the proportions of dominant species.

No dugong feeding trails were observed within these long-term monitoring meadows during this survey. Historically, the Cape Pallarenda and Shelley Beach region has been a high-use area for dugongs.

The other large subtidal meadow that borders Meadow 12 and extends from the Breakwater Marina to Cape Pallarenda (Meadow 14) remained in poor condition (Table 3; Figure 18). This was primarily due to persistently low above-ground biomass (Table 3; Figure 18). Meadow extent has declined over the past two years and is now positioned at the boundary between satisfactory and poor condition. Increasing fragmentation was recorded along the southern end of the meadow. Species composition remains in very good condition, with *H. uninervis* continuing to dominate over *H. spinulosa*. *H. spinulosa* has had a lower presence in the meadow since 2021 but has re-established after being absent in the previous survey (Figure 18; Appendix 1).

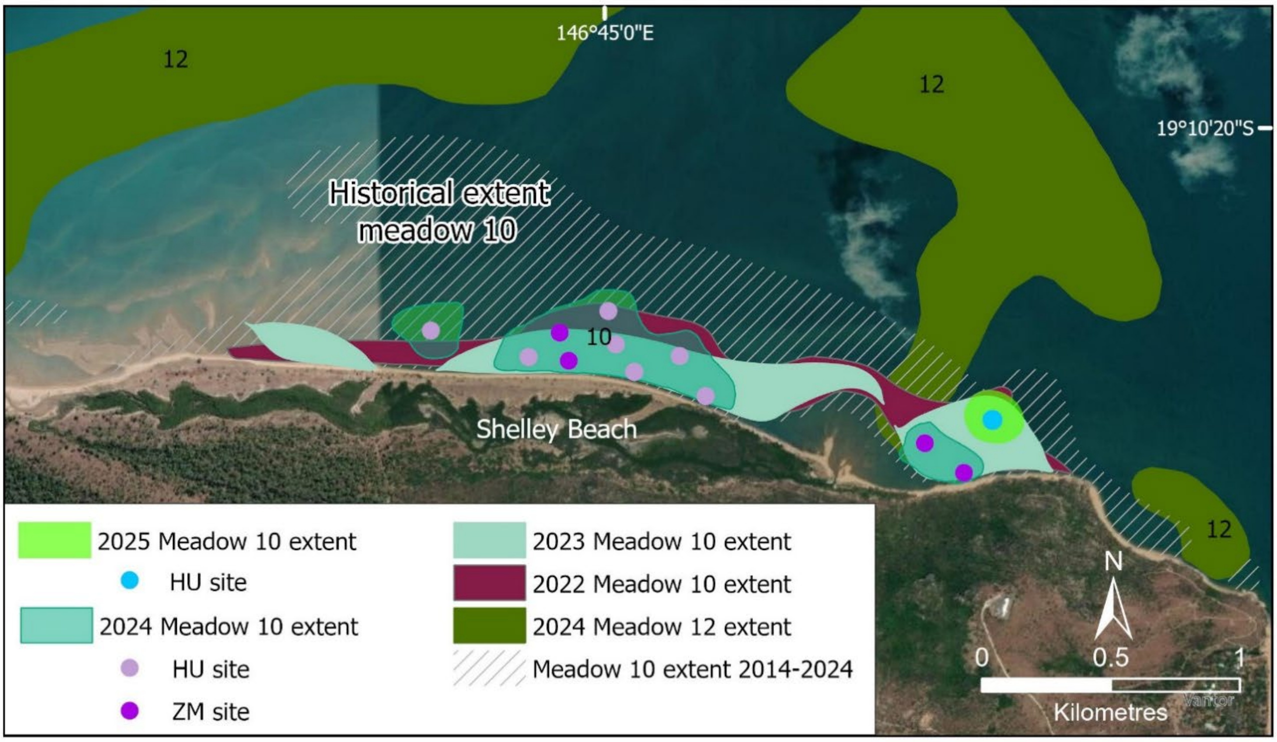



**Figure 9.** Seagrass spatial extent and footprint in the Shelley Beach meadow (Meadow 10) (2014–2025), showing the retraction of seagrass and species change recorded in 2025.

The intertidal strand meadow extending between the Mariner rock wall and the second sea groyne (Meadow 15) was the only long-term monitoring meadow in very good condition at the end of 2025 (Table 3; Figure 19). All condition indicators (biomass, area and species composition) were in very good condition. Species composition remained stable, with *H. uninervis* maintaining dominance. Numerous dugong feeding trails were observed within this meadow (Figure 10).


**Figure 10:** Dugong feeding trails in the intertidal *Halodule uninervis* dominant meadow at the southern end of The Strand, Townsville, during the September-October 2025 annual long-term seagrass monitoring surveys.

### 4.2.3 Cleveland Bay seagrass meadows

Two monitoring meadows occur within the Cleveland Bay region: the intertidal *Z. muelleri* meadow (Meadow 16) and the shallow subtidal *H. uninervis* meadow (Meadow 17/18) (Figures 20, 21). These represent the largest continuous coastal meadows in Townsville (Figure 6).

The intertidal *Z. muelleri* meadow (16) remained in poor condition for the second consecutive year, due to poor meadow biomass (Table 3; Figure 20). Area of the meadow also declined, with the indicator changing from satisfactory to poor, continuing a downward trend evident since 2018. The decline in meadow biomass corresponds to a continued decline in the proportional dominance of *Z. muelleri*. Historically, this meadow exhibits cyclical biomass peaks and troughs every 3 to 4 years; however, current biomass levels are approaching the lows recorded after TC Yasi in 2011. A notable shift over recent years has been the loss of high-density biomass 'hotspots' within the meadow. These have declined from assessment sites recording up to ~100 g DW $m^{-2}$ in 2022 to ~34 g DW $m^{-2}$ in 2023, then ~9 and 13 g DW $m^{-2}$ in 2024 and 2025 respectively.

Numerous dugong feeding trails were recorded within this meadow. Feeding trails are not often seen in this monitoring meadow. This may reflect the higher proportion of *H. uninervis* in the meadow; a preferred foraging species for dugong, compared to *Z. muelleri*.

The adjacent subtidal meadow (17/18) declined from an overall score of satisfactory in 2024 to poor at the end of 2025 (Table 3; Figure 21). This was due to a reduction in above-ground biomass for the third consecutive year. The biomass indicator dropped from satisfactory to poor, although it remained composed of the normally dominant *H. uninervis* (Figure 21; Appendix 1). The extent of the meadow remained in good condition. Species composition has remained very good since 2014, despite the continued decline in the presence of *C. serrulata* (Appendix 1), which is likely contributing to the overall biomass decline. This species has been present in the meadow since 2015 but had declined to a single assessment site in this survey (Appendix 1). Seagrass was detected down to 3.3m below mean sea level, consistent with previous surveys.

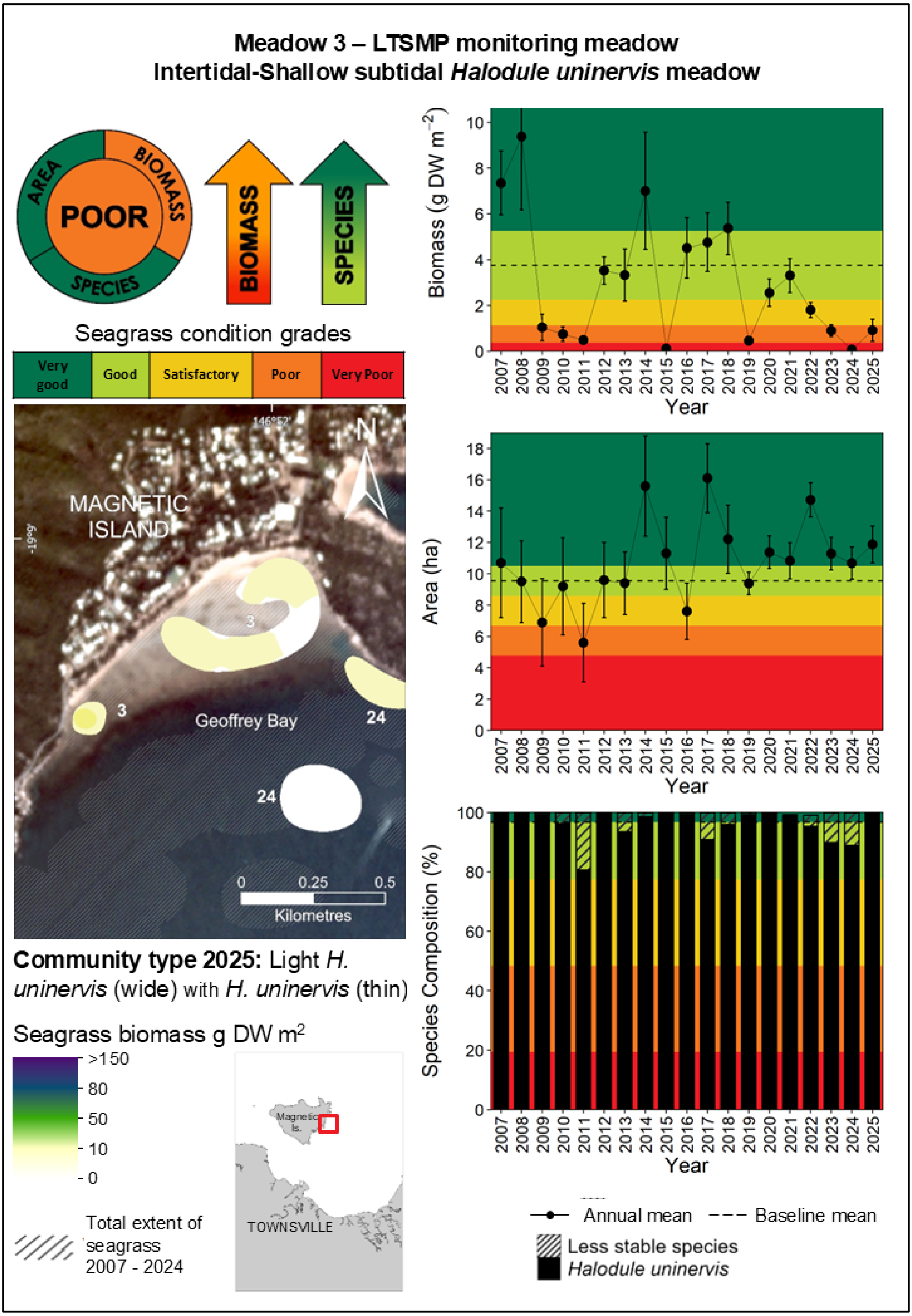



**Figure 11**. Changes in meadow area (ha), above-ground biomass (gDWm$^{-2}$), and species composition for seagrass in long-term monitoring Meadow 3 at Magnetic Island, 2007–2025. (Above-ground biomass error bars = SE; area error bars = R (reliability estimate)). Lack of arrows indicates no change in condition index from the previous year.

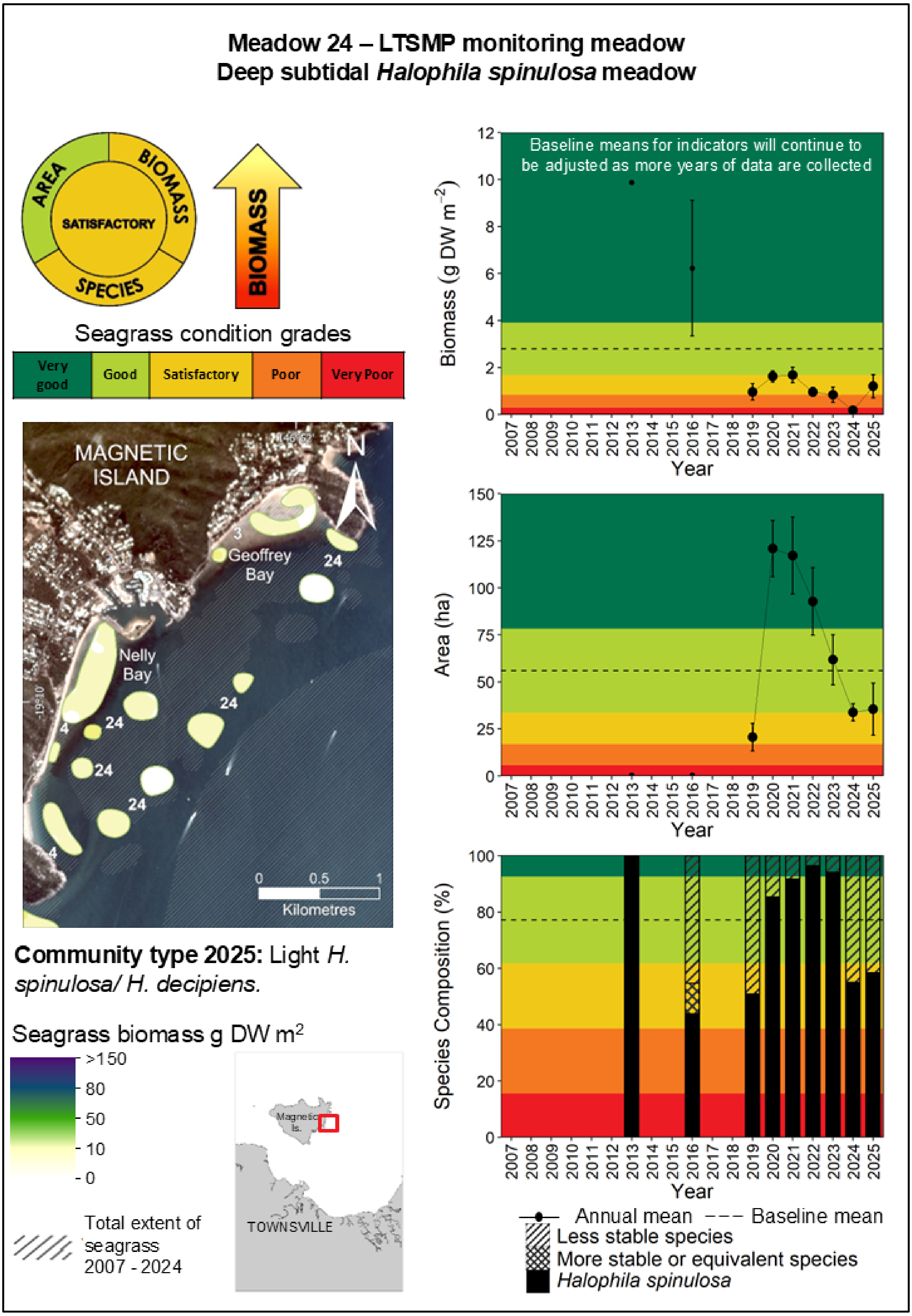



**Figure 12**. Changes in meadow area (ha), above-ground biomass (gDWm$^{-2}$), and species composition for long-term monitoring Meadow 24 at Magnetic Island, 2007–2025. (Above-ground biomass error bars = SE; area error bars = R (reliability estimate)). Lack of arrows indicates no change in condition index from the previous year.

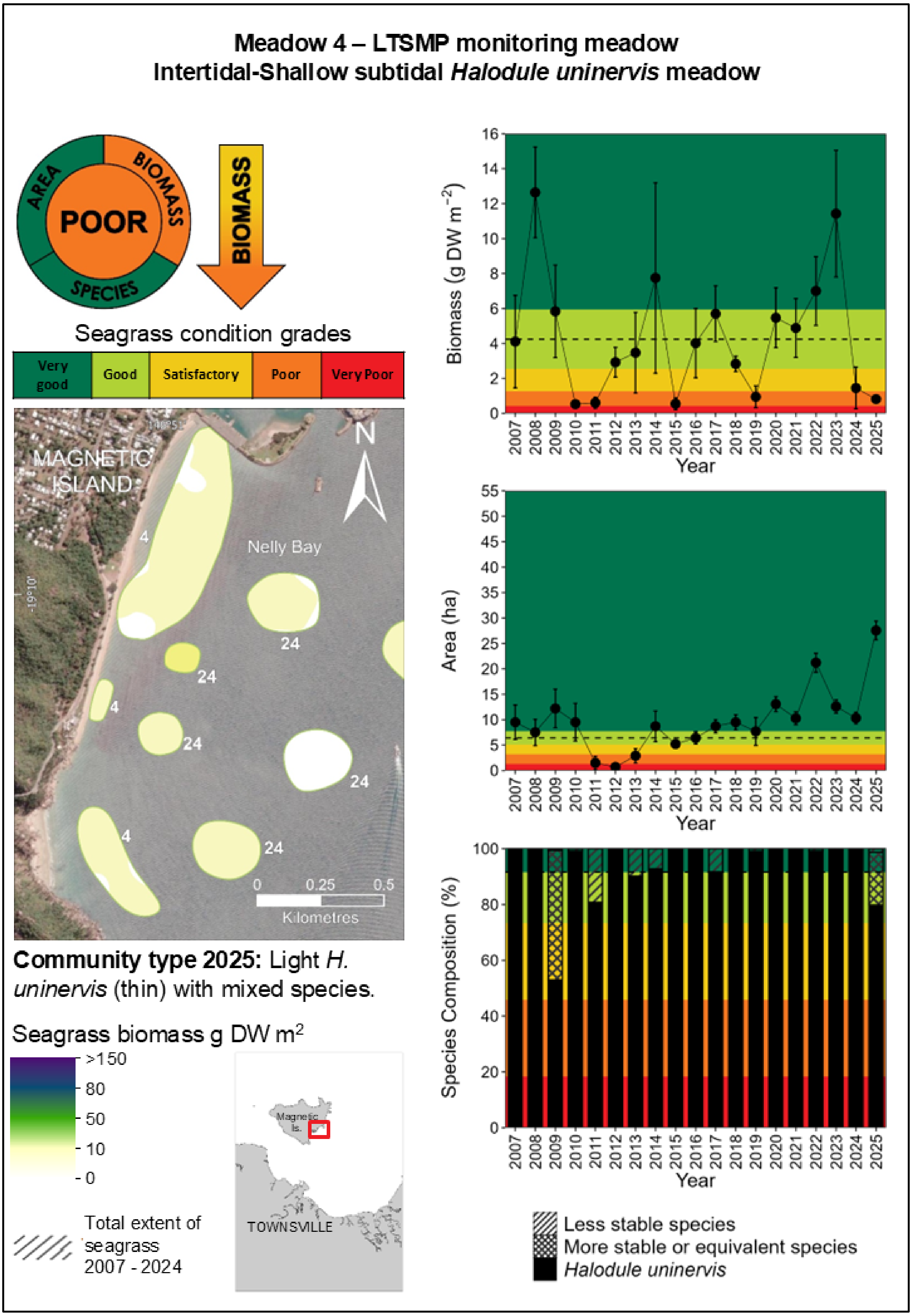



**Figure 13**. Changes in meadow area (ha), above-ground biomass (gDWm$^{-2}$), and species composition for long-term monitoring Meadow 4 at Magnetic Island, 2007–2025. (Above-ground biomass error bars = SE; area error bars = R (reliability estimate)). Lack of arrows indicates no change in condition index from the previous year.

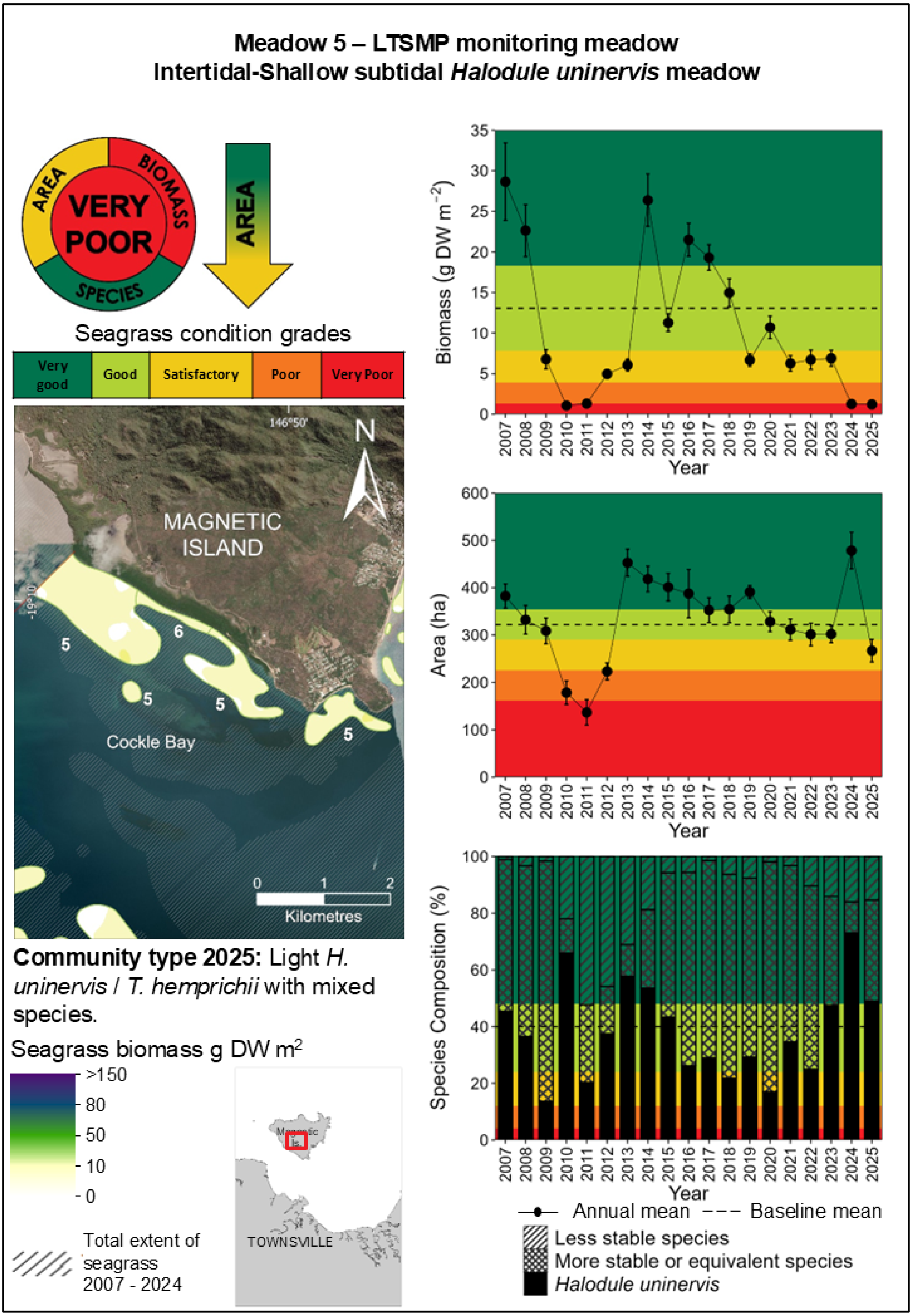



**Figure 14**. Changes in meadow area (ha), above-ground biomass (gDWm$^{-2}$), and species composition for long-term monitoring Meadow 5 at Magnetic Island, 2007–2025. (Above-ground biomass error bars = SE; area error bars = R (reliability estimate)). Lack of arrows indicates no change in condition index from the previous year.

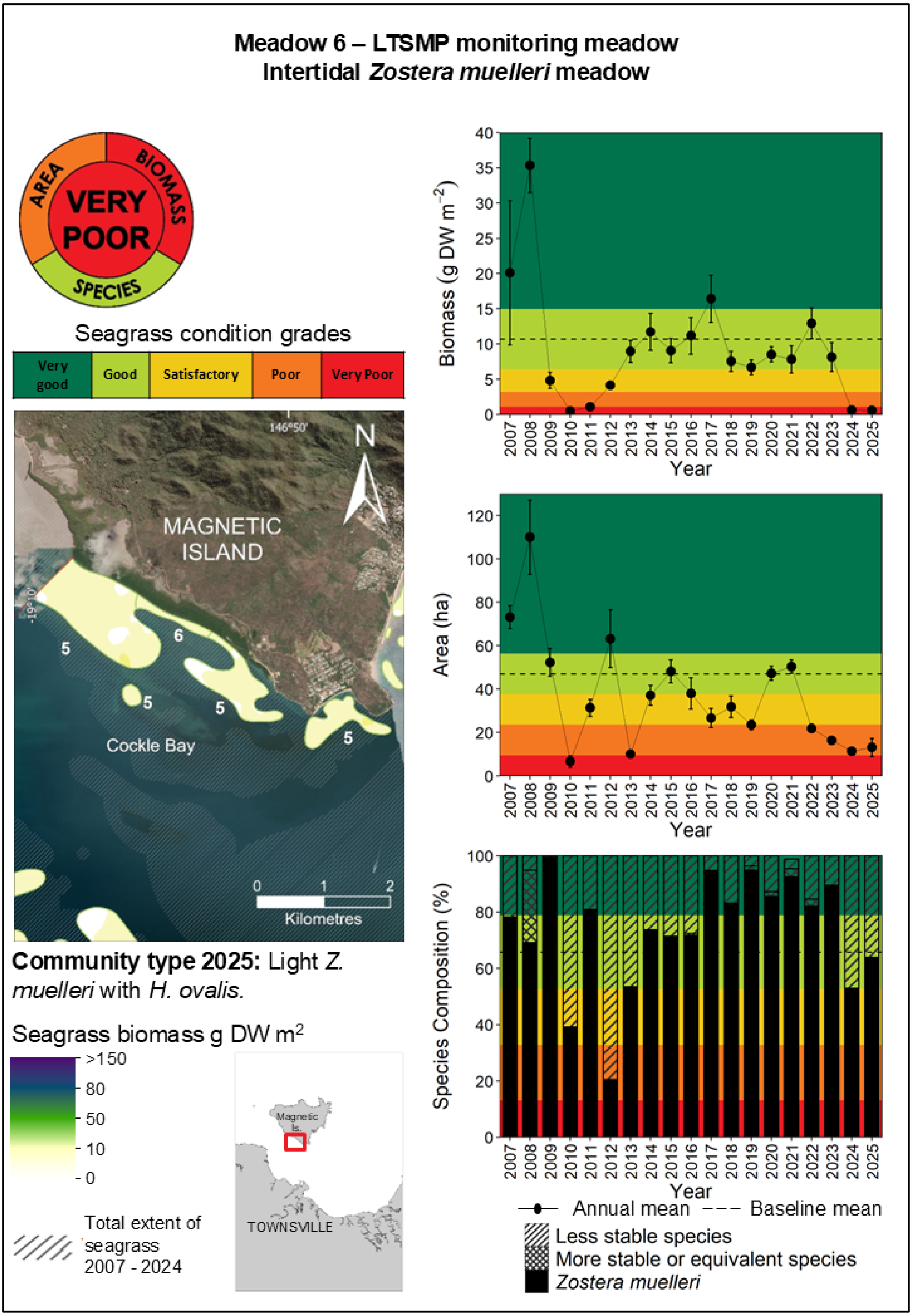



**Figure 15**. Changes in meadow area (ha), above-ground biomass (gDWm$^{-2}$), and species composition for long-term monitoring Meadow 6 at Magnetic Island, 2007–2025. (Above-ground biomass error bars = SE; area error bars = R (reliability estimate)). Lack of arrows indicates no change in condition index from the previous year.

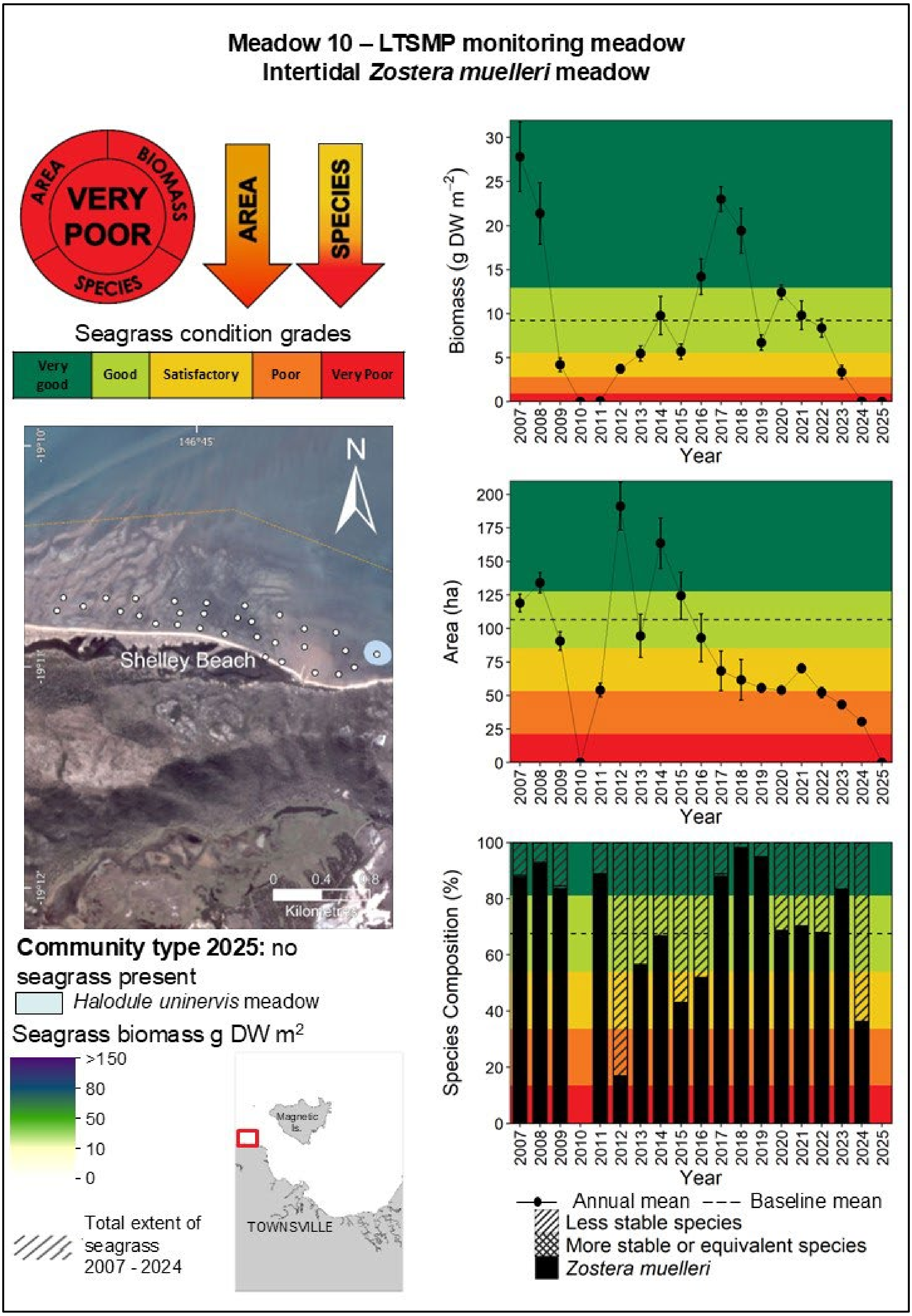



**Figure 16**. Changes in meadow area (ha), above-ground biomass ($gDWm^{-2}$), and species composition for long-term monitoring Meadow 10 at Shelley Beach, 2007–2025. (Above-ground biomass error bars = SE; area error bars = R (reliability estimate)). Lack of arrows indicates no change in condition index from the previous year.

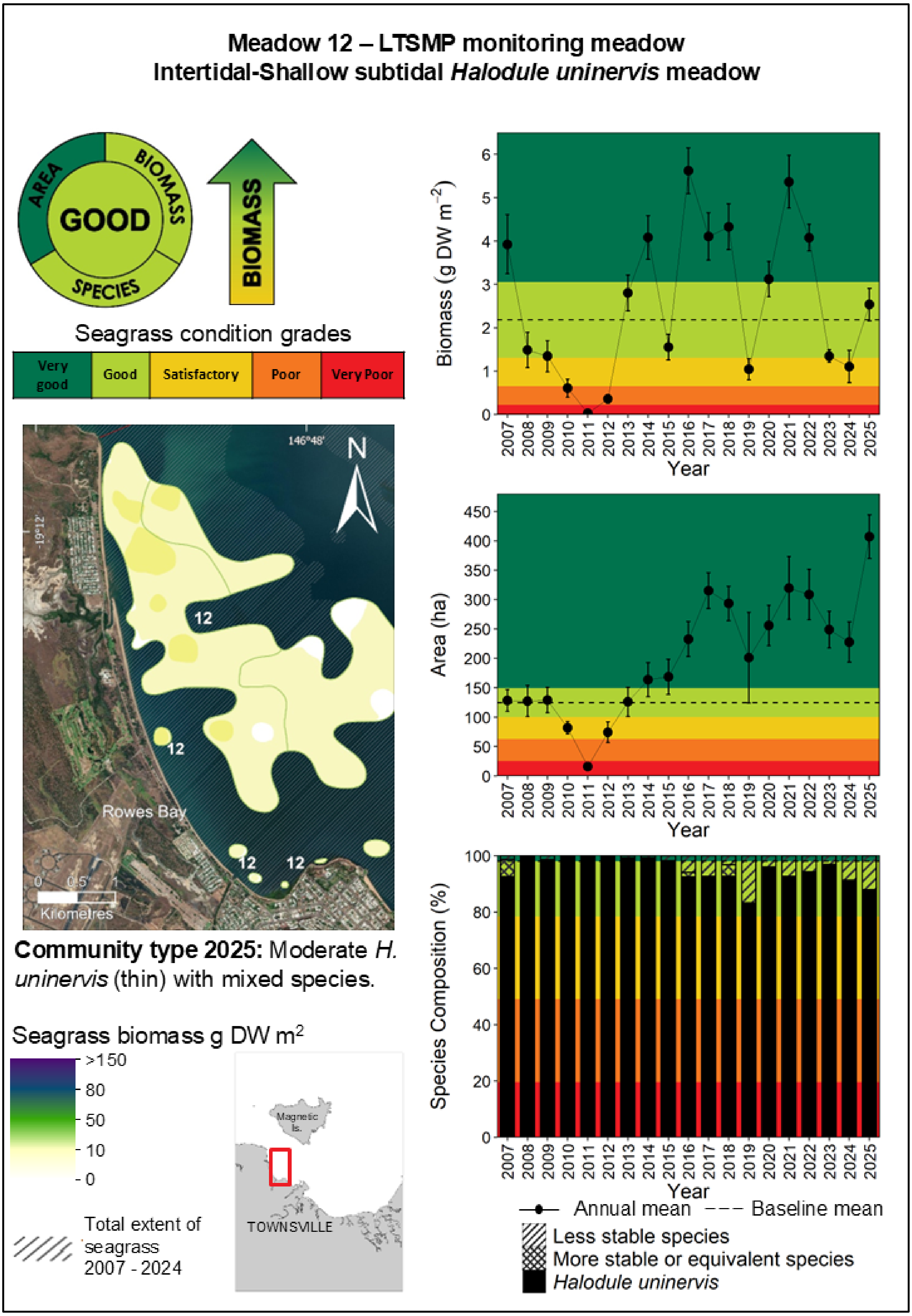



**Figure 17**. Changes in meadow area (ha), above-ground biomass (gDWm$^{-2}$), and species composition for long-term monitoring Meadow 12, at Rowes Bay to Cape Pallarenda, 2007–2025. (Above-ground biomass error bars = SE; area error bars = R (reliability estimate)). Lack of arrows indicates no change in condition index from the previous year.

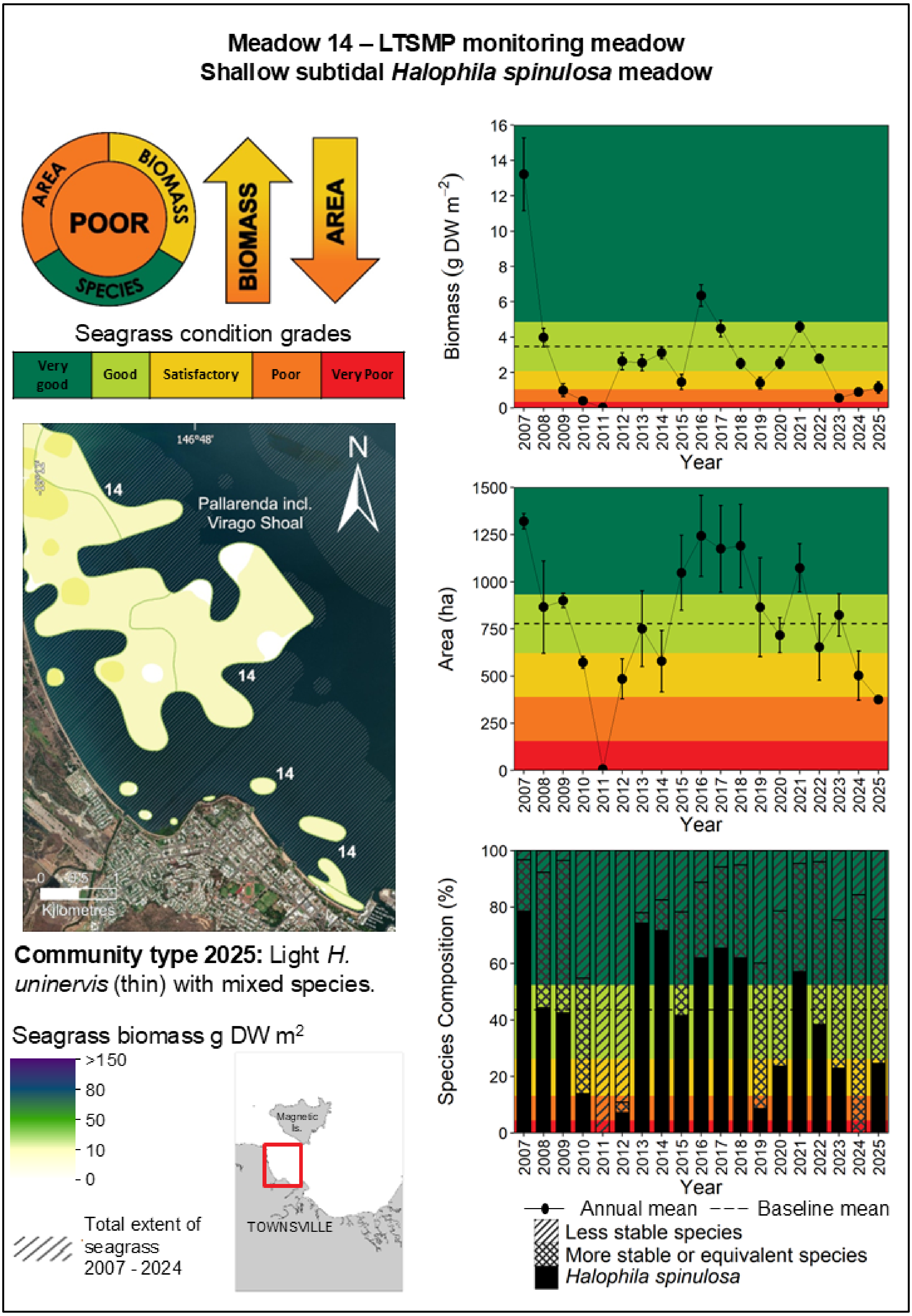



**Figure 18**. Changes in meadow area (ha), above-ground biomass (gDWm$^{-2}$), and species composition for long-term monitoring Meadow 14 at the Strand to Cape Pallarenda, 2007–2025. (Above-ground biomass error bars = SE; area error bars = R (reliability estimate)). Lack of arrows indicates no change in condition index from the previous year.

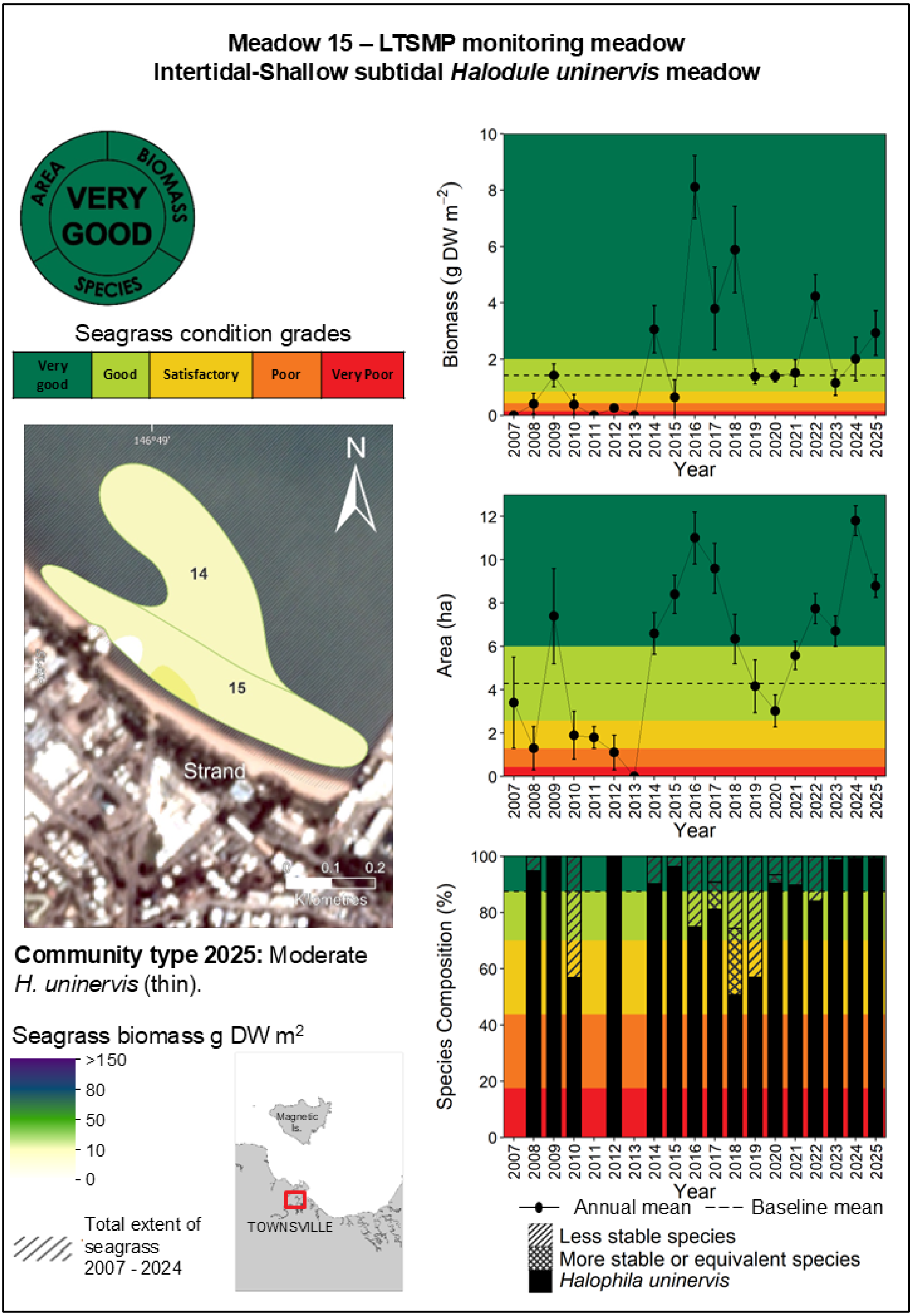



**Figure 19.** Changes in meadow area (ha), above-ground biomass (gDWm$^{-2}$), and species composition for long-term monitoring Meadow 15 at the Strand, 2007–2025. (Above-ground biomass error bars = SE; area error bars = R (reliability estimate)). Lack of arrows indicates no change in condition index from the previous year.

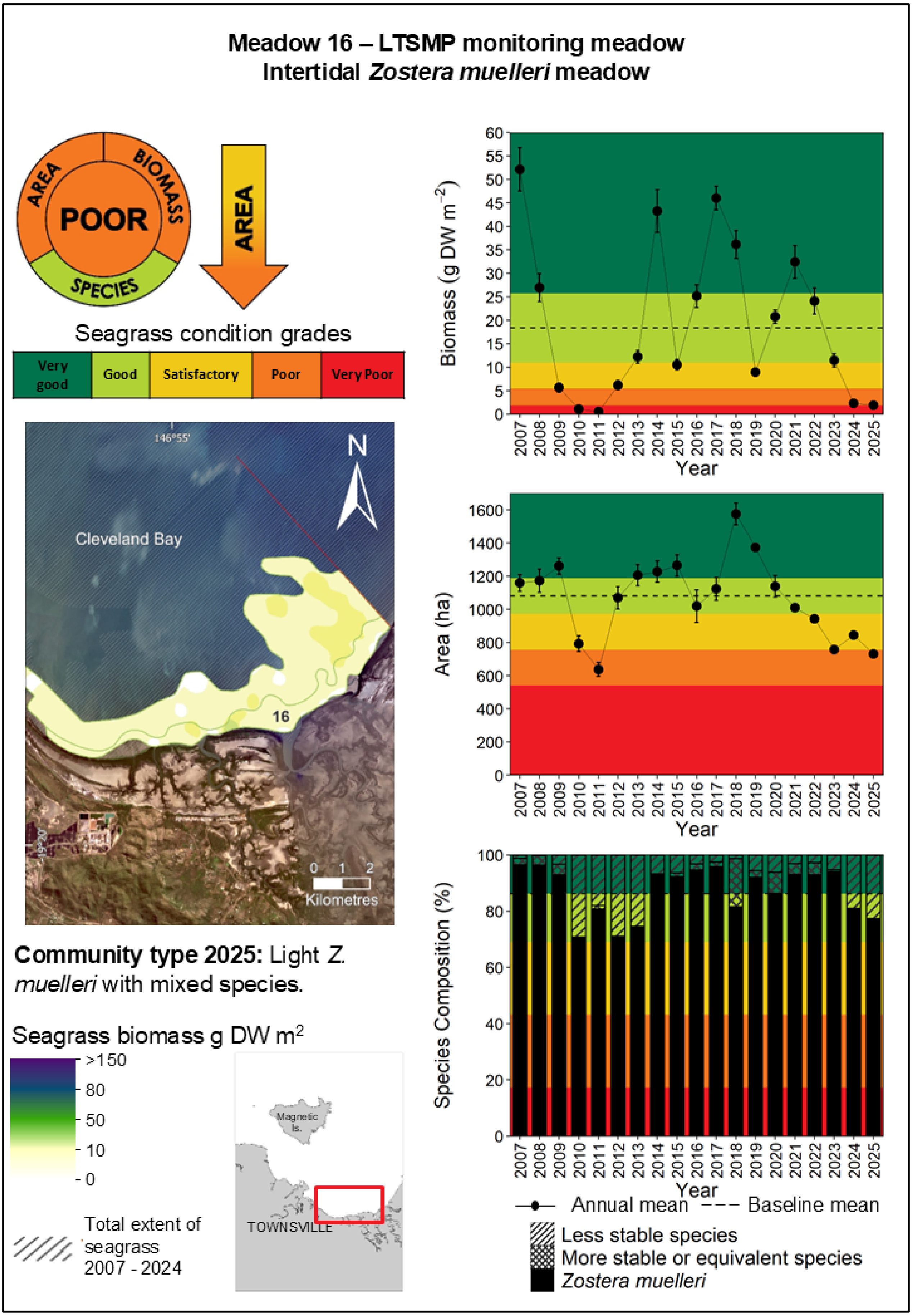



**Figure 20**. Changes in meadow area (ha), above-ground biomass (gDWm$^{-2}$), and species composition for long-term monitoring Meadow 16 in Cleveland Bay, 2007–2025. (Above-ground biomass error bars = SE; area error bars = R (reliability estimate)). Lack of arrows indicates no change in condition index from the previous year.

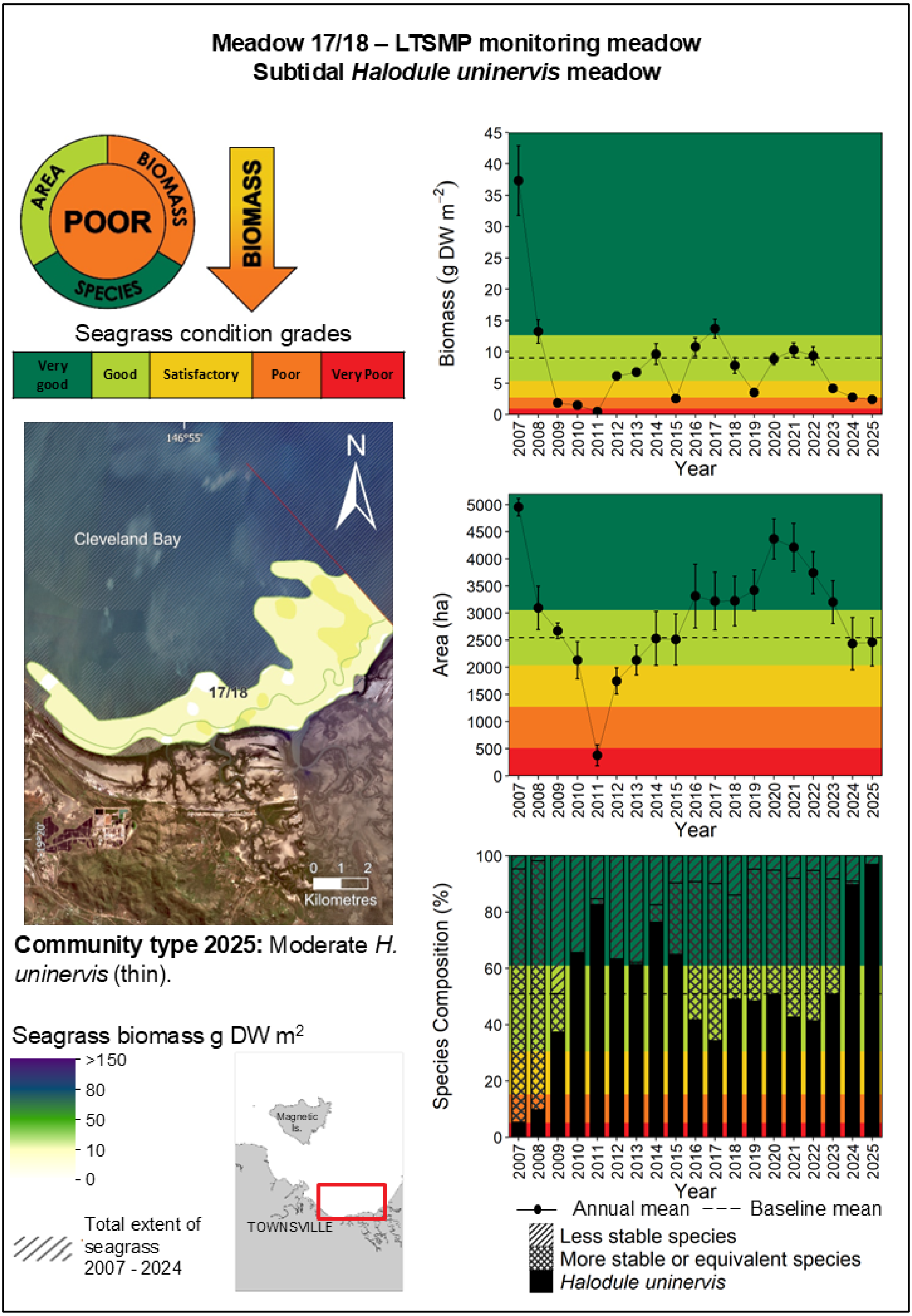



**Figure 21**. Changes in meadow area (ha), above-ground biomass (gDWm$^{-2}$), and species composition for long-term monitoring Meadow 17/18 in Cleveland Bay, 2007–2025. (Above-ground biomass error bars = SE; area error bars = R (reliability estimate)). Lack of arrows indicates no change in condition index from the previous year.

## 4.3 Seasonal comparisons of Townville seagrass meadows

The availability of biannual monitoring data between 2019 and 2025 provides an opportunity to examine seasonal patterns in seagrass condition between post-wet-season (May–June) and pre-wet/dry-season (September–November) surveys. To maintain spatial consistency across the time series, seasonal comparisons were undertaken using the standardised biannual survey boundaries established for these meadows between 2019 and 2024, rather than the LTSMP meadow boundaries presented elsewhere in this report (see McKenna et al. 2025b for survey extents). This longer time series provides context for interpreting changes observed between the May and September–October 2025 surveys and allows assessment of whether consistent seasonal patterns occur in seagrass above-ground biomass and meadow area.

Mixed-effects modelling of log-transformed above-ground biomass data, including Year as a random effect, detected no significant differences between post-wet and pre-wet/dry seasons across monitored meadows (Season effect: $p = 0.49$). Seasonal differences were small and inconsistent among years, indicating that interannual variability exerts a stronger influence on biomass than within year seasonal patterns (Figure 22).

In contrast, mixed-effects modelling detected a significant seasonal effect on meadow area ($p = 0.003$), with pre-wet/dry season meadow areas generally exceeding post-wet season meadow areas. The interaction between season and meadow was not statistically significant ($p = 0.07$), indicating that the seasonal signal was broadly consistent across meadows. Meadow-specific contrasts identified significant seasonal increases at the subtidal meadows at Pallarenda (Meadow 14; ~55% higher in dry season) and Geoffrey Bay (Meadow 24; ~74% higher in dry season), while other meadows showed no consistent seasonal difference (Figure 23). Subtidal areas are continuously submerged and therefore more directly influenced by seasonal changes in water clarity (i.e., light availability) and hydrodynamic conditions. Whereas intertidal meadows may experience additional constraints related to tidal exposure and air temperature (Manassa et al. 2017; Schrameyer et al. 2018).

The direction of change between post-wet and pre-wet/dry season surveys for both area and above-ground biomass tend to vary at the individual meadow scale. Seagrass meadows in Townsville have historically been highly variable. While the total meadow footprint expanded seasonally in some locations, biomass per unit area did not exhibit a consistent seasonal signal, suggesting that seasonal dynamics in Townsville are expressed more strongly through changes in spatial extent than in biomass density.

Meadows 4 and 15 were not included in the analysis because they were only surveyed during the pre-wet/dry season monitoring period and therefore lacked sufficient biannual data for seasonal comparison.

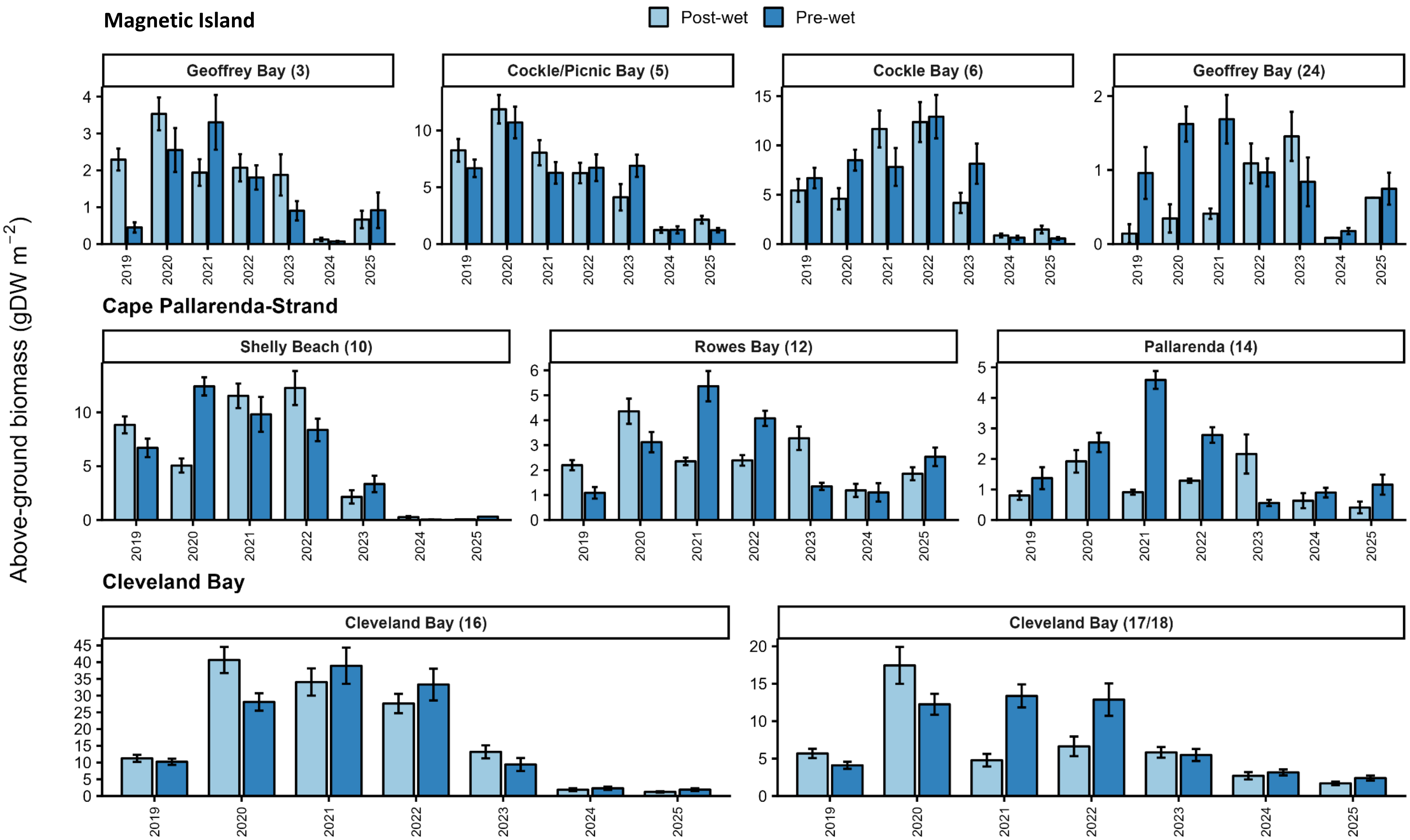



**Figure 22.** Seasonal mean meadow above-ground biomass (g DW m$^{-2}$) during post-wet season (May–June) and pre-wet/dry season (September–November) surveys from 2019–2025. Comparisons use the standardised biannual survey boundaries described in McKenna et al. (2025b), rather than the Long-Term Seagrass Monitoring Program (LTSMP) meadow boundaries. Meadows 4 and 15 are not included as they were only surveyed during the pre-wet/dry season monitoring period.

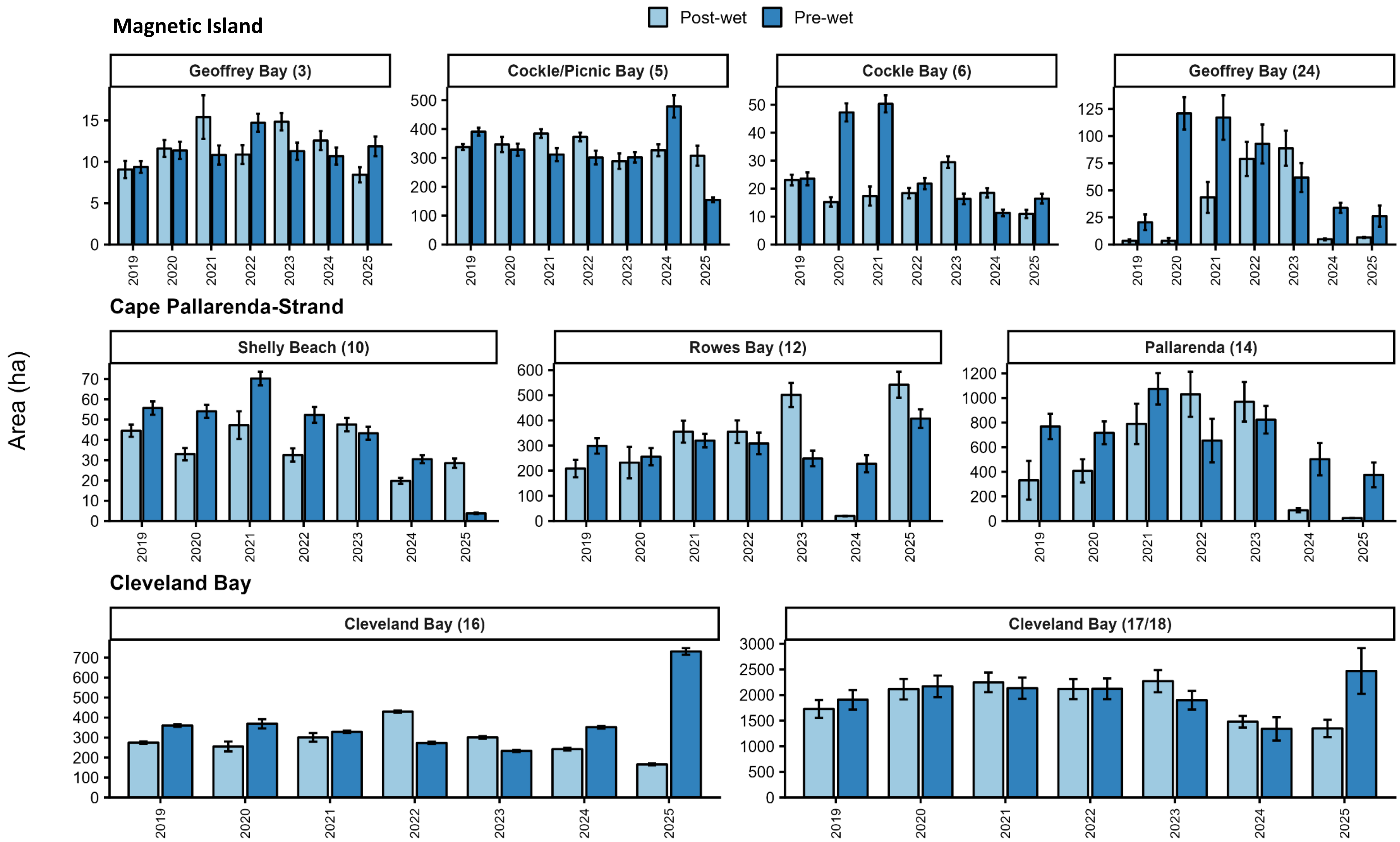



**Figure 23.** Seasonal total meadow area (ha) during post-wet season (May–June) and pre-wet/dry-season (September–November) surveys from 2019–2025. Comparisons use the standardised biannual survey boundaries described in McKenna et al. (2025b), rather than the Long-Term Seagrass Monitoring Program (LTSMP) meadow boundaries. Meadows 4 and 15 are not included as they were only surveyed during the pre-wet/dry-season monitoring period

# 5 TOWNSVILLE CLIMATE PATTERNS

### 5.1.1 General climate patterns

Townsville experiences a tropical climate characterised by distinct wet and dry seasons. The wet season (typically November–April) contributes most of the annual rainfall and is highly variable, influenced by tropical lows, monsoonal systems, and broader climatic drivers such as the El Niño–Southern Oscillation (ENSO). In contrast, the dry season (typically May–October) is dominated by southeasterly trade winds, generally associated with more stable atmospheric conditions, lower rainfall, and clearer skies.

Cleveland Bay is a naturally turbid environment. Turbidity is driven primarily by wind- and wave-induced sediment resuspension. Long-term observations indicate that elevated turbidity conditions frequently coincide with periods of strong winds (~>36 km/hr), reflecting the bay's highly dynamic sedimentary environment (Orpin et al. 1999; Orpin et al. 2004; Jones et al. 2020; GHD 2024). As such, episodic increases in turbidity and reductions in light availability are characteristic features of the system rather than anomalous conditions.

Over the past seven years (2019–2025), the Townsville region has experienced multiple large-scale climatic and hydrodynamic disturbances. These include:

***Rainfall, flooding and river discharge***

- Record flooding during January–February 2019.
- Above-average rainfall and river discharge during the 2018/19, 2021/22, 2022/23 and 2024/25 wet seasons.
- 2025 recorded as the wettest year on record for Townsville, including the wettest February and wettest single day (19 March 2025; 301.4 mm).

These events have the potential to increase catchment runoff, freshwater input and sediment delivery into Cleveland Bay (Orpin et al. 1999; Moran et al. 2025), alongside associated nutrient loading (Furnas et al. 2005; Brodie et al. 2009).

***Elevated temperatures and marine heatwaves***

- 2019: Australia's hottest year on record (air temperature) (Great Barrier Reef Marine Park Authority (GBRMPA)).
- February 2020: Record high sea surface temperatures (GBRMPA 2024).
- Summer 2021/22 and 2023/24: Sea surface temperatures above long-term averages (GBRMPA 2024).

***Prolonged low-light conditions***

Prolonged periods of low light were recorded in Cleveland Bay with multiple threshold exceedances documented in recent years (GHD 2024; PoTL's Marine Water Quality Monitoring Program). Periods of reduced light availability were associated with elevated turbidity and reduced water clarity, particularly during periods of high rainfall, river discharge and wind driven sediment resuspension.

***Tropical weather systems and cyclones***

- Tropical Cyclone Jasper (December 2023), during which the Port entered Condition Yellow and water quality monitoring instrumentation was removed.
- Tropical Cyclone Kirrily (January 2024).
- Prolonged tropical low (January–February 2025), with wind gusts reaching 89 km/h in Townsville.

### 5.1.2 Rainfall and river flow

Rainfall in Townsville is strongly seasonal, with the majority occurring between December and April. Total rainfall in the 12 months preceding the September–October 2025 survey was above the long-term average (Figure 23B). November and December 2024 and February and March 2025 recorded above-average monthly rainfall, with February and March 2025 recording the highest monthly totals during the reporting period (Figure 24A) (1st February recording 284.0 mm and 19th March recording 301.4 mm). More broadly, four of the past six years have recorded annual rainfall totals above the long-term average, indicating a sustained period of elevated wet-season inputs (Figure 24B).

Elevated rainfall during the 2024/25 wet season translated into above-average river discharge across the major local catchments. In the 12 months preceding the survey, total discharge from the Burdekin River, the dominant riverine input influencing coastal waters in the Townsville region, was the second-highest recorded in the past decade (Figure 25A). Similarly, both Black River and Alligator Creek (Ross Basin) recorded their highest discharge volumes of the past ten years (Figure 25B). In each case, the annual discharge exceeded the long-term average.

Discharge was strongly seasonal: >98% of annual flow occurred during the wet season (November–April) across all three catchments (Burdekin 98.3%, Black River 99.1%, Alligator Creek 98.4%), with comparatively low discharge through the dry season. Discharge was also highly event-concentrated, consistent with pulsed wet-season hydrology. February 2025 alone accounted for most of the annual discharge, contributing ~59% of Burdekin flow, ~49% of Black River flow, and ~38% of Alligator Creek flow. Notably, Alligator Creek recorded zero discharge on 87 days over the 12-month period, reflecting the intermittency of smaller coastal catchments relative to the Burdekin.

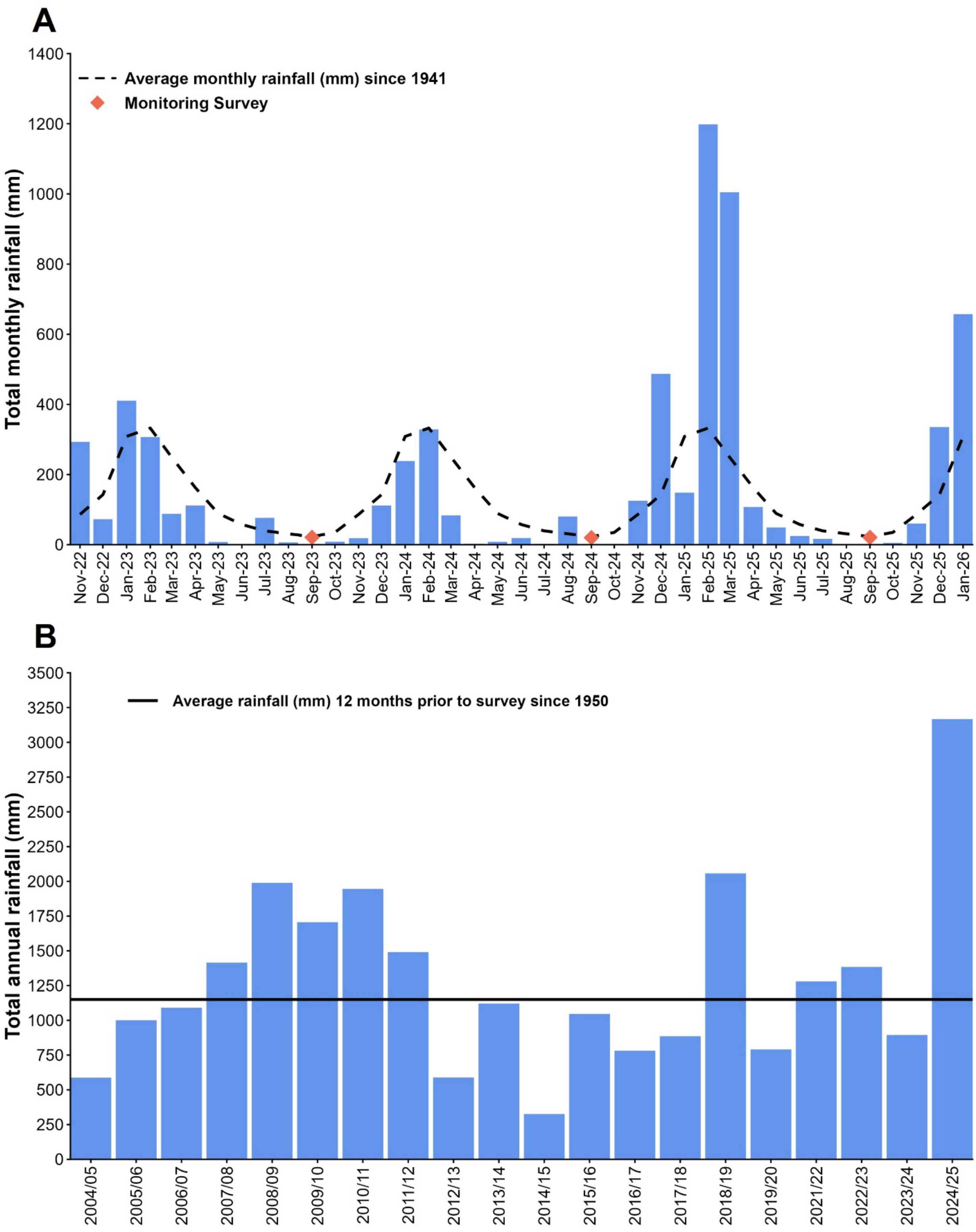



**Figure 24. (A)** Total monthly rainfall (mm) from November 2022–January 2025; and **(B)** total annual rainfall in the 12 months preceding each annual seagrass monitoring survey from 2004/2005–2024/25. Source: Bureau of Meteorology, Station 032040.

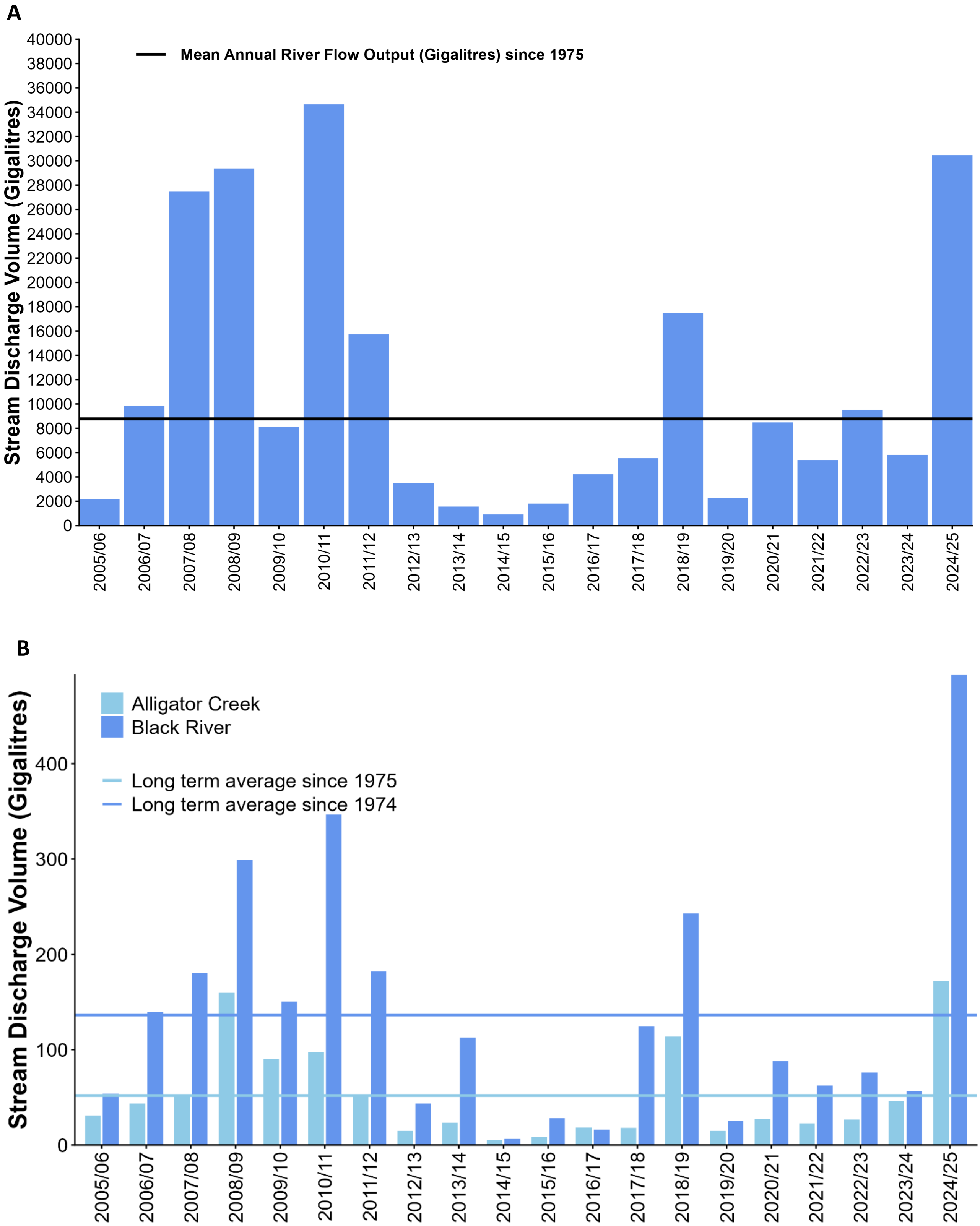


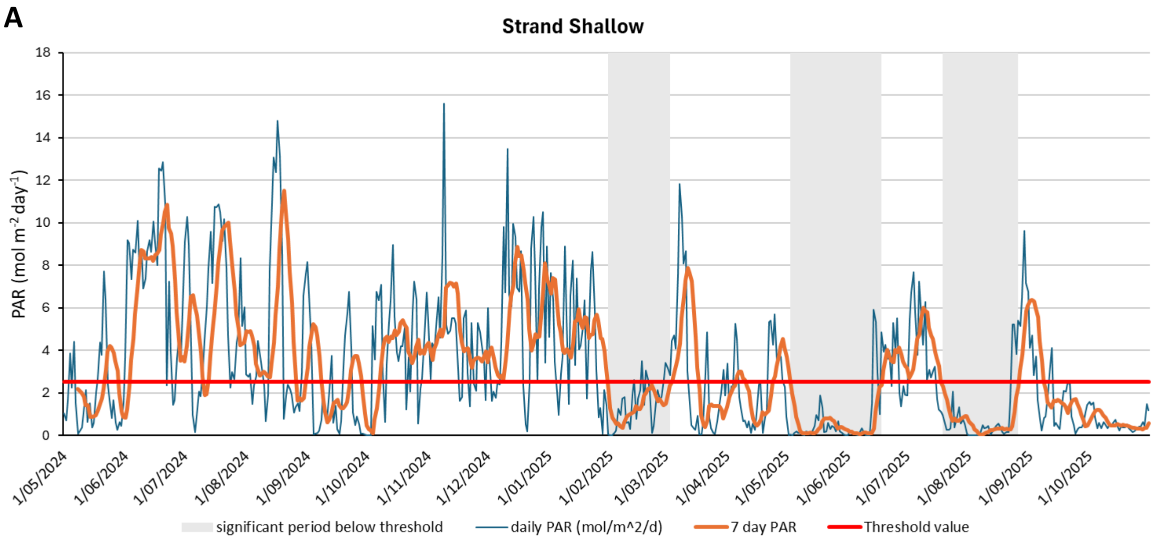

**Figure 25.** Total annual flow (Gigalitres) in the 12 months preceding each annual seagrass survey from 2005/06–2024/25 of the **(A)** Burdekin River the **(B)** Black River and Alligator Creek. Source: Queensland Government Water Monitoring Information Portal.

### 5.1.3 Photosynthetically Active Radiation (PAR) and seabed temperature

Photosynthetically Active Radiation (PAR) and seabed temperature data collected across the Townsville region by the Port of Townsville indicated that light availability was generally low across subtidal sites in the 12 months preceding the 2025 survey. PAR levels at most subtidal locations were frequently below thresholds associated with seagrass growth and persistence, particularly from March 2025 through to the survey period. This pattern is consistent with findings from the Great Barrier Reef Marine Monitoring Program (MMP), which identifies light limitation associated with turbidity and river discharge as the primary driver of seagrass condition in regions such as the Burdekin and Wet Tropics (Leahy et al. 2026).

The most pronounced periods of reduced light availability occurred in mid to late 2025, during which several sites experienced extended periods below threshold conditions. For example, at the 'Strand Shallow' monitoring site (Figure 26A), PAR remained below key light thresholds for prolonged periods (up to ~4-6 weeks) during February–March, May–June and July–August.

In contrast, the intertidal site at Cockle Bay generally experienced higher light availability, with PAR values remaining above growth thresholds for most of the year (Figure 26B). Some subtidal sites (e.g. Geoffrey Bay) also showed periods of comparatively higher light availability, particularly in the months leading up to the survey, although these conditions were not consistent across the broader region (PoTL, unpublished data).



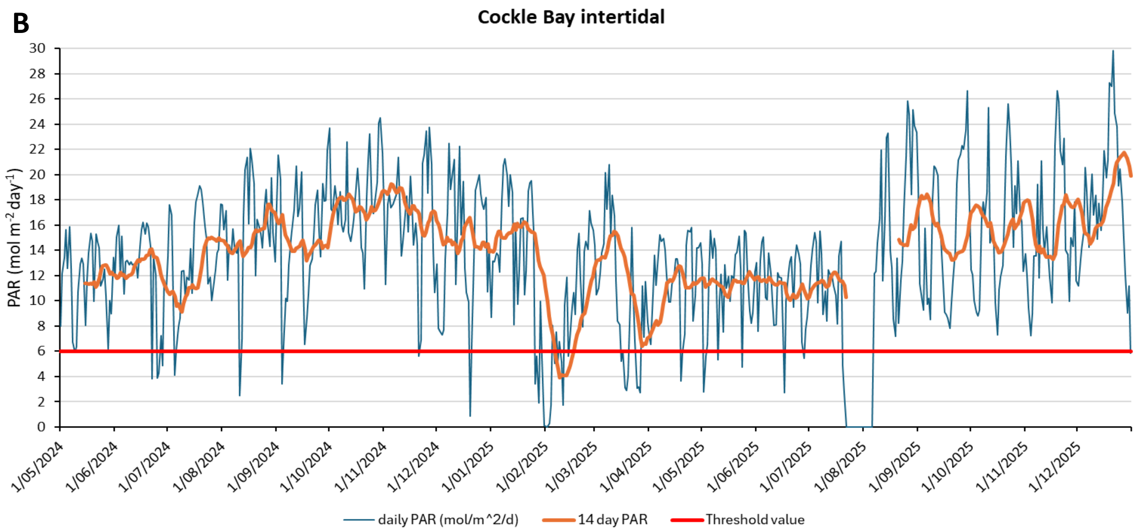




**Figure 26:** Photosynthetically Active Radiation (PAR mol photons $m^{-2}day^{-1}$ – light) at the **A)** 'Strand Shallow' monitoring site showing extended periods below seagrass light thresholds; and **B)** 'Cockle Bay' monitoring site showing extended periods of above seagrass light thresholds prior to the 2025 survey. Source: Port of Townsville.

### 5.1.4 Daily maximum wind speed

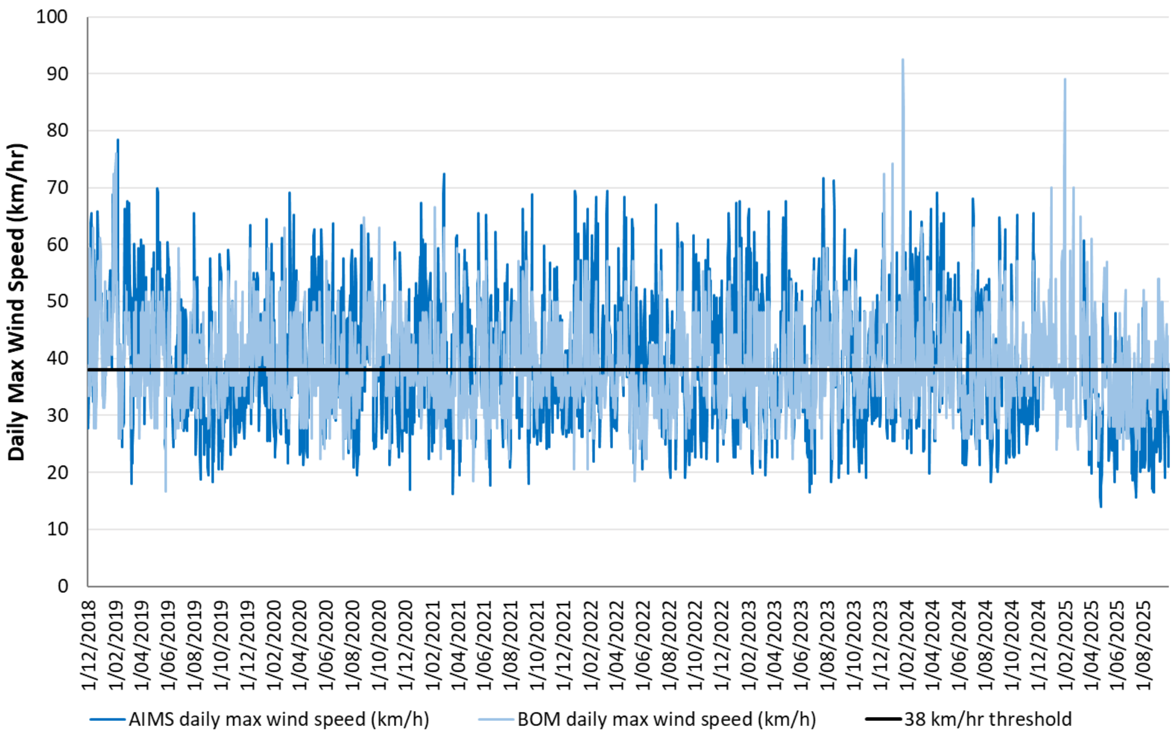
Wind-driven resuspension of sediment is a key driver of turbidity in Cleveland Bay and influences the amount of PAR reaching benthic habitats (Orpin et al. 1999; Orpin et al. 2004; GHD 2024). Elevated turbidity has previously been associated with wind speeds exceeding approximately 36-38 km/hr (GHD 2024), while sediment resuspension from shallow banks may initiate at speeds as low as 20 km/hr (Orpin et al. 2004).

In the 12 months preceding the September–October 2025 survey, daily maximum wind speeds exceeded 38 km/hr on 182 days, representing approximately half of all days within the reporting period (Figure 27A and B). The longest consecutive exceedance period was nine days, including a maximum daily wind speed of 89 km/hr recorded on 2 February 2025, occurring during late January to early February 2025 coinciding with a persistent large pressure system. This also coincided with peak rainfall and elevated river discharge.

Exceedances were more frequent during the wet season (November–April), when 109 days (~60% of wet-season days) exceeded 38 km/hr, compared to 73 days (~40%) during the dry season (May–September). The concurrence of elevated wind speeds with high rainfall and river discharge during the wet season likely amplified sediment resuspension and reduced light availability across intertidal and shallow subtidal meadows during peak growth periods.

Given that Cleveland Bay is a naturally wind-driven sedimentary resuspension environment, the sustained frequency of wind speeds above turbidity thresholds during 2024/25 represents a significant hydrodynamic pressure. The limited intervals between high-wind events, particularly during the wet season, may have reduced recovery windows for seagrass prior to the 2025 survey.

**A**




**B**

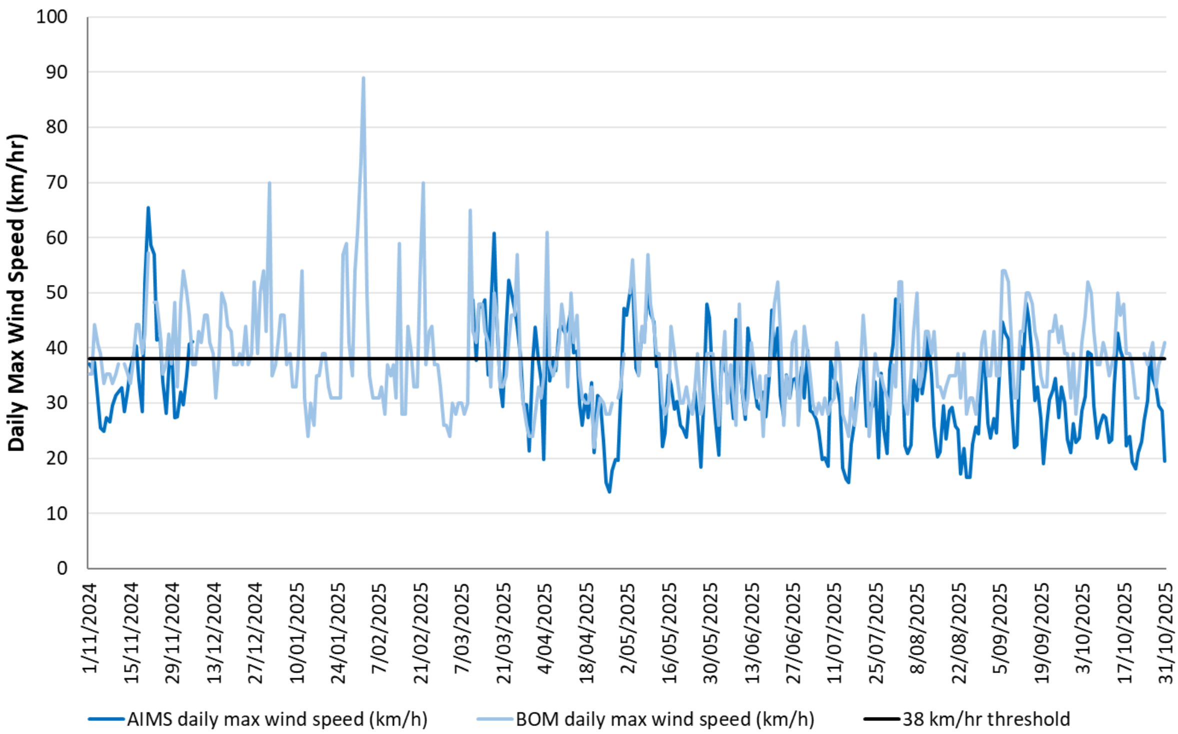



**Figure 27**. **(A)** Daily maximum wind speeds recorded from December 2018 to August 2025; and **(B)** for the 12 months preceding the current survey year. Source: Bureau Of Meteorology (BOM) station 032040 and AIMS Cleveland Bay weather station. The black solid line shows the 38 km/hr wind speed threshold at which the Channel Upgrade Marine Water Monitoring Program found elevated turbidity in Cleveland Bay. Note: the AIMS weather station was inactive from 7/12/2024 to 11/03/2025.

### 5.1.5 Air and benthic sea temperature

Mean annual daily maximum air temperature for 2024/25 (29.8 °C) was marginally above the long-term average (29.5 °C), consistent with recent years but not in the range of thermal stress for seagrass (Campbell et al. 2006; Collier et al. 2017; Figure 28B). Mean annual maximum air temperature has exceeded the long-term average for twelve consecutive years, indicating sustained above-average thermal conditions in the Townsville region.

Monthly mean maximum air temperatures during the 2024/25 monitoring period were generally consistent with, or above, long-term monthly averages (Figure 28A). Elevated temperatures were particularly evident during the 2024/25 wet season, coinciding with periods of high rainfall and river discharge. While intertidal canopy temperatures can exceed ambient air temperature during low tide exposure, recorded air temperature exceedances were short-lived relative to the frequency and duration of wind-driven and hydrological disturbance events.

Benthic water temperatures were generally within expected seasonal ranges, with short periods of elevated temperatures (>30 °C) recorded during summer months (January–February 2025) at several sites (PoTL unpublished data). However, these events were brief compared with the extended periods of low light observed in subtidal environments and below levels likely to cause harm to Cleveland Bay seagrasses (Campbell et al. 2006; Collier et al. 2017). This pattern is consistent with findings from the Great Barrier Reef Marine Monitoring Program (MMP), which identify elevated temperatures as a recurrent but a secondary stressor of seagrass condition in regions such as the Burdekin and Wet Tropics (Leahy et al. 2026).

Temperature-response modelling for the Townsville meadows identified optimal 7-day running mean benthic sea temperatures of 33.4 °C for intertidal meadows (*Z. muelleri* and *H. uninervis*) and 24.3 °C for subtidal meadows (McKenna et al. 2025b). When interpreted within a seasonal growth context, temperature conditions during 2024/25 were largely within or slightly below the optimal range during the primary growing season for meadow expansion (September–December 2024). A cluster of exceedances of the optimal temperature threshold for intertidal meadows (>33.4 °C) occurred from mid-January to mid-February 2025, totalling 11 days, with a maximum consecutive exceedance of 3 days (PoTL unpublished data). These short-duration heat pulses may have contributed to episodic physiological stress. However, there were no prolonged periods of sustained thermal exceedance. Overall, thermal conditions during 2024/25 appear unlikely to have imposed sustained growth-limiting or heatwave-level stress relative to hydrological and light drivers.

While 2024/25 did not exhibit prolonged thermal exceedance relative to modelled optima, the Townsville region has experienced multiple documented extreme temperature and marine heatwave events over the past seven years, including:

- 2019: Australia's hottest year on record (GBRMPA).
- February 2020: Record high sea surface temperatures (GBRMPA 2024).
- Summer 2021/22 and 2023/24: Sea surface temperatures above long-term averages (GBRMPA 2024).

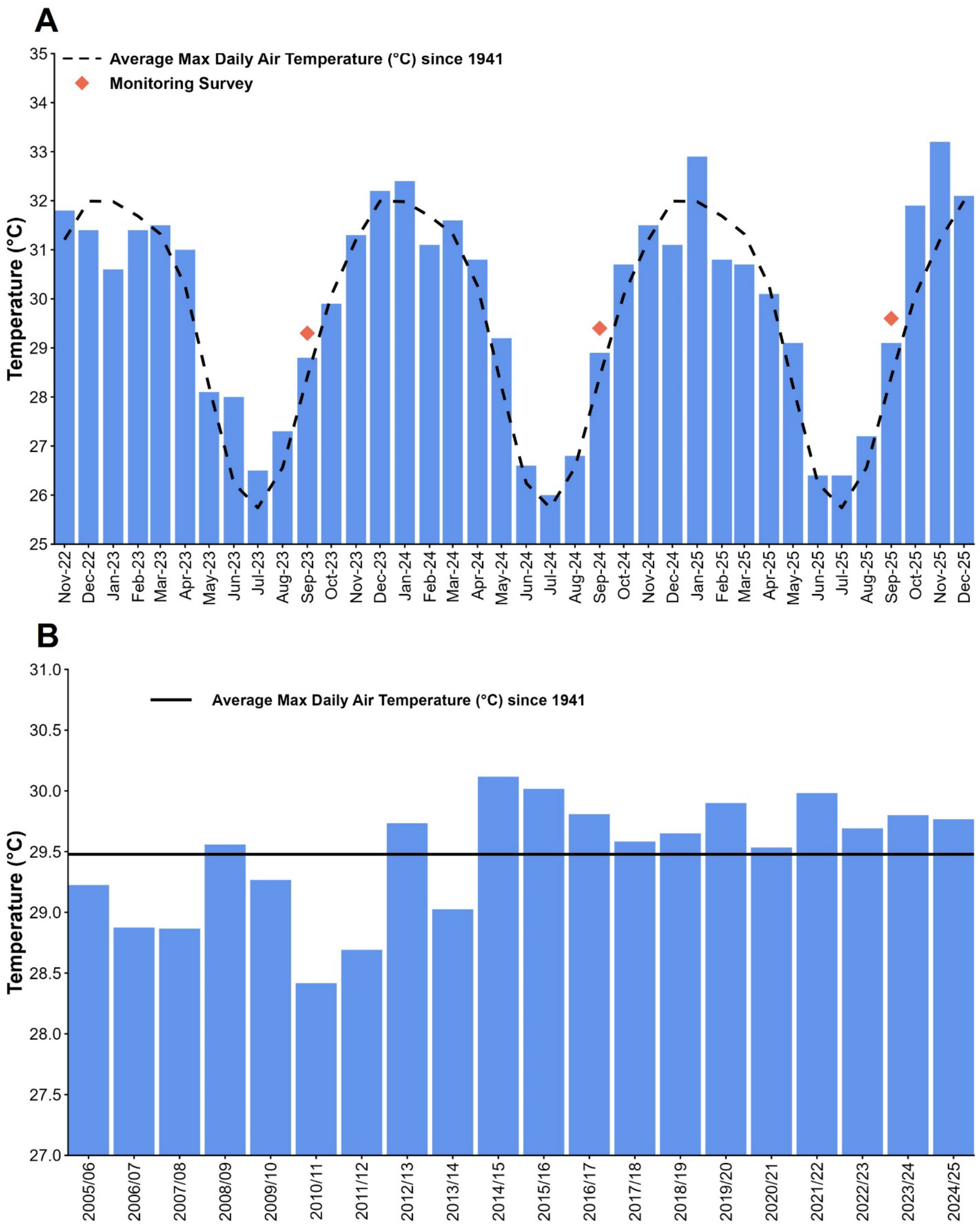



**Figure 28. (A)** Mean monthly maximum daily air temperature (°C) November 2022 – December 2025, and **(B)** mean annual maximum daily air temperature (°C) in the 12 months preceding each annual survey 2005/06 to 2024/25. Source: Bureau of Meteorology, Station 032040

### 5.1.6 Seagrass exposure to air (intertidal seagrass meadows)

Total daytime exposure to air of intertidal seagrass meadows in Townsville remains seasonally variable, with exposure duration typically increasing through the dry season and declining during the wet season (Figure 29A). In the month preceding the September–October 2025 survey, total exposure of intertidal seagrass meadows to air was approximately 22 hours, slightly below the long-term monthly average. In the three months preceding the dry-season survey, cumulative exposure was approximately 95 hours, less than the long-term three-month average (Figure 29B). These values indicate that tidal exposure duration during 2024/25 was not anomalously high relative to historical conditions.

However, exposure duration alone does not determine stress; the magnitude of solar radiation during exposure windows strongly influences both desiccation risk and photosynthetic opportunity (Petrou et al. 2013; Jiang et al. 2014).

Daily global solar exposure during periods when intertidal banks were exposed (filtered using tidal height ≤0.8 m and daylight conditions) ranged from 0.8 to 30.1 MJ $m^{-2}$ during October 2024–September 2025. High solar exposure values (>28 MJ $m^{-2}$) occurred predominantly during October–November 2024 and again in late December 2024, coinciding with early wet-season growth conditions.

In contrast, the peak wet season (January–March 2025) was characterised by multiple extended periods of reduced solar exposure during tidal exposure windows. Notably:

- 20 December 2024 (1.9 MJ $m^{-2}$)
- 28–31 January 2025 (2.7–5.2 MJ $m^{-2}$)
- 1–4 February 2025 (0.8–10.5 MJ $m^{-2}$)

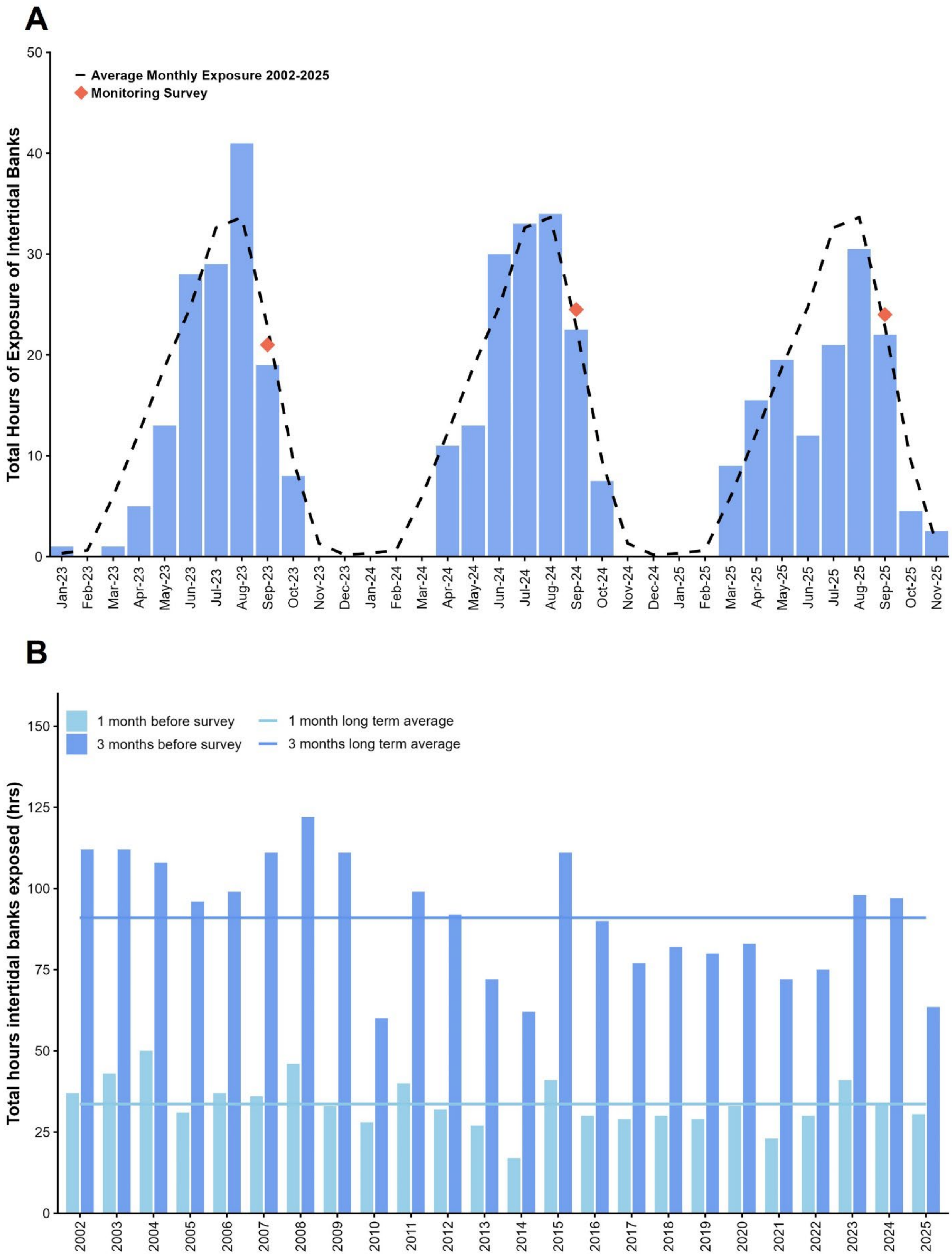



**Figure 29. (A)** Total monthly hours seagrass meadows exposed to daytime intertidal air, Jan 2023–November 2025; and **(B)** total daytime exposure one month and three months (<0.8 m tidal height) prior to the annual monitoring surveys in Townsville (Maritime Safety Queensland, www.msq.qld.gov.au).

# 6 DISCUSSION

At the end of 2025, seagrass in the Townsville region remained in an overall poor condition for the second consecutive year. Poor seagrass condition was largely due to low or declining seagrass biomass, with spatial extent remaining in satisfactory or better condition for most monitoring meadows. Declines were particularly pronounced for *Zostera muelleri* dominated meadows and included the complete loss of the Shelley Beach (Cape Pallarenda) monitoring meadow. Despite these declines, an extensive seagrass footprint remains in the Townsville region, and persistent higher-light-requiring species persist across much of their historical range, providing an opportunity for recovery if conditions are right. The presence of turtles and dugongs, and dugong feeding trails in meadows, indicated that herbivorous marine megafauna continue to make extensive use of the available seagrass habitat.

The continued poor condition of seagrasses in 2025 was likely driven by a range of consecutive, as well as cumulative, environmental pressures during 2025 and for several years prior. The 2025 monitoring period was characterised by some extreme hydrological and meteorological conditions. The year recorded the highest annual rainfall on record, including the wettest month (February 2025) and wettest day (19 March 2025) in recorded history. River discharge in the Black River and Alligator Creek was also the highest on record. These hydrological extremes were accompanied by a prolonged tropical low system between late January and late February 2025, during which wind gusts reached near Category 1 cyclone strength. Periods where daily maximum wind speeds exceeded 38 km/hr, a threshold associated with elevated turbidity in Cleveland Bay (GHD 2024)  were frequent during this system. Individual disturbance events, such as a single flood, cyclone, or heatwave, are often followed by seagrass recovery under favourable environmental conditions. However, the period since 2019 has been characterised by successive and overlapping disturbances, including extreme rainfall (2018/19, 2021/22, 2022/23, 2024/25), marine heatwave conditions (2020; 2021/22; 2023/24), tropical cyclones (Kirrily), and prolonged low-light periods. Such cumulative stress is increasingly recognised as a driver of seagrass decline (Dunic et al. 2021; Turschwell et al. 2021).

Periods of high rainfall and river discharge are known to increase freshwater input, suspend sediment, increase nutrient loading, and reduce salinity in nearshore waters (Orpin et al. 1999; Orpin et al. 2004; Furnas et al. 2005; Brodie et al. 2009). These processes reduce light availability, increase sediment deposition across intertidal and shallow subtidal banks, and alter sediment biogeochemistry (Furnas et al. 2005; Brodie et al. 2009). The concurrence of elevated rainfall and river discharge in the year preceding the 2025 survey, therefore, represents a significant pressure, consistent with the widespread reduction in above-ground biomass observed across the monitoring region. Tropical weather systems and cyclonic activity during the reporting period also likely contributed additional physical disturbance through increased wave energy, sediment resuspension, seabed scouring, and localised burial (Orpin et al. 1999; Correia and Smee 2022).

While annual tidal exposure and solar radiation in 2025 was generally within long-term ranges, elevated cloud cover during peak rainfall months would also have reduced benthic light availability. In Cleveland Bay, benthic light is strongly influenced not only by cloud cover but also by wind-driven wave resuspension and riverine sediment inputs (Lambrechts et al. 2010; Bainbridge et al. 2012; Petus et al. 2014; Jones et al. 2020; GHD 2024). Wave resuspension occurs for much of the year and represents the dominant turbidity-generating process in Townsville waters (Orpin et al. 1999; Orpin et al. 2004; GHD 2024). When combined with record river discharge, these processes likely reduced total available photosynthetically active radiation (PAR) reaching seagrass meadows during critical growth windows.

PAR data collected across the Townsville region by PoTL confirmed that light availability was consistently low at most subtidal sites during the 12 months preceding the survey, with PAR frequently below thresholds associated with seagrass growth and persistence. Extended low-light periods during peak growing seasons are known to constrain seagrass recovery (Gacia et al. 2005; York et al. 2013). Prolonged periods of below-threshold light availability were observed during mid to late 2025, including in the months immediately preceding the survey.

Air temperature during 2025 continued a sustained period of above-average conditions, and while seabed temperatures were above-average levels during the summer months, they were unlikely to have reached sustained levels known to directly impact seagrass health (Campbell et al. 2006; Collier et al. 2017). Elevated temperatures and marine heatwave conditions can reduce seagrass physiological performance, particularly when coinciding with reduced light availability (York et al. 2013; Jung et al. 2023). Although extreme temperature exceedances were relatively short-lived, elevated air temperatures were recorded during the summer months, and the persistence of above-average conditions since 2019 represents an ongoing background thermal pressure that may influence long-term recovery capacity and resilience of seagrass meadows.

Temperature further interacts with light limitation to affect seagrass growth, with experimental studies showing that *Z. muelleri* can sustain growth at elevated temperatures if light is sufficient but declines sharply once temperatures exceed ~30–33 °C under light-limited conditions (Collier et al. 2011; York et al. 2013; Chartrand et al. 2016). Thermal optima for gross photosynthesis were found to be approximately 31 °C for *Z. muelleri* and 35 °C for *H. uninervis* and *C. serrulata* (Collier et al. 2017). Modelling of seagrass changes and environmental variables in Townsville as part of the Channel Upgrade Seagrass Program identified that a 7-day running mean of ~33.4 °C was associated with biomass gains for intertidal meadows and ~24.3 °C for subtidal meadows (McKenna et al. 2025b). Additionally, *Z. muelleri* carbon fixation and above-ground biomass have been shown to decline significantly under saturating light levels in conjunction with temperatures exceeding 33°C (Collier et al. 2011). Although this reporting period did not exhibit prolonged exceedances of these optima, repeated exposure to above-average temperatures across consecutive years may reduce resilience when combined with chronic turbidity and resultant low light (Collier et al. 2011; Jung et al. 2023).

Intertidal meadows are additionally influenced by tidal exposure to air. While shoulder periods around low tide can provide high light conditions, excessive exposure during periods of high air temperature can induce photo-inhibition and desiccation stress (Petrou et al. 2013). Although tidal exposure has not been extreme in recent years, a system already under pressure may be vulnerable to the combined effects of elevated air temperature and tidal exposure.

Analysis of the biannual monitoring record from 2019–2025 revealed seasonal patterns in seagrass meadow area between post-wet-season (April–May) and pre-wet/dry-season (September–November) surveys. Across this longer time series, meadow area was generally greater during the pre-wet/dry-season surveys, with the strongest seasonal patterns occurring in subtidal meadows. This pattern remained evident when the 2025 post-wet and pre-wet/dry-season surveys were incorporated into the longer-term analysis. In contrast, mixed-effects modelling detected no significant seasonal difference in above-ground biomass, with interannual variability having a substantially stronger influence than seasonal timing. The contrast between biomass and area responses suggests that seasonal dynamics in Townsville are expressed more strongly through changes in spatial extent, including meadow expansion, contraction or fragmentation, than through changes in above-ground biomass density. These changes may reflect seasonal expansion into, or loss from, marginal areas of suitable habitat in response to seasonal variation in environmental conditions.

Additional factors not directly monitored in this program, including sediment dynamics, grazing pressure, nutrient regimes, and propagule supply, may also influence changes in seagrass. For example, we recorded declines in the condition of the *H. uninervis* meadow along the Strand between the May 2022 and July 2022 surveys, attributed to herbivory (McKenna et al. 2023). Substantial numbers of dugong feeding trails and significant cropping of seagrass leaves were observed in this meadow (McKenna et al. 2023), leading to temporary reductions in above-ground biomass despite stable meadow extent (Scott et al. 2018; Cleguer et al. 2026). Such processes may interact with climate-driven stress to explain differences between individual meadows observed in the monitoring program.

The most concerning trend in recent years has been the decline of *Zostera muelleri* meadows, particularly those along the Cape Pallarenda-Shelly Beach coastline. Field observations since 2023 have documented substantial sediment redistribution in this region, with areas previously dominated by mud, preferred by *Z. muelleri*, now characterised by mobile sandbanks and/or sand substrates. During the 2024 and 2025 surveys, extensive sediment scouring was observed along the Pallarenda coastline, with seagrass rhizomes and roots exposed above the sediment surface. In some locations, only exposed rhizome networks remained, indicating significant sediment loss or a shift in substrate. Recent geomorphic analysis indicates severe coastal erosion north of Three Mile Creek since 2020, with sand cliffs forming by late 2022 (Wolanski and Hopper 2025). While this analysis focused on Cape Pallarenda, similar sediment dynamics may extend northwards toward the Bohle River, consistent with scouring observed within the Shelley Beach meadow.

Collectively, these findings show that seagrass meadows in Townsville have been subjected to sustained and overlapping environmental stressors since 2019, including high rainfall, extreme river discharge, elevated turbidity associated with strong winds, reduced light availability, short periods of above-average seabed temperatures, and repeated storm activity. The limited intervals between disturbance events likely reduced recovery windows, particularly for biomass accumulation, even when meadow extent and species composition remained relatively stable.

## 6.1 Implications for seagrass resilience, port management and future monitoring

The widespread nature of seagrass declines in intertidal and subtidal meadows and across the monitoring meadow network is consistent with cumulative climatic and hydrodynamic pressures acting at a regional/Cleveland Bay wide scale, rather than a single, isolated disturbance such as maintenance dredging activities. The patterns of decline were not spatially confined to areas adjacent to port infrastructure and channels but observed across the broader Cleveland Bay region. Outside of Townsville, similar changes in seagrass have been observed in other Queensland monitoring programs. Just south of Cleveland Bay, the GBRMPA Marine Monitoring Program sites in Bowling Green Bay recorded the lowest cover since monitoring began (2012), with both sites measuring below 3 % cover (Leahy et al. 2026). North of Townsville, Mourilyan Harbour's seagrass meadows have been in decline since 2009, while Cairns Harbour/Trinity Inlet has recorded declines in seagrass above-ground biomass and area for the last two years (Scott et al. 2026; Shepherd et al. 2026). These suggest that Townsville's seagrass meadows were responding to both local climate conditions and broader regional climate drivers.

Annual seagrass monitoring in Townsville provides a long-term insight into the resilience of Townsville seagrasses to environmental disturbances. Over the duration of the program, seagrasses in Townsville have repeatedly demonstrated the capacity to recover from major disturbance events and to withstand prolonged periods of reduced light availability. By 2017/2018, most meadows had recovered from losses associated with Tropical Cyclone Yasi and associated La Niña conditions (consecutive years of above-average rainfall and river discharge). Cleveland Bay is naturally turbid and experiences inherent fluctuations in light and turbidity (Orpin et al. 1999; Petus et al. 2014; GHD 2024). The persistence of seagrass meadows under these conditions and their historical recovery following disturbance indicate a degree of adaptation and resilience. However, experience from other Queensland locations (e.g., Mourilyan Harbour; Shepherd et al. 2024) indicates that repeated disturbances over multiple consecutive years may result in longer-term declines and no recovery at all, or recovery trajectories becoming increasingly uncertain.

Despite the overall poor condition of seagrass in Townsville at the end of 2025, several indicators suggest that some level of resilience has been retained. Spatial coverage remains satisfactory in most meadows, species composition has been largely maintained, and persistent, higher-light-requiring species remain present in subtidal habitats. These are all positive indicators that recovery could occur should environmental conditions return to be more favourable for seagrass growth.

Of most concern, however, is the decline of *Z. muelleri* meadows, which in 2025 resulted in the complete loss of the Shelley Beach monitoring meadow (10) for the first time in the program. As discussed earlier, a shift in sediment composition and movement along this section of the coast may have contributed to the pressures and explain the declining trend over recent years. There is still reasonable potential for *Z. muelleri* to re-establish naturally by recruiting from propagules generated elsewhere in Cleveland Bay, but experience from similar *Z. muelleri* losses in Cairns and Mourilyan in 2011 has shown that this can be a slow process or may not occur without intervention and active restoration. This highlights the need for a greater understanding of meadow specific drivers of loss and how to restore seagrass for the local Cleveland Bay species and meadows, to ensure we are prepared should interventions be required.

The legacy effects of successive meteorological pressures since 2019, including extreme rainfall, record river discharge, flooding, elevated turbidity, strong wind events, and above-average temperatures, have contributed to the deterioration of seagrass conditions observed in 2025. The cumulative pressures of disturbances reduce the frequency and duration of favourable environmental windows required for recovery. Continued monitoring is therefore critical to determine whether meadows stabilise under improved conditions or whether declines represent a longer-term shift. Given the overall poor condition of Townsville seagrass at the end of 2025, PoTL has commissioned a post-wet-season 2026 assessment to provide an updated evaluation of meadow condition and recovery trajectories and inform any potential management or intervention requirements.

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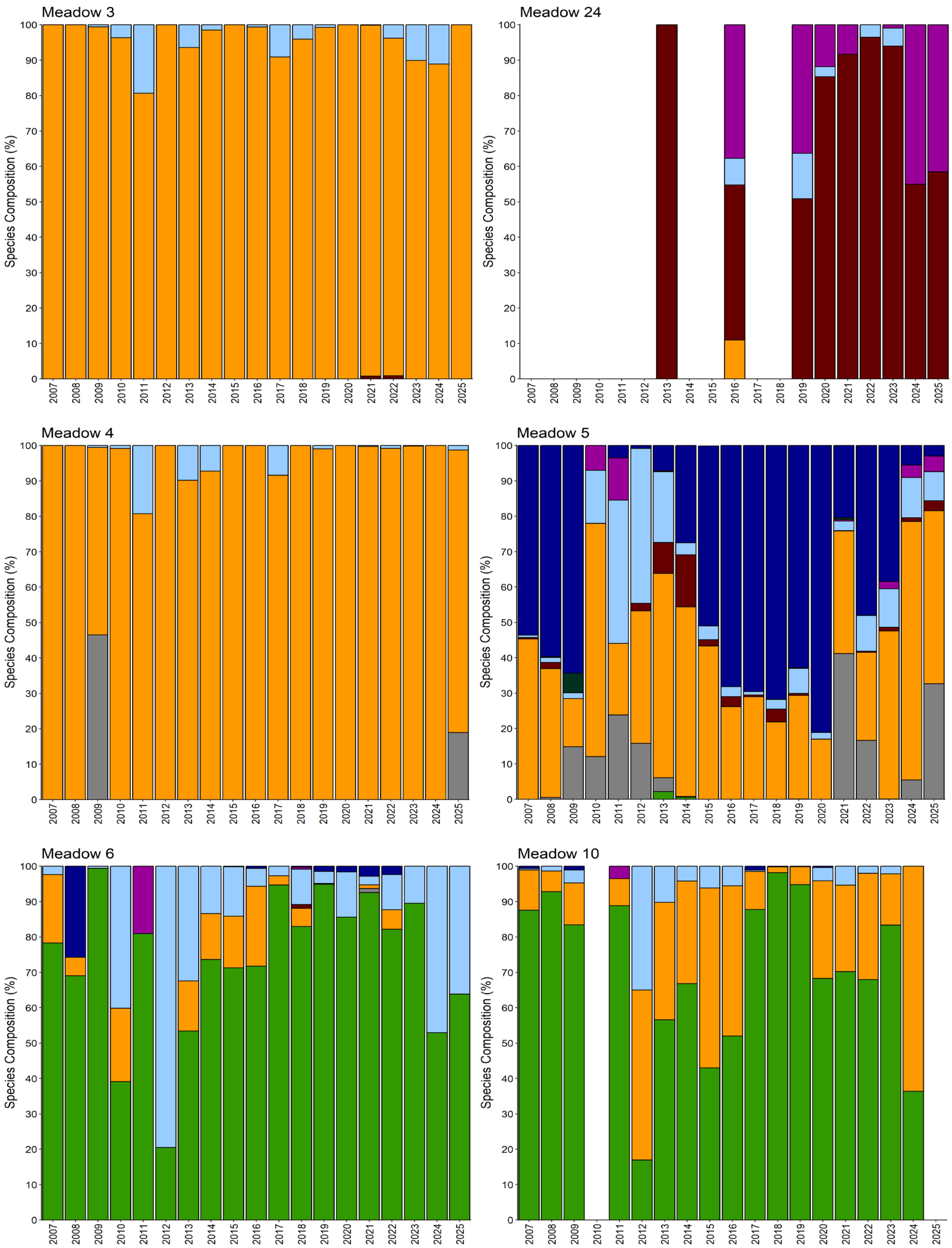
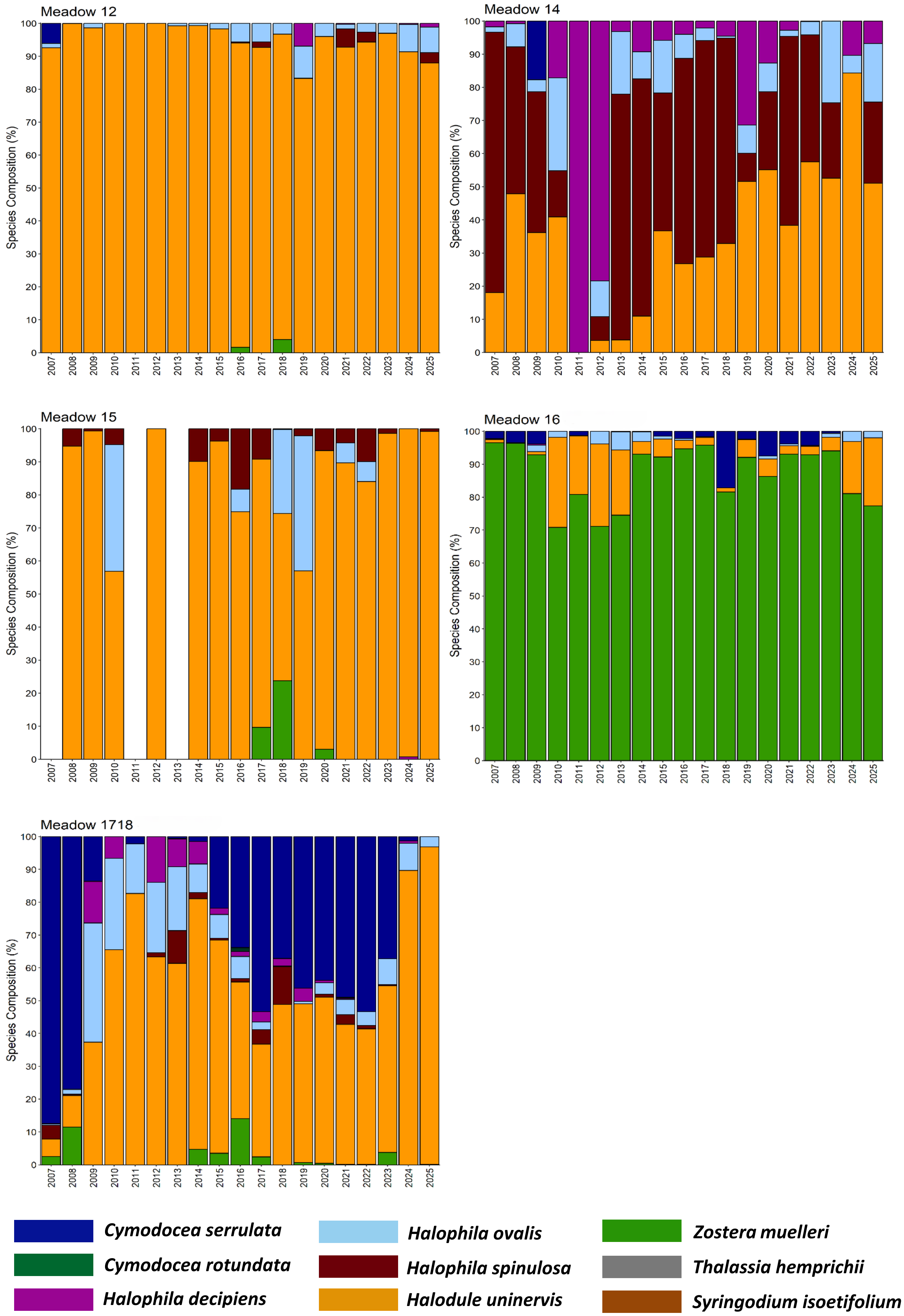
# 8 APPENDICES

## 8.1 Appendix 1. Detailed meadow species composition; 2007-2025

Meadow 24 (subtidal Geoffrey Bay monitoring meadow) was surveyed as part of the annual LTSMP survey in 2025. Meadow 24 is on its eighth annual survey (excluding baseline surveys in 2013 and 2016), so the baseline levels are likely to adjust.




Meadow 12
Meadow 14
Meadow 15
Meadow 16
Meadow 1718
Species Composition (%)
Cymodocea serrulata
Halophila ovalis
Zostera muelleri
Cymodocea rotundata
Halophila spinulosa
Thalassia hemprichii
Halophila decipiens
Halodule uninervis
Syringodium isoetifolium