Port of Townsville Seagrass Monitoring Program 2022

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Port of Townsville Seagrass Monitoring Program 2022

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We acknowledge the Australian Aboriginal and Torres Strait Islander peoples as the traditional owners of the lands and waters where we live and work.

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CONTENTS

1 KEY FINDINGS

Seagrass Condition 2022

GOOD

LTSMP meadows

SATISFACTORY

CUSP meadows

A Long-term Seagrass Monitoring Program (LTSMP) for the Port of Townsville was established in 2007. The program was expanded in 2019 to incorporate targeted monitoring for the Townsville Channel Upgrade Project (CU Project) referred to as the Channel Upgrade Seagrass Program (CUSP).

This report presents the results of the 16th year of the LTSMP and the 4th year of the CUSP. Key findings for the 2022 surveys include:

- Overall, seagrass condition was good for the LTSMP meadows and satisfactory for the CUSP meadows.
- All but three meadows in the region were in a satisfactory or better condition in October 2022. All meadows however were within the range of previously recorded values for area, biomass, and species composition.
- Seagrass inside the whole-of-port survey limit covered 12,306 ha. Of this distribution:
    - CUSP meadows covered 3,841 ha
    - LTSMP meadows covered 6,069 ha
- Nine of the eleven seagrass species that are known to occur in the Townsville region were present in areas surveyed in 2022.
- *Halophila tricostata* that was recorded for the first time in the LTSMP in 2021, was again present in the deeper areas of Cleveland Bay in 2022.
- Nearly all meadows underwent minor declines in area and/or biomass between October 2021 and October 2022. Declines were region wide and not confined to areas closest to the port or dredging activity, pointing to wider/regional drivers of change.
- Unfavourable growing conditions for seagrass including a heatwave, above average out of season rainfall, sustained periods of high wind and multiple periods of low light conditions across many sites likely contributed to declines in seagrass condition in most meadows.
- Green sea turtles, dugongs and their feeding trails in seagrass meadows were observed during field surveys indicating a high use of the area by herbivorous marine megafauna.

2 IN BRIEF

The Port of Townsville Long-term Seagrass Monitoring Program (LTSMP) was established in 2007. Seagrass in the region has been monitored annually since then. In 2019 the LTSMP was modified to a fit-for-purpose program to address regulator conditions outlined for the Channel Upgrade Project (CU Project): the Channel Upgrade Seagrass Program (CUSP). This specified monitoring program builds on the LTSMP and is designed to assess and monitor seagrass habitat bi-annually before, during and after planned project works. The CUSP includes the monitoring meadows that form the LTSMP and expanded areas of seagrass in assessments to meet regulatory requirements and conditions associated with the CU Project (Figure 1). At the end of each year all seagrasses within the broader port limits are surveyed (Figure 1). This report presents the results of the 16th year of the LTSMP and the 4th year of the CUSP.

In 2022, the April-May survey was expanded to include the LTSMP meadows, not just CUSP meadows. This increase in survey extent was to identify if the March 2022 heatwave in Townsville had any impacts, and the scale (if any) of these impacts on seagrass in Townsville. An additional survey at the CUSP monitoring extent was also conducted in July 2022 to determine and capture any delayed response of seagrass loss to the heatwave and periods of low light recorded in May 2022.

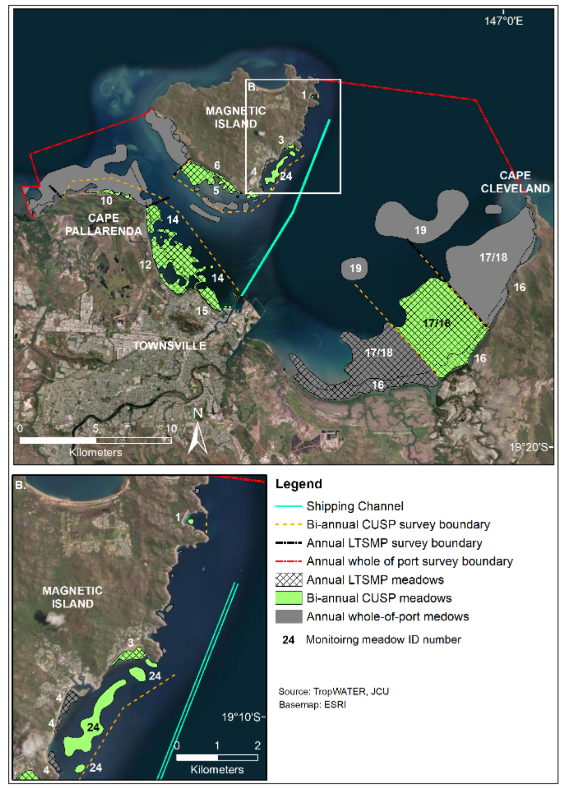

Figure 1. Location and survey extent of meadows assessed in annually surveyed LTSMP meadows, biannually surveyed CUSP meadows, and at the whole-of-port scale.

Seagrass in the Port of Townsville were in an overall satisfactory (CUSP meadows) or better (LTSMP meadows) condition in 2022. The whole-of-port seagrass footprint covered 12,306 ha in 2022 of which the LTSMP meadows covered 6,069 ha, the CUSP meadows covered 3,841 ha and the deep-water *Halophila* meadow (Meadow 19) covered 1,449 ha (Figure 2). Total area of LTSMP meadows remained above the long-term average (Figure 3).

At the individual meadow level, all but three meadows in the region were in a satisfactory or better condition in 2022 (Figure 2). Nearly all meadows underwent minor declines in area and/or biomass between October 2021 and October 2022. Individual meadow condition for biomass and area ranged between poor and very good while species composition in all meadows was in good or better condition. The fact that declines occurred throughout the entire region suggests regional scale drivers of change rather than localised declines associated with the CU dredging works. Local environmental conditions through 2022 are likely to have driven the relatively small declines in meadow biomass and/or area recorded in seagrass meadows throughout Townsville.

During 2022 there were many periods when environmental conditions were not favourable for seagrass growth and productivity. As individual one-off events these unfavourable conditions were not likely to be sufficient to impact seagrass in the region, however, the cumulative impact of multiple events throughout the year were likely to have been behind the relatively small declines recorded in October 2022. Unfavourable environmental conditions in 2022 included a March heat wave, out of season above average rainfall, persistent elevated wind conditions (> 20 knots) coinciding with the above-average rainfall months, and low light conditions for significant periods of time (i.e., greater than 28 days) throughout the year at various times and sites.

Three seagrass meadows in the Townsville region have shown declining trends over recent years: the Cockle Bay intertidal reef top Meadow 5, Cleveland Bay intertidal *Z. muelleri* Meadow 16 and the Shelley Beach intertidal *Z. muelleri* Meadow 10. Declines in the two *Z. muelleri* meadows can be explained by competing boundaries with adjacent seagrass meadows, expanding stands of mangroves, and expanding and shifting sand banks. The Cockle Bay reef top meadow may be experiencing a localised disturbance contributing to declining trends over recent years. Our field observations over the past decade suggest that the reef top has changed to be dominated by unconsolidated rubble rather than consolidated rubble/rock and hard coral making the landscape more difficult for seagrass to colonise and persist. While the exact cause of these changes is not clear it is unlikely to be associated with the CU Project as changes predate the start of the project and light levels recorded in the meadow through the CU Marine Water Monitoring Program have not fallen below biologically relevant thresholds during the project in this meadow.

The deep-water *Halophila* meadows in Townsville continued to be highly variable in extent from year to year. The footprint of the Cleveland Bay meadow decreased between October 2021 and October 2022 but was similar to the spatial extent recorded in 2016.

The condition of seagrass meadows in Townsville reflected local environmental changes. Long term monitoring at other locations in the Queensland wide seagrass monitoring network showed similar results. In Gladstone local weather-related changes in seagrass were recorded with some meadows being impacted by high rainfall events, whereas seagrass in Cairns, Clairview and Abbot Point were in good condition with generally favourable local weather conditions (Rasheed et al. 2023; Reason et al. 2023; Smith et al. 2023). For full details of the Queensland ports seagrass monitoring program see: www.tropwater.com/project/management-of-ports-and-coastal-facilities/

Green sea turtles, dugongs and their feeding trails in seagrass meadows were observed during helicopter and boat-based field surveys indicating a high use of the area by herbivorous marine megafauna.

While some indicators of seagrass condition in some meadows may mean they are more susceptible to future pressures than previously, their good spatial coverage and species composition means they have some resilience with a capacity to return to better overall meadow condition if favourable environmental conditions are present through 2023.

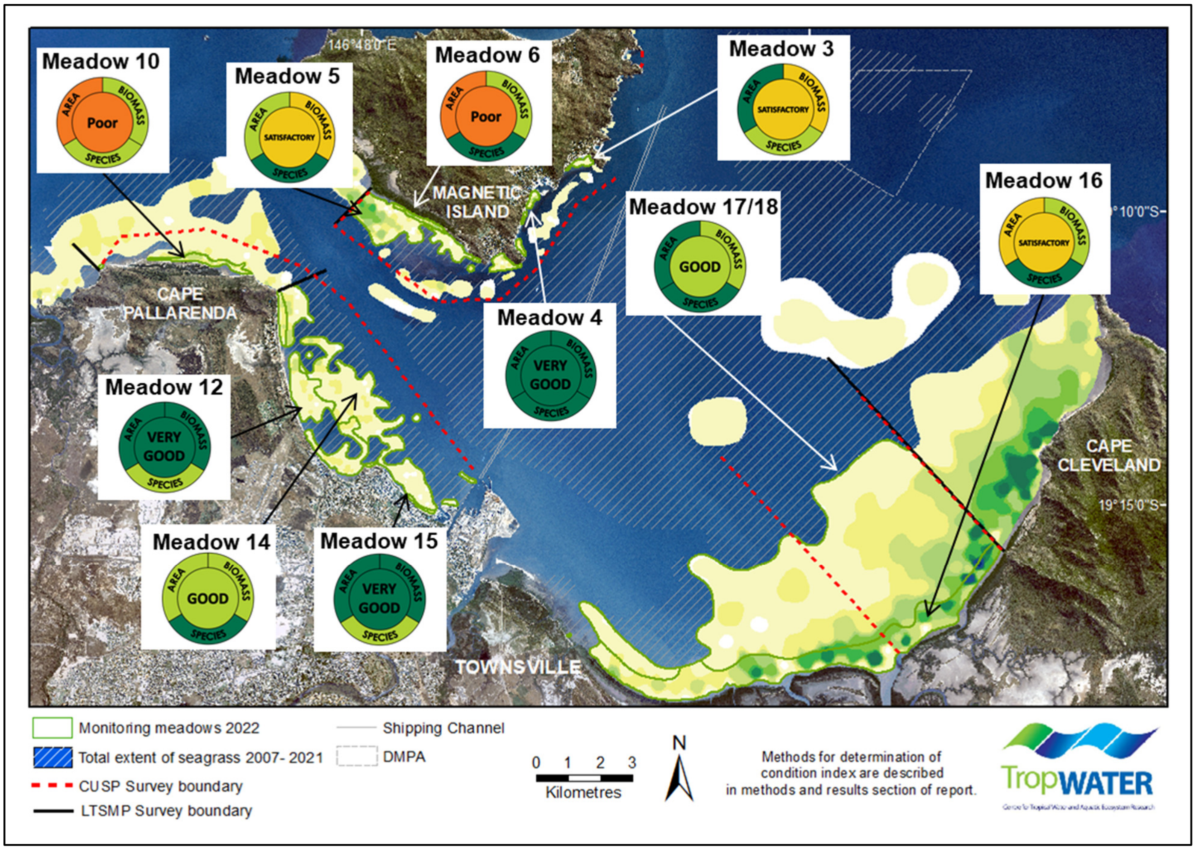

Figure 2. Seagrass condition for meadows monitored as part of the Long-Term Seagrass Monitoring Program (LTSMP) September/October 2022. For CUSP meadow condition see results section 5.2.

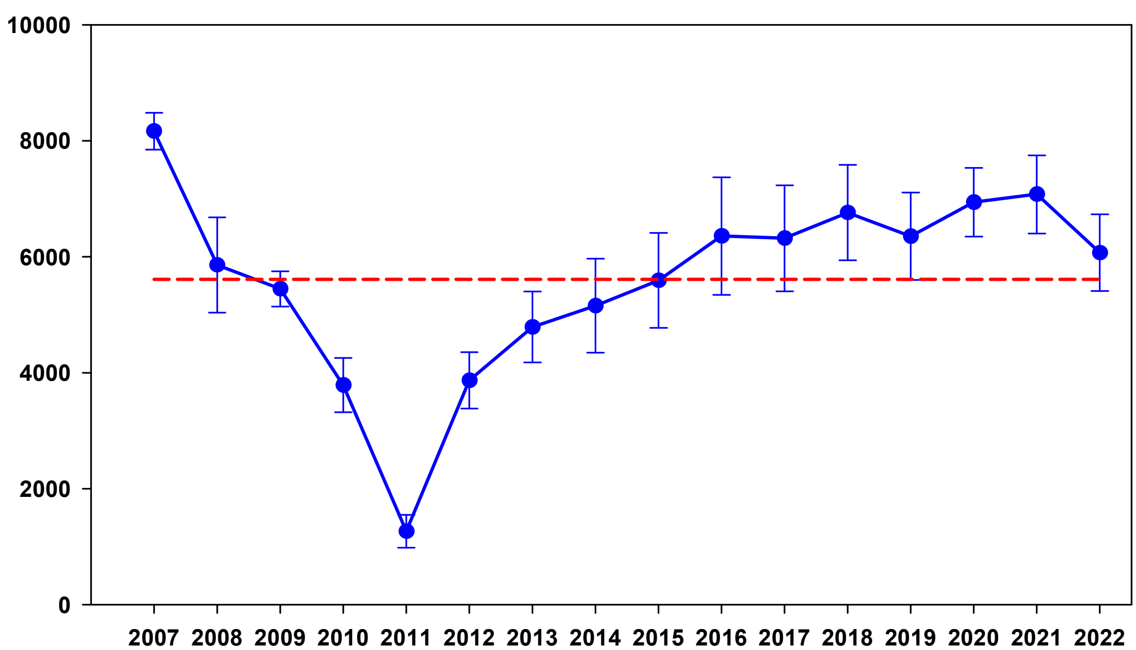

Figure 3. Total area of the Long-Term Seagrass Monitoring Program meadows (LTSMP); 2007-2022 (error bars = "R" reliability estimate), (red dashed line = long-term average).

3 INTRODUCTION

Seagrasses are one of the most productive marine habitats on earth and provide a variety of important ecosystem services with substantial economic value (Barbier et al. 2011; Costanza et al. 2014). These services include the provision of nursery habitat for economically important fish and crustaceans (Coles et al. 1993; Heck et al. 2003), and food for grazing marine megaherbivores like dugongs and sea turtles (Heck et al. 2008; Scott et al. 2018). Seagrasses also play a major role in the cycling of nutrients (McMahon and Walker 1998), sequestration of carbon (Fourqurean et al. 2012; Lavery et al. 2013; York et al. 2018, Rasheed et al. 2019), stabilisation of sediments (James et al. 2019), and the improvement of water quality (McGlathery et al. 2007).

Globally, seagrasses have been declining due to natural and anthropogenic causes (Dunic et al. 2021; Waycott et al. 2009). Explanations for seagrass decline include natural disturbances such as storms and cyclones, disease and overgrazing by herbivores, as well as anthropogenic stresses including direct disturbance from coastal development, dredging and trawling, coupled with indirect effects through changes in water quality due to sedimentation, pollution, and eutrophication (Short and Wyllie-Echeverria 1996). In the Great Barrier Reef (GBR) coastal region, the hot spots with the highest threat exposure for seagrasses all occur in the southern two thirds of the GBR, in areas where multiple threats accumulate including urban, port, industrial and agricultural runoff (Grech et al. 2011). These hot spots 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).

3.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program is 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 the various Queensland port authorities. While each location is funded separately, a common methodology and rationale is used providing a network of seagrass monitoring locations throughout Queensland (Figure 4).

Figure 4. Location of Queensland port seagrass monitoring sites.

This strategic long-term assessment and monitoring program for seagrasses provides port managers and regulators with key information to ensure effective management of seagrass habitat and ecosystem function. This information is often central to planning and implementing port development and maintenance programs that ensure minimal impact on seagrass.

The program provides an ongoing assessment of many of the most vulnerable seagrass communities in Queensland, and feeds into regional assessments of the status of seagrass habitats. The program has also provided significant advances in the science and knowledge of tropical seagrass and habitat ecology. This includes the development of tools, indicators and thresholds for the protection and management of seagrass, and an understanding of the drivers of seagrass change.

For more information on the program and reports from the other monitoring locations see: www.tropwater.com/project/management-of-ports-and-coastal-facilities/

3.2 Port of Townsville Seagrass Monitoring Programs

3.2.1 The Long-Term Seagrass Monitoring Program (LTSMP)

The Townsville port environment is managed by Port of Townsville Limited (PoTL). The port is situated in the Great Barrier Reef World Heritage Area, outside of the Great Barrier Reef Marine Park, and supports a diverse range of habitats including significant and productive seagrass meadows and reefs that begin in the intertidal zone and extend down to ~15m below mean sea level. Townsville seagrass meadows are a connectivity hot spot in the central GBR (Grech et al. 2018).

As part of their commitment to the environmental health of the port, PoTL in partnership with James Cook University's TropWATER established a seagrass monitoring program in 2007 to assess and monitor the seagrass habitat surrounding Townsville and Magnetic Island; the Long-term Seagrass Monitoring Program (LTSMP). Detailed baseline surveys were conducted in summer 2007/2008 and winter 2008 to provide information on the distribution, abundance and seasonality of seagrasses within the broader port limits (Rasheed and Taylor 2008). From these baseline surveys representative meadows (currently 10 meadows; Figure 5) were selected for annual monitoring, with broader whole-of-port mapping occurring in some years (2007, 2008, 2013, 2016, 2019, 2020, 2021 & 2022). The areas selected for annual monitoring represent the range of seagrass communities within the port, and include meadows considered most likely to be influenced by port activity and development, along with areas outside the zone of influence of port activity and development. The LTSMP has mapped up to 25,000 ha (2007) of coastal and deep-water seagrass in the broader Townsville area.

The program provides a regular assessment of seagrass condition and resilience in the area and provides an annual update on the marine environmental health of Cleveland Bay to inform port management. The monitoring program forms part of Queensland's network of long-term monitoring sites of important fish habitats in high-risk areas. Information from the program also provides key input into the condition and trend of habitats for the Dry Tropics Partnership for Healthy Water reporting (www.drytropicshealthywaters.org).

3.2.2 The Channel Upgrade Seagrass Program (CUSP)

The Port of Townsville Limited is upgrading the approach channel as part of their Port Expansion Project: The Channel Upgrade Project (CU Project). The CU Project is Stage 1 of the long-term port plans and involves capital dredging-related activities of the Platypus and Sea channels, and the construction of a reclamation area and temporary offloading facility.

To address regulator conditions outlined for the project, a fit-for-purpose seagrass program was developed in 2019; the Channel Upgrade Seagrass Program (CUSP). This specified monitoring program builds on the established LTSMP and is designed to assess and monitor seagrass habitat bi-annually surrounding Townsville, Cleveland Bay and Magnetic Island before, during and after the planned works. The CUSP includes the monitoring meadows that form the LTSMP and expanded areas of seagrass in assessments to meet regulatory requirements and conditions associated with the CU Project (Table 1; Figure 5). The CUSP involves:

- Establishing baseline conditions of seagrass communities before project works begin (seagrass senescent and peak season conditions).
- Monitoring the condition of seagrass communities before, during and after project works.
- Assessing seagrass condition at selected monitoring meadows biannually and at the whole-of-port scale annually.
- Examining changes to seagrass habitat due to project works, climate/weather events or natural background changes.

This report presents the results of the 16th year of the LTSMP, and the 4th year of the CUSP and compares the results with previous surveys.

4 METHODS

4.1 Sampling Approach

Survey and monitoring methods for assessing seagrass in the Townsville region follow those of the established techniques for Townsville and TropWATER's Queensland-wide seagrass monitoring programs. The application of standardised methods in Townsville and throughout Queensland allows for direct comparison of local seagrass dynamics with other seagrass monitoring programs in the broader Queensland region.

Detailed methods and sampling approach for the LTSMP and CUSP are in previous reports (McKenna et al. 2022; Wells & Rasheed 2017). Briefly, the LTSMP monitors ten seagrass meadows annually, with most of these meadows or meadow sections also forming the CUSP (Table 1, Figure 5). Table 1 provides details on what meadows are assessed in each program.

Seagrass assessments for the LTSMP occur annually between September – November, while assessments for the CUSP occur twice a year: post-wet season (April-May) and in the dry season (September-November) when seagrasses are generally at the peak of distribution and abundance.

The CUSP is structured using two levels of monitoring:

- *Whole-of-port seagrass assessments* – Whole-of-port seagrass assessments occur annually, at the same time as the LTSMP (Table 1, Figure 5). Assessing seagrass at the whole-of-port scale provides better context for the changes observed within the CUSP and LTSMP meadows. It also ensures trends observed in the monitoring meadows represent the broader Townsville area, and conversely the changes in seagrasses in the broader area add important perspective and confidence to any changes seen in the monitoring meadows. It is at this whole-of-port scale that the deep-water highly variable seagrasses between Cleveland Bay and Magnetic Island are assessed (Figure 5).
- *Monitoring meadow seagrass assessments* – These meadows/meadow sections are monitored biannually: post-wet season (April/May) and dry season (September-November) and capture meadows that are reference and potential impact regions for the CU Project (Figure 5).

Table 1. The Long-term Seagrass Monitoring Program (LTSMP) and Channel Upgrade Seagrass Program (CUSP) monitoring meadows.

Monitoring Location (Meadow ID)	Long-term Seagrass Monitoring Program (LTSMP)	Survey frequency	Channel Upgrade Seagrass Program (CUSP)	Survey frequency	Seagrass Meadow Depth	Seagrass Meadow Type (dominant species)	Species Present	Monitoring History
Florence Bay (1)	No	-	Yes	Biannually	Intertidal/shallow subtidal	Halodule uninervis	HU	Limited: (2007, 08, 16, 19, 20, 21, 22)
Geoffrey Bay (3)	Yes	Annually	Yes	Biannually	Intertidal	Halodule uninervis	HU, HO, CS	Detailed Annual >10 years
Nelly Bay (4)	Yes	Annually	No	-	Intertidal/shallow subtidal	Halodule uninervis	HU, HO, CS	Detailed Annual >10 years
Geoffrey Bay (24)	No	-	Yes	Biannually	Subtidal	Halophila spinulosa	HS	Limited: (2013, 16, 19, 20, 21, 22)
Cockle/Picnic Bay (5)	Yes	Annually	Yes	Biannually	Intertidal/shallow subtidal	Halodule uninervis	CS, HU, HO, HS, HD	Detailed Annual >10 years
Cockle Bay (6)	Yes	Annually	Yes	Biannually	Intertidal	Zostera muelleri	ZM, HU, HO	Detailed Annual >10 years
Shelly Beach (10)	Yes	Annually	Yes	Biannually	Intertidal	Zostera muelleri	ZM, HU, HO	Detailed Annual >10 years
Rowes Bay (12)	Yes	Annually	Yes	Biannually	Intertidal/shallow subtidal	Halodule uninervis	HU, HO, HD, ZM, HS, CS	Detailed Annual >10 years
Pallarenda inc. Virago Shoal) (14)	Yes	Annually	Yes	Biannually	Shallow subtidal	Halophila spinulosa	HS, HU, HO, HD, CS	Detailed Annual >10 years
Strand (15)	Yes	Annually	No	-	Intertidal/shallow subtidal	Halodule uninervis	HU, HO, HD, ZM, HS	Detailed Annual >10 years
Cleveland Bay (16)	Yes	Annually	Yes (meadow section)	Biannually	Intertidal	Zostera muelleri	ZM, HU, CS	Detailed Annual >10 years
Cleveland Bay (17/18)	Yes	Annually	Yes (meadow section)	Biannually	Subtidal	Halodule uninervis / Cymodocea serrulata / Halophila spinulosa	HU, CS, HD, HS	Detailed Annual >10 years
Deep-water seagrass - Cleveland Bay to Magnetic Is. (19)	No	Periodically, before CUSP began	Yes	Annually	Subtidal	Halophila decipiens/Halophila spinulosa	HD, HS	Limited: (2007, 08, 13, 16, 19, 20, 21, 22)

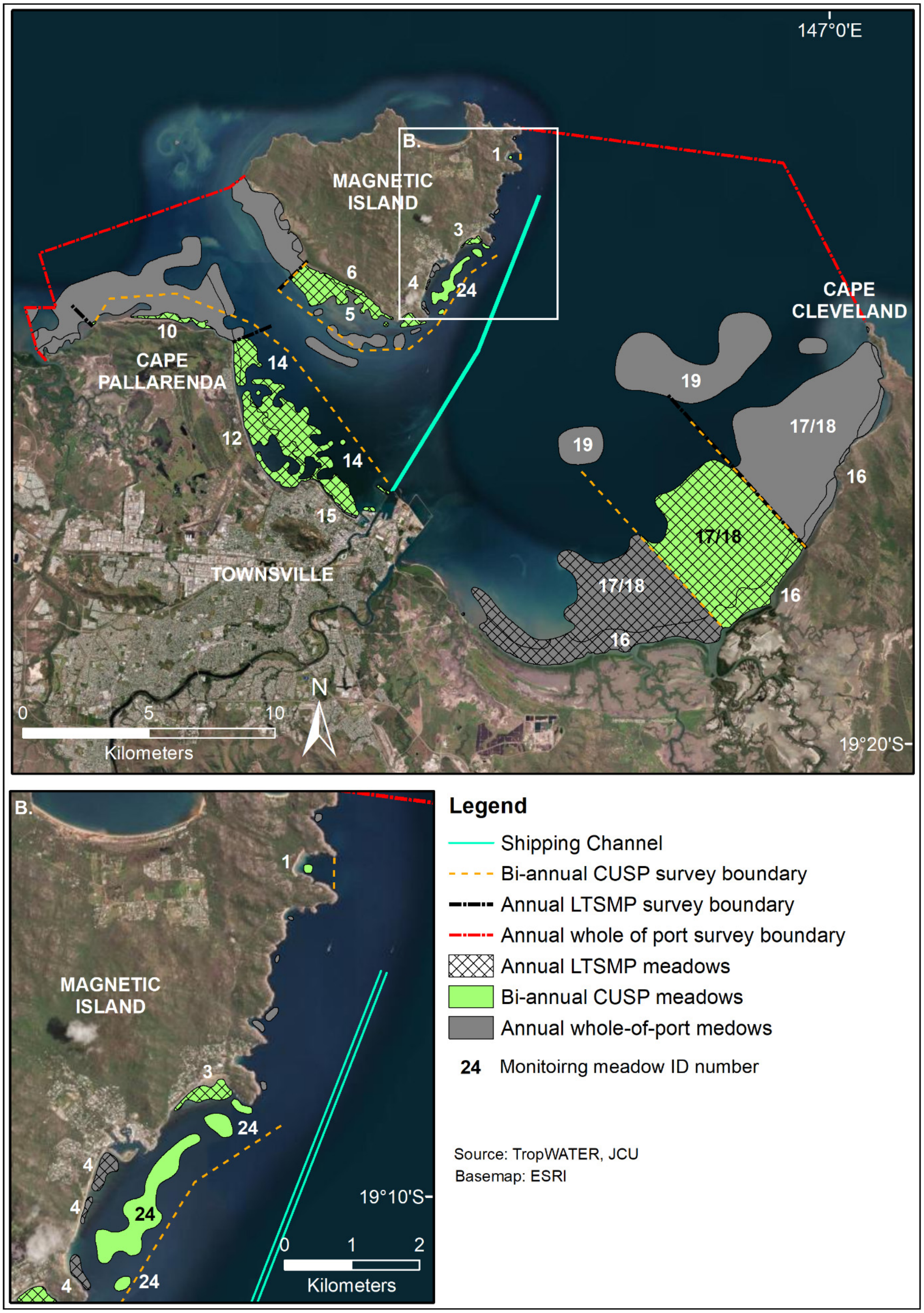

Figure 5. Location and survey extent of meadows assessed in annually surveyed LTSMP meadows, biannually surveyed CUSP meadows, and at the whole-of-port scale.

4.2 Seagrass Indicators & Sampling Techniques

Three principal indicators of seagrass condition are assessed at each survey: seagrass biomass, species composition and meadow area. These are fundamental indicators used to answer questions surrounding seagrass condition, i.e., is seagrass present? What is the spatial footprint of the meadow? How dense is the seagrass? What species define the meadow?

Sampling techniques include (Figure 6):

1. *Intertidal seagrass*: helicopter survey of exposed banks during low tide – sites are scattered throughout the seagrass meadow and sampled when the helicopter comes into a low hover <1m from substrate.
2. *Shallow subtidal seagrass*: digital camera drop surveys – sites are sampled perpendicular to the shoreline approximately every 50-200 m or where major changes in bottom topography and seagrass community type occur. Sites extend to the offshore edge of seagrass meadows and measure continuity of seagrass communities.
3. *Deep-water seagrass*: boat-based sled tows with digital camera attached – sites are sampled using an underwater camera system towed for approximately 100 m while footage is observed on a monitor. Surface benthos is captured in a towed net and used to confirm seagrass, algal and benthic macro-invertebrate habitat characteristics observed on the monitor. The technique ensures that a large area of seafloor is surveyed and integrated at each site so that patchily distributed seagrass and benthic life typically found in deep-water habitats is detected.

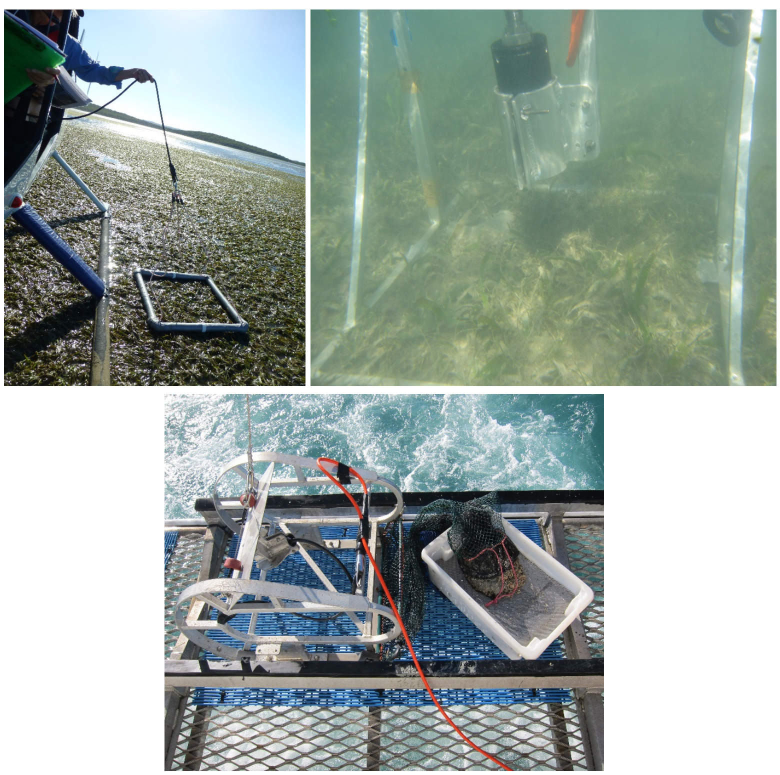

Figure 6. The different seagrass monitoring techniques: helicopter aerial surveillance, boat based digital, live feed camera systems.

Seagrass above-ground biomass was determined using a "visual estimate of biomass" technique (see Kirkman, 1978; Mellors, 1991). Biomass and species change calculations for meadows 3 and 4 on Magnetic Island were performed excluding the contribution of *Cymodocea serrulata.* The focus of monitoring at these meadows is to track changes in *Halodule uninervis,* however the presence of the much larger *C. serrulata* in some isolated patches had the potential to mask changes to *H. uninervis* between years. This was due to the haphazard site locations occasionally falling on one of these isolated patches. Similarly, *Enhalus acoroides* has been excluded from meadow biomass calculations in meadows 5 and 6 on Magnetic Island.

4.3 Habitat Mapping and Geographic Information System

All survey data were entered into the Port of Townsville Limited Geographic Information System (GIS) using ArcGIS 10.8®. GIS layers were created to describe spatial features of the region: a site layer, seagrass meadow layers, and seagrass biomass interpolation layers.

- *Site Layer:* The site (point) layer contains data collected at each site, including:
    - 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 biomass standard error (SE); percent 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 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 (Figure 6).
    - 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 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 system are in previous reports (see McKenna et al. 2022).

Seagrass meadow boundaries were constructed using GPS marked meadow boundaries where possible, seagrass presence/absence site data, field notes, colour satellite imagery of the survey region (Source: ESRI), depth contours and aerial photographs taken during helicopter surveys. Meadow area was determined using the calculate geometry function in ArcGIS® 10.8. Meadows were assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 2). The mapping precision estimate was used to calculate a buffer around each meadow representing error; the area of this buffer is expressed as a meadow reliability estimate (R) in hectares.

Table 2. Mapping precision and methodology for seagrass meadows in Townsville, 2022.

Mapping precision	Mapping methodology
3-20 m	• Intertidal meadows completely exposed or visible at low tide. • Inshore meadow boundaries determined from helicopter. • Offshore meadow boundaries determined from helicopter and/or free diver/camera. • Relatively high density of mapping and survey sites. • Recent aerial photography aided in mapping.
20-50 m	• Meadow boundary interpreted from free diver/camera surveys. • Most meadows partially-completely subtidal. • Moderate density of survey sites. • Recent aerial photography aided in mapping.
100 m	• Subtidal meadow boundaries determined from free diving/camera/grab/distance between survey sites/ presence/absence of seagrass. • Meadows subtidal. • Moderate – sparse density of survey sites;

4.4 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 (see Carter et al. 2023 for full details). Seagrass condition for each indicator in each meadow was scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). Overall meadow condition is the lowest indicator score where this is biomass or area. Where species composition is the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50% (Carter et al. 2023).

We have previously established baseline conditions for seagrass meadow biomass, area and species composition at the ten LTSMP meadows. For CUSP meadows that are also LTSMP meadows (Table 1), these baseline conditions are the same. The baseline condition for the CUSP sub-section of the Cleveland Bay meadows (meadows 16 and 17/18) has been extracted from the historical data available and calculated for the CUSP section (10 years of baseline data). For the two CUSP meadows that are not part of the LTSMP (Meadows 1 and 24; Table 1) we have developed an interim baseline condition using the data available at the time of this report (seven years for Meadow 1 and six years for Meadow 24). Baseline conditions for these meadows will continue to be added to and adjusted with additional years of monitoring data as appropriate.

4.5 Statistical design and analysis specific to the channel upgrade project and CUSP

The statistical design and analysis of data specific to the CU Project and CUSP will follow the typical BACI design commonly used in impact assessments (before-during-after and control-impact). As a minimum, seagrass will be assessed as either a reference or impact location (noting meadows may change monitoring type (i.e., reference/impact/gradient) as the dredging moves through different locations).

A finer-scale analysis will be incorporated with several impact levels (zones of influence, low impact, moderate impact, and high impact – if applicable). We will also analyse dredging effects along a gradient of impact for seagrass meadows that span several of the zones, e.g., the Strand-Cape Pallarenda meadows, to allow an evaluation of the potential changes to seagrass at increasing distance from the disturbance (dredge and/or plume).

Seagrass data in tropical Queensland rarely meets the assumptions required to conduct standard statistical analysis used in BACI impact assessments, such as ANOVA. Advanced statistical techniques will be used on the data and options include logistic regression, zero-inflated models and zero-altered gamma models. Other 'gradient from impact' tools that can be used to analyse data include proximity from impact and spatial interpolation tools.

Other information that will be required and feed into the data analysis include knowledge of where the dredge is operating at any given point in time, and integration with the network of water quality monitoring sites. Other environmental data (e.g., rainfall, river flow) will also be incorporated into analysis.

A power analysis for each meadow was completed prior to the monitoring program to determine the appropriate number of sampling sites for each meadow to detect ecologically relevant seagrass meadow change.

4.6 Environmental Data

Environmental data presented in this report were collated for the twelve months preceding each survey. Tidal data was provided by Maritime Safety Queensland (MSQ). Total daily rainfall (mm), solar exposure and air temperatures were obtained for the nearest weather station from the Australian Bureau of Meteorology (Townsville airport #032040; http://www.bom.gov.au/climate/data/). River data was obtained from the Queensland Governments Water Monitoring Information Portal https://water-monitoring.information.qld.gov.au/.

Detailed water quality data for the Townsville area (i.e., Photosynthetically Active Radiation (PAR) mol photons m^{-2} day^{-1}) is supplied by the CU Project Marine Water Monitoring program (CU MWMP).

5 RESULTS

5.1 Seagrass Presence and Species Throughout Townsville

In 2022 three monitoring surveys were conducted in the Port of Townsville. The April-May survey was expanded to include the LTSMP meadows and sections of meadows that are not common with the CUSP. This increase in survey extent in 2022 was to identify if the March 2022 heatwave in Townsville had any impacts, and the scale (if any) of these impacts on seagrass in Townsville.

An additional survey at the CUSP monitoring extent was also conducted in July 2022. This July survey was to determine and capture any delayed response of seagrass loss from the March 2022 heatwave and periods of low light recorded in May 2022. Key figures of the 2022 surveys include:

- April-May 2022; post-wet season CUSP survey:
  - Survey was expanded to LTSMP survey extent.
  - A total of 1,086 sites were assessed for seagrass condition with seagrass present at 62% of sites.
  - The CUSP seagrass meadow footprint covered 4,445 ± 476 ha.
  - The LTSMP seagrass meadow footprint covered 6,899 ± 661 ha.
  - Deep-water meadows (e.g., Meadow 19) are not surveyed in the post-wet season survey.

- July 2022; additional survey including all intertidal and subtidal meadows that make up the CUSP and LTSMP programs at Magnetic Island and between Cape Pallarenda and the Strand (9 meadows in total) surveyed (Figure 5):
  - A total of 449 sites were assessed for seagrass condition with seagrass present at 31% of sites.
  - A total of 1,848 ± 135 ha was mapped in this survey.
  - Seagrass meadows surveyed maintained an area, species composition and density at expected levels measured against previous surveys. Meadows either increased or remained the same in density and area between the May 2022 and July 2022 surveys.

- September-October 2022; dry season whole-of-port survey that encompassed the LTSMP and CUSP monitoring meadows, as well as all seagrass within the extended broader port area (Figures 5):
  - A total of 1,541 sites were assessed for seagrass condition with seagrass present at 54% of sites.
  - The whole-of-port seagrass footprint covered 12,306 ± 1,296 ha of which the:
    - CUSP meadows covered 3,841 ± 477 ha.
    - LTSMP meadows covered 6,069 ± 658 ha
    - The deep-water *Halophila* meadow (Meadow 19) covered 1,449 ± 237 ha.

Eleven seagrass species have historically been identified in the LTSMP (Figure 7). Except for *Syringodium isoetifolium* and *C. rotundata*, all species (nine) were present at assessment sites or noted in the area in the 2022 surveys (Figure 7). *Syringodium isoetifolium* was last found in the program in 2015. *Cymodocea rotundata* was present in monitoring meadows in 2021 so it is likely we just did not come across the species in the 2022 surveys, rather than it being absent from the region.

In the 2021 annual report, we noted the presence of *Halophila tricostata* in the deeper areas of Cleveland Bay (Figure 7). This species had not been recorded in the LTSMP until the 2021 surveys, although had previously been recorded in the region. *Halophila tricostata* was again present in Cleveland Bay in 2022.

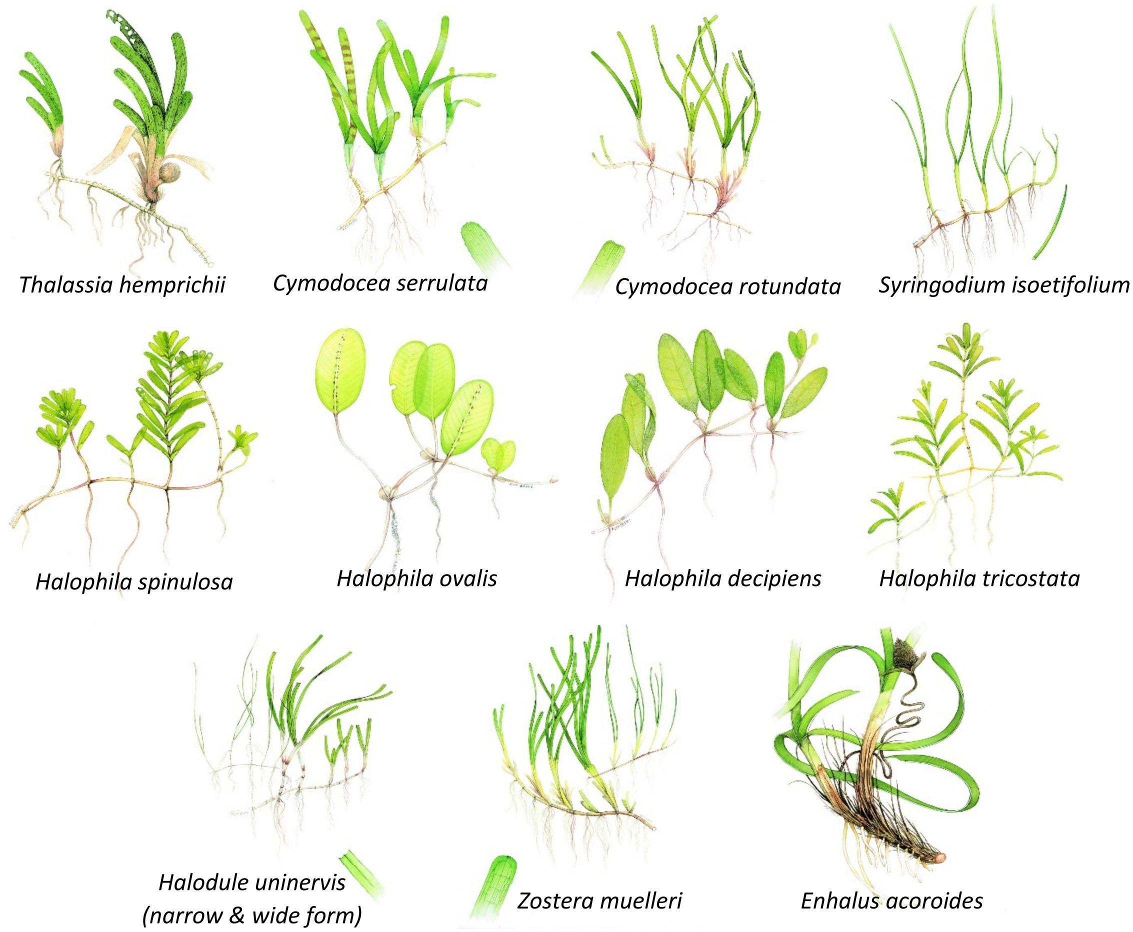

Figure 7. Seagrass species identified in the Townsville Long-term Seagrass Monitoring Program (LTSMP).

5.2 Seagrass Condition in The Townsville LTSMP & CUSP Monitoring Meadows

5.2.1 Seagrass Distribution, Abundance and Composition in Townsville

Townsville seagrass meadows were in an overall satisfactory or better condition between the two programs: LTSMP and CUSP (Table 3) with an extensive footprint of seagrass present (Figure 8). Nine of the twelve monitoring meadows where in a satisfactory or better condition while three meadows were in poor condition due to declines in meadow biomass or area. These three meadows included two meadows at Magnetic Island: the intertidal Cockle Bay *Zostera muelleri* Meadow 6 and the subtidal Geoffrey Bay *Halophila spinulosa* Meadow 24 and one meadow at Shelley Beach: the intertidal *Z. muelleri* Meadow 10. The downgrade in conditions was due to area and biomass losses that only just pushed the condition scores into poor. The species composition of all meadows was in good or very good condition (Table 3).

While an extensive footprint was present, declines in meadow biomass and/or area between October 2021 to October 2022 were recorded across most meadows and are explained by local environmental conditions. Total LTSMP meadow area was lower than the previous two years but remained above the long-term average (Figure 3). Individual monitoring meadow area ranged from 1.5 ha in the subtidal *H. uninervis* Florence Bay meadow (Meadow 1; Figure 11) to 3,743 ha for the subtidal *H. uninervis* Cleveland Bay meadow (Meadow 17/18; Figure 23).

Monitoring meadow biomass ranged from 0.97 g DW m^{-2} in the subtidal *H. spinulosa* meadow along Geoffrey Bay (Meadow 24) to 33.32 g DW m^{-2} in the intertidal *Z. muelleri* meadow in Cleveland Bay (CUSP section of Meadow 16; Figure 22). These density ranges were like the previous two years.

The deep-water meadow (Meadow 19) that is surveyed annually in Cleveland Bay as part of the annual whole-of-port surveys during the dry season, continued to be highly variable from year to year in biomass, area, and footprint (Figure 28). In 2022, this *Halophila* meadow covered 1,449 ± 237 ha (Figure 28).

Table 3. Grades and scores for seagrass indicators (biomass, area, and species composition) for the LTSMP and CUSP meadows in Townsville; September/October 2022 survey.

Meadow	Region	LTSMP/CUSP	Biomass	Area	Species Composition	LTSMP Overall Meadow Score	CUSP Overall Meadow Score
1	Magnetic Island	CUSP	0.77	0.88	0.91		0.77
3		LTSMP & CUSP	0.59	0.93	0.84	0.59	0.59
4		LTSMP	0.87	1	0.99	0.87	
5		LTSMP & CUSP	0.61	0.69	0.97	0.61	0.61
6		LTSMP & CUSP	0.8	0.47	0.89	0.47	0.47
24		CUSP	0.47	0.88	0.92		0.47
10	Cape Pallarenda - Strand	LTSMP & CUSP	0.73	0.49	0.75	0.49	0.49
12		LTSMP & CUSP	0.90	1	0.81	0.86	0.86
14		LTSMP & CUSP	0.70	0.67	0.99	0.67	0.67
15		LTSMP	0.90	0.89	0.81	0.85	
16	Cleveland Bay	LTSMP	0.83	0.63	0.97	0.63	
16 (CUSP meadow section)		CUSP	0.87	0.65	0.99		0.65
17/18		LTSMP	0.76	0.90	0.98	0.76	
17/18 (CUSP meadow section)		CUSP	0.80	0.89	0.99		0.80
LTSMP - Overall Score for the Port of Townsville 2022						**0.68**	
CUSP - Overall Score for the Port of Townsville 2022							**0.64**

= very good condition = good condition = satisfactory condition

= poor condition = very poor condition

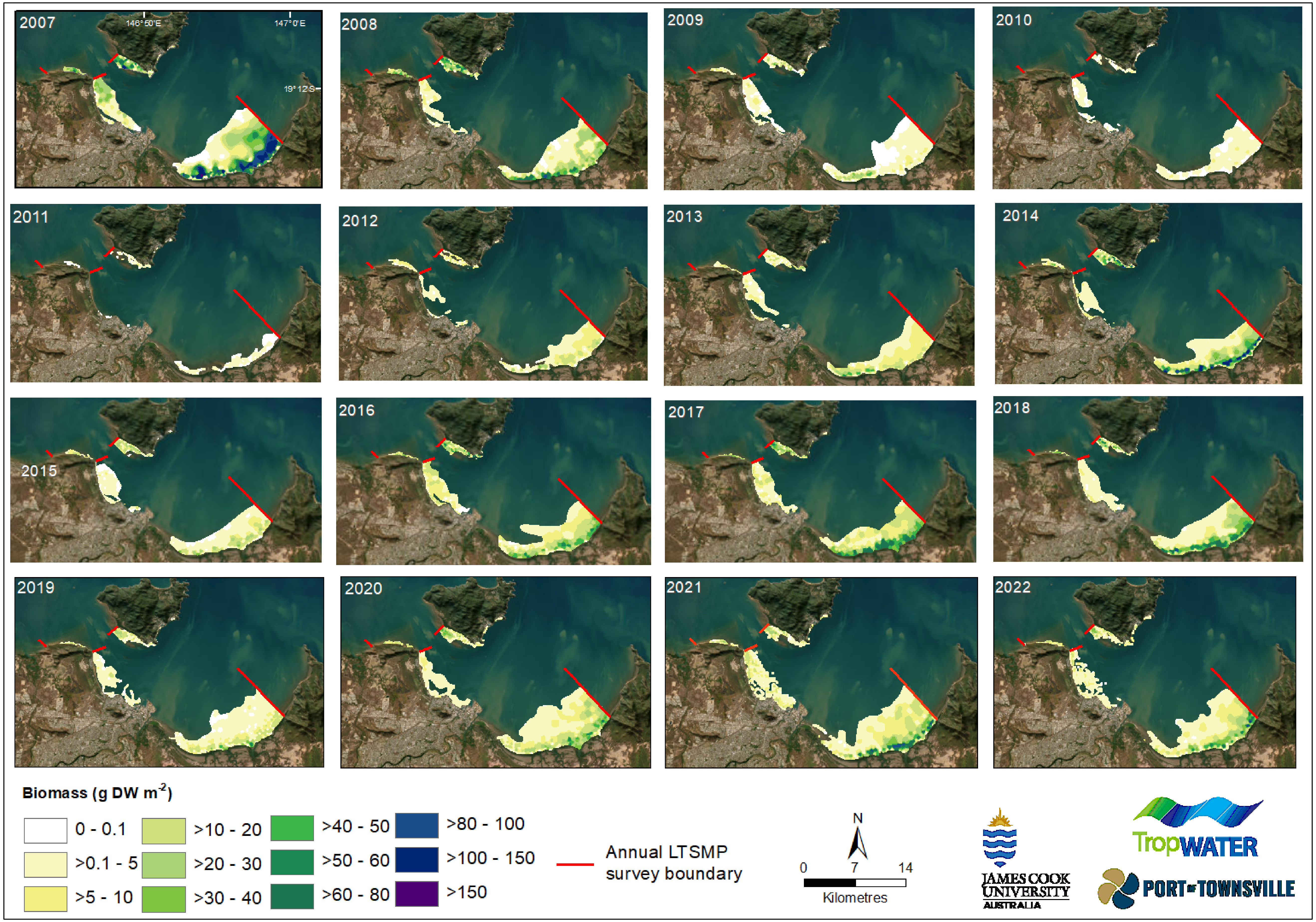

Figure 8. Long-Term Seagrass Monitoring Program (LTSMP) meadow location and spatial extent from 2007 – 2022.

5.2.2 Magnetic Island Seagrass Meadows

Between the LTSMP and CUSP there are six monitoring meadows around Magnetic Island (Meadows 1, 3, 4, 5, 6, 24) (Figures 11-16). These meadows range from intertidal to deep-water (>8m below MSL) meadows. Four of the six meadows were of satisfactory or better condition in 2022 (Table 3). The Cockle Bay intertidal *Z. muelleri* meadow (Meadow 6) and the Geoffrey Bay subtidal *H. spinulosa* meadow (Meadow 24) were the two meadows in poor condition.

Meadow 24 spans the deep-water areas between Geoffrey Bay and Nelly Bay (Figure 16). The meadow was given a poor condition score in 2022 because of a decrease in biomass between 2021 and 2022. This decrease however, was only relatively small and remained within biomass values recorded since 2019 when the meadow became part of the annual monitoring program and therefore surveyed more regularly (Figure 16). The meadow footprint and species composition remained in very good condition in 2022. Seagrass was found to 9.8m below MSL, the deepest seagrass in the 2022 program. Seagrass has been found to 11.2m below MSL in this meadow.

All other monitoring meadows on the eastern side of Magnetic Island and closest to the channel, were in satisfactory or better condition in October 2022. The meadow area of the intertidal-shallow subtidal meadow in Nelly Bay (Meadow 4) was the largest it has been in the program (16 years); 21 ha (Figure 13). The meadow had expanded deeper in 2022 from 2021, and smaller patches of seagrass along the shore had joined up in 2022 compared to previous years (Figure 13).

The other monitoring meadow at Magnetic Island that recorded a poor score in 2022 was the Cockle Bay intertidal *Z. muelleri* meadow (Meadow 6). The meadow was given a poor condition score because of a decrease in area from 50 ha in October 2021 to 22 ha in October 2022 (Figure 14). In contrast biomass in the meadow increased from 7.8 gDW m^{-2} to 12.92 gDW m^{-2} over the same period. This meadow is highly variable in extent from year to year (Figure 14). Much of this variability is because of presence and inclusion, then the absence of isolated patches of *Z. muelleri* when aerially mapping the boundary of the meadow on the seaward side of the meadow.

The intertidal Cockle Bay reef top meadow (Meadow 5) remained in a satisfactory condition in 2022 for the second year in a row (Figure 14). The satisfactory condition of the meadow for the last two years is due to satisfactory biomass scores. The area of this reef-top meadow remains in good condition even though there is a long-term trend of meadow area decline (Figure 14). The extent of the meadow peaked at 452 ha in 2013 after rapid recovery from impacts of Tropical Cyclone Yasi and multiple consecutive years of above-average rainfall (river discharge) and has declined to 301 ha in 2022 (Figure 9 & 14). Much of the decline in area has occurred at various sections along the seaward edge of the meadow (Figure 9). This downward trend in meadow area is discussed further in section 6.

Species composition at all Magnetic Island meadows was above baseline conditions, with a species mix that reflected a very good condition in all meadows (Table 3; Appendix 1).

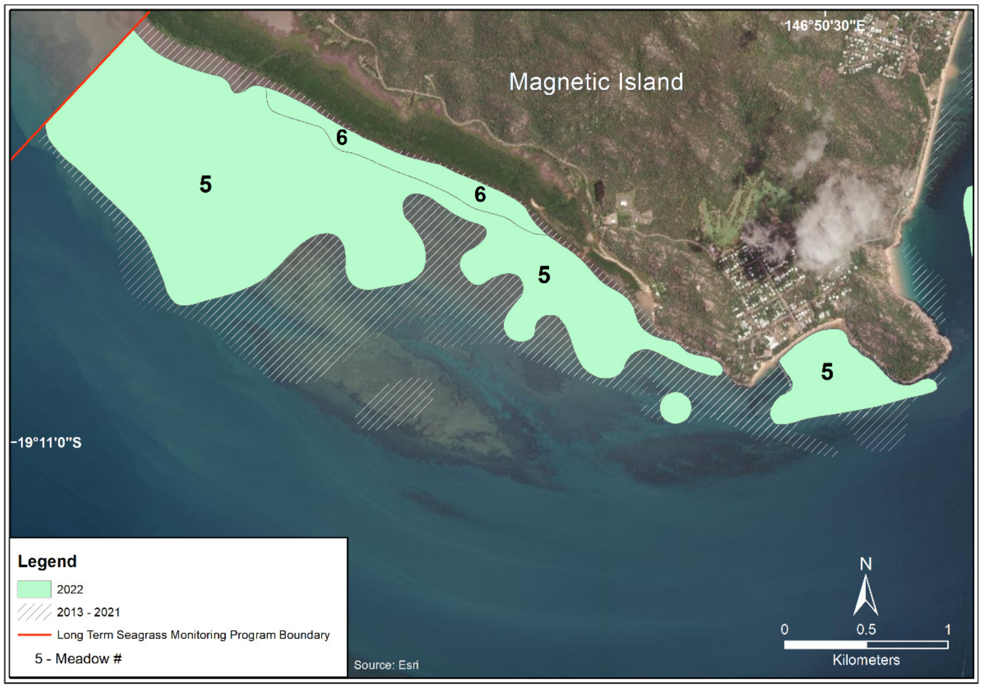

Figure 9. Seagrass spatial extent and footprint in the Cockle Bay reef top meadow (Meadow 5) demonstrating the retraction of seagrass along the seaward edge of some areas of the meadow 2013 - 2022.

5.2.3 Cape Pallarenda-Strand Seagrass Meadows

There are four monitoring meadows that make up the Cape Pallarenda - Strand region (Meadows 10, 12, 14, 15) (Figures 17-20). Three of the four meadows were in good or very good condition in October 2022: Strand to Pallarenda meadows 12, 14, 15 (Table 3; Figures 18-20). These are also the meadows closest to the CU Project works. The Shelley Beach intertidal *Z. muelleri* meadow (Meadow 10) was in a poor condition in October 2022 due the area indicator just falling into the poor category in 2022 from satisfactory in 2021 (Figure 17).

Similar to the Cockle Bay reef top meadow (Meadow 5), the spatial footprint of the Shelley Beach intertidal *Z. muelleri* meadow (Meadow 10) has been on a downward trajectory since 2014 (Figure 17). This meadow has fluctuated between 190 ha and 52 ha when present with seagrass loss occurring on all sides of the meadow (Figure 10). The *Halodule uninervis* meadow (Meadow 12) that bounds and is on the seaward side of Meadow 10 has continued to expand shoreward as Meadow 10 retracts (Figure 10). Biomass and species composition remain in good condition in Meadow 10 (Table 3; Figure 17).

For the meadows closest to the CU Project works; Meadows 12, 14 and 15, area, biomass and species composition all remain in good or very good condition in 2022. Meadows 12 and 14 were slightly patchier in 2022 compared to 2021 but similar to previous years (Figure 8). Seagrass was present to 5.2m below MSL in October 2022 similar to previous surveys (Figure 8).

At the time of the survey, we recorded many dugong feeding trails in this region. The seagrass meadows around Cape Pallarenda tend to be a high use area for marine megaherbivores.

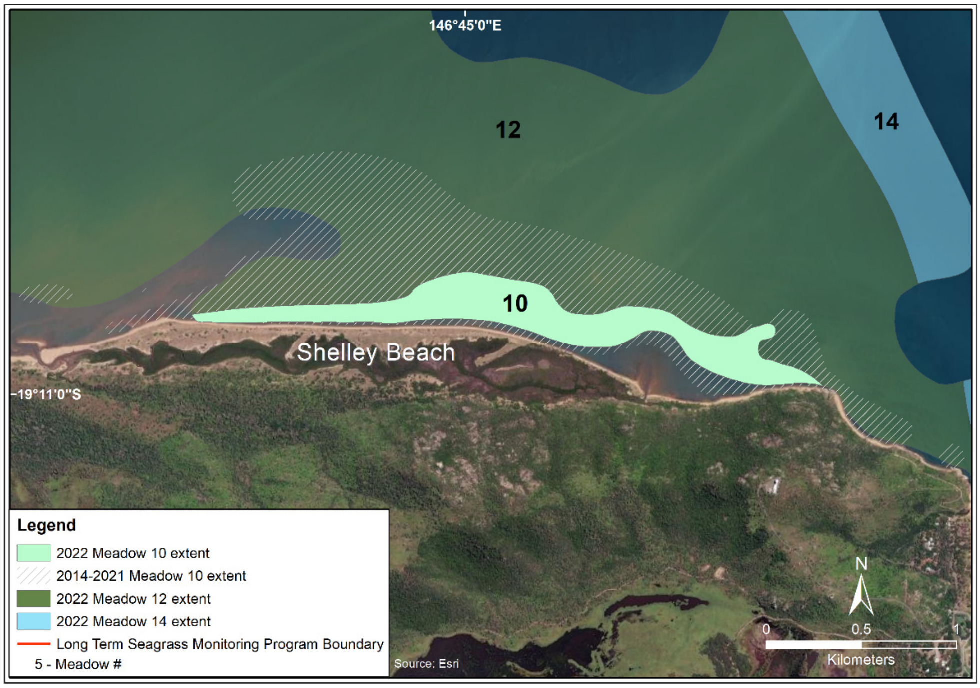

Figure 10. Seagrass spatial extent and footprint in the Shelley Beach meadow (Meadow 10) demonstrating the retraction of seagrass along edges of the meadow 2013 - 2022

5.2.4 Cleveland Bay Seagrass Meadows

There are two monitoring meadows in Cleveland Bay; the intertidal *Z. muelleri* meadow (Meadow 16) and the shallow subtidal *H. uninervis* meadow (Meadow 17/18) (Figures 21-24). These meadows are the largest coastal meadows in Townsville (Figure 8). For the CUSP, only a section of these large meadows is monitored biannually. Both meadows were in a satisfactory or better condition in 2022 (Table 3; Figures 21-24).

At the intertidal *Z. muelleri* meadow (16), biomass was in good condition at the end of 2022 with density 'hotspots' that had returned to the meadow in 2021 remaining through 2022 (Figures 21 & 22). Densities of up to 100 gDW m^{-2} were recorded in these 'hotspots' in 2022. In 2021, the largest biomass recorded in the meadow was 60 gDW m^{-2}. The spatial extent of this meadow was in satisfactory condition at the end of 2022. This is the first time since 2011 the area of the meadow has been below good condition (Figure 21 & 22). Similar to the other intertidal *Z. muelleri* meadows in the region, the area of this *Z. muelleri* meadow has been trending downwards since 2018. The seaward Meadow 17/18 that bounds this Meadow 16 has coincidingly expanded shallower. Species composition has been in very good condition in Meadow 16 since 2014.

At the adjacent subtidal *H. uninervis* meadow (Meadow 17/18), meadow biomass rebounded from a low in 2019 to be in good condition for the last three years (Table 3; Figures 23 & 24). The area of the meadow has also been in very good condition for the last seven years. The species composition in the meadow has been stable since 2018. *Halodule uninervis* accounts for around 50% of the meadow biomass with the more stable species *C. serrulata* making up the bulk of the remaining species composition in the meadow (Appendix 1).

5.2.5 Cleveland Bay deep-water Seagrass Meadow

The Cleveland Bay deep-water meadow (Meadow 19) is the primary deep-water meadow in the monitoring program (Figure 28). In 2019, the extent of this variable deep-water meadow was the largest recorded since

2007; 8,023 ha (Figure 28). In 2020, this area decreased by nearly 67% to 2,329 ha, and became fragmented (Figure 28). In 2021, the meadow increased again to a significant footprint of 5,405 ha and has decreased again to 1,449 ha in 2022.

Meadow biomass has been of low density and similar for the last couple of years (Figure 27 & 28). Of note in 2021 was the sighting of *H. tricostata* in this meadow. This species had not been recorded in the LTSMP until then, although has previously been recorded in the region. *Halophila tricostata* was again present in the meadow in 2022. *Halophila decipiens* was recorded to 8.9m below mean sea MSL in this meadow in 2022 whereas in 2021 seagrass was recorded to 14m.

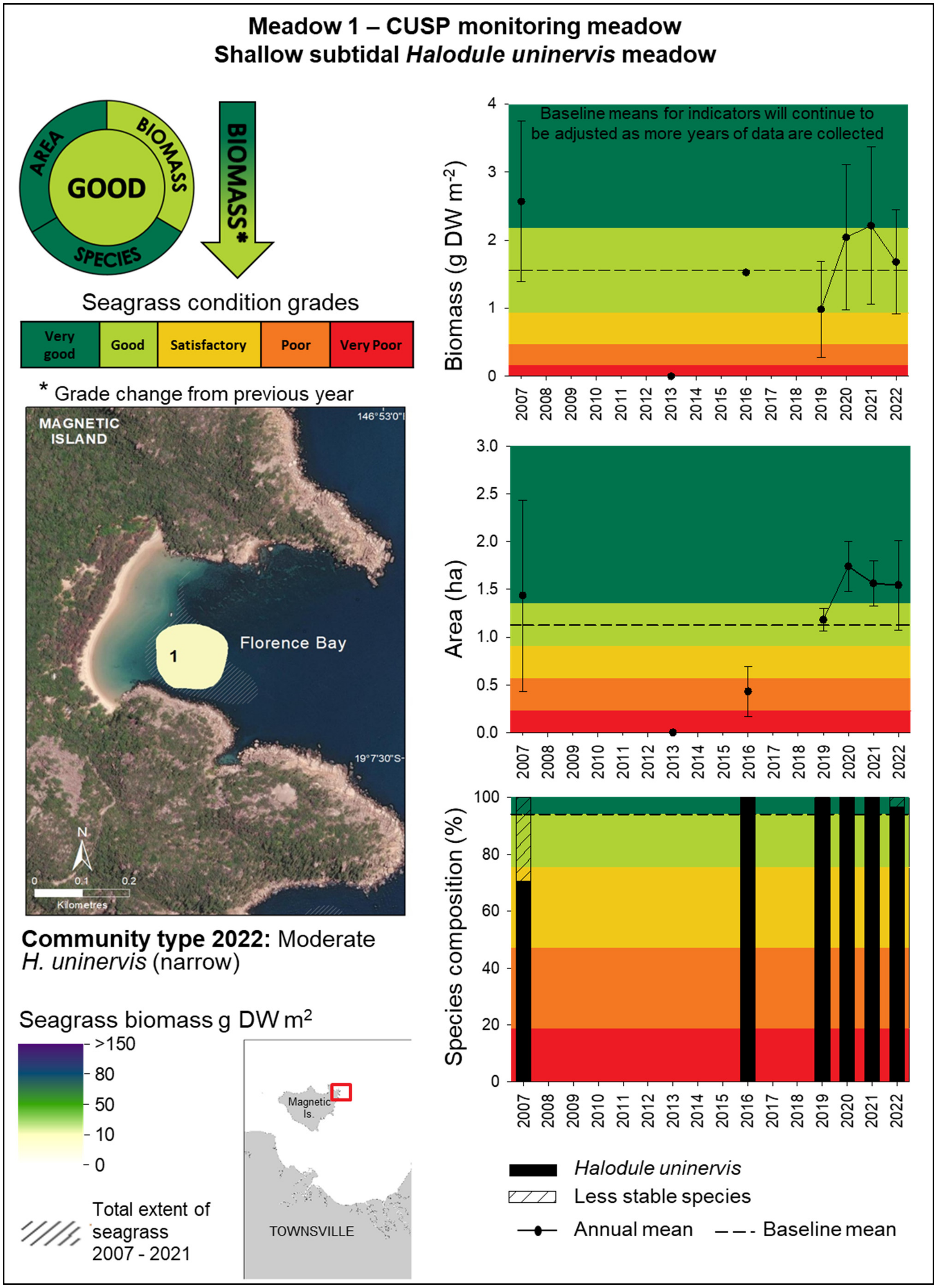

Figure 11. Changes in meadow area, biomass, and species composition for seagrass Meadow 1 at Magnetic Island, 2007 – 2022. (biomass error bars = SE; area error bars = “R” reliability estimate).

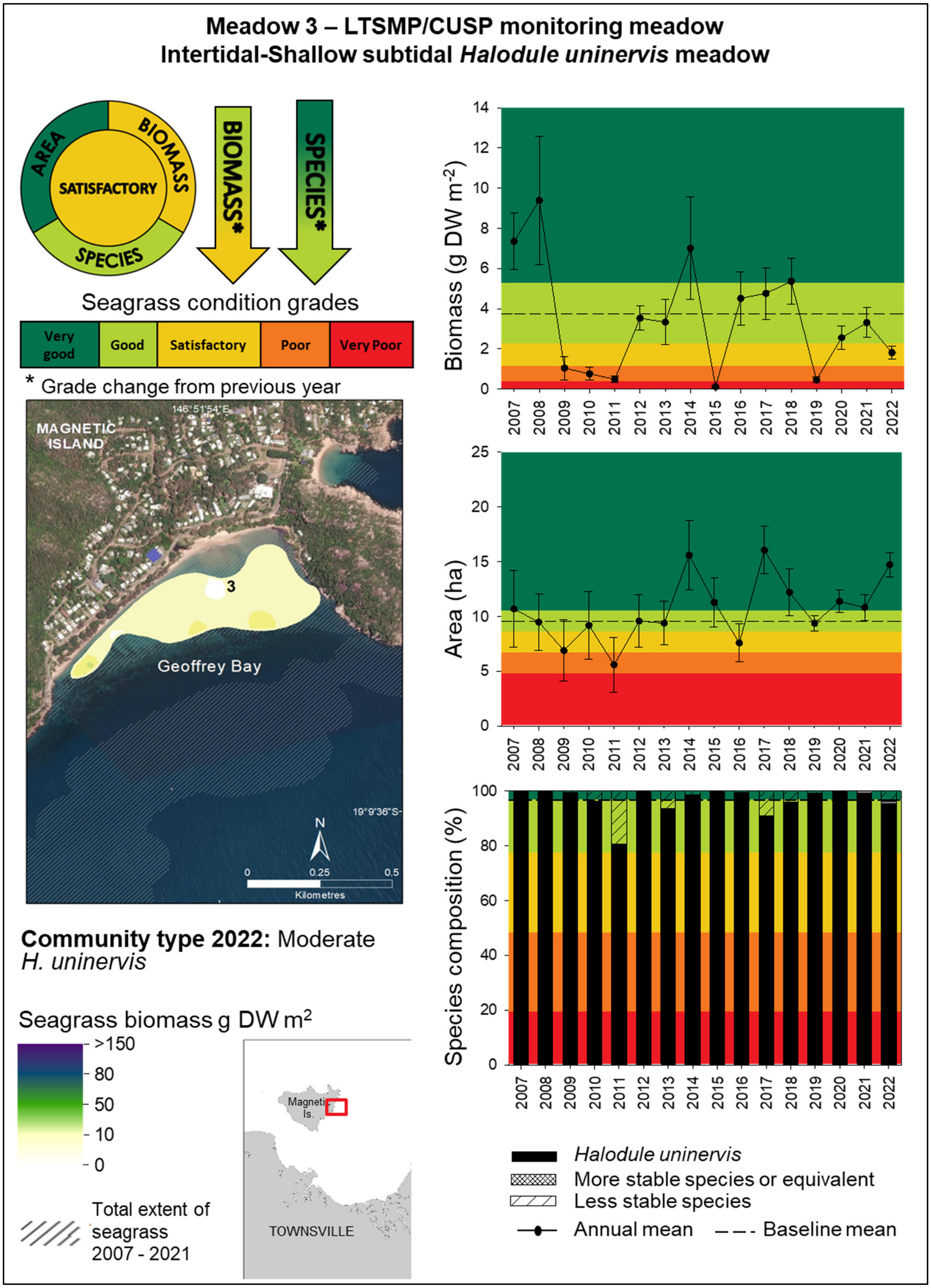

Figure 12. Changes in meadow area, biomass, and species composition for seagrass Meadow 3 at Magnetic Island, 2007 – 2022. (biomass error bars = SE; area error bars = “R” reliability estimate).

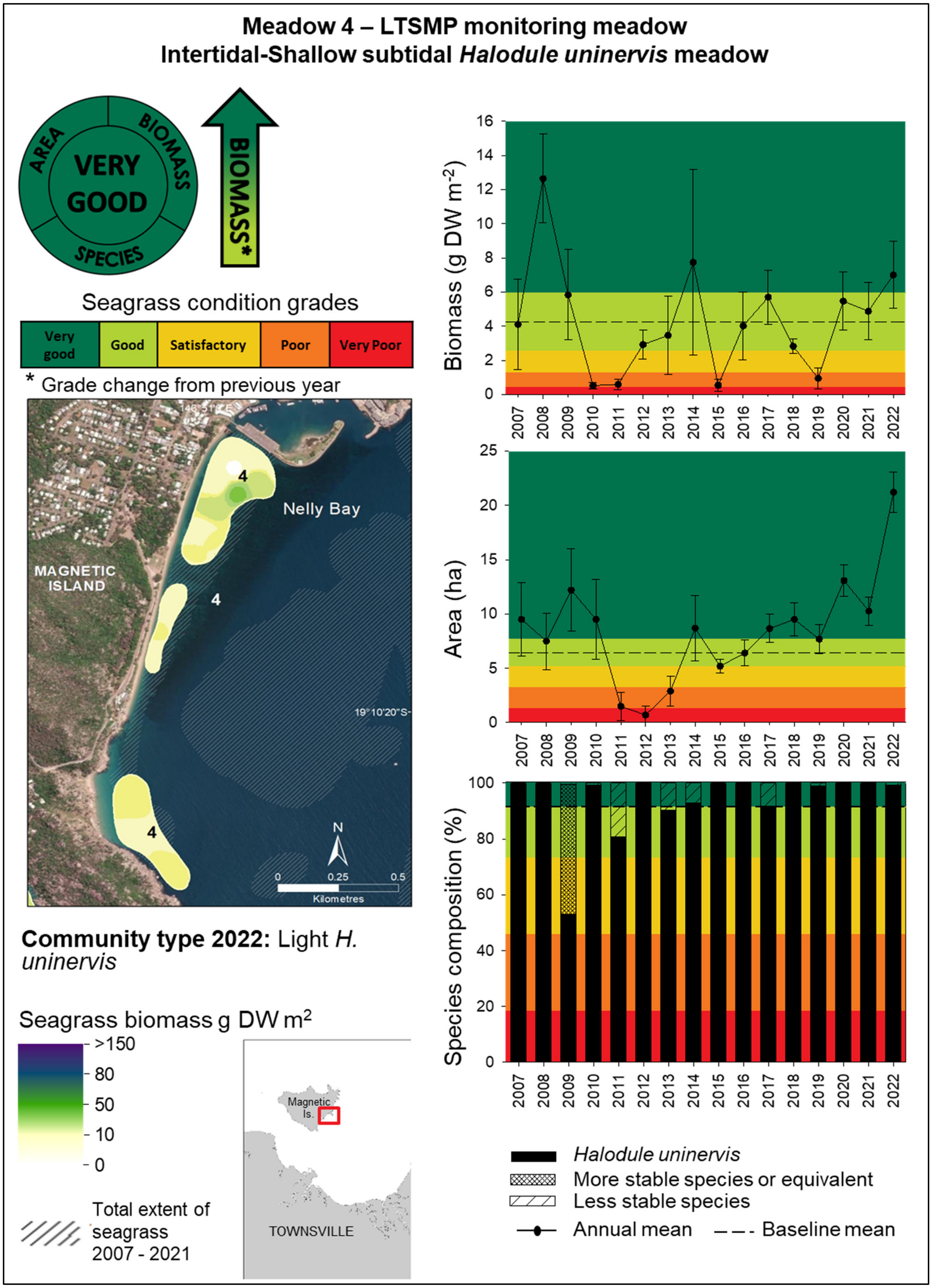

Figure 13. Changes in meadow area, biomass, and species composition for LTSMP seagrass Meadow 4 at Magnetic Island, 2007 – 2022. (biomass error bars = SE; area error bars = "R" reliability estimate).

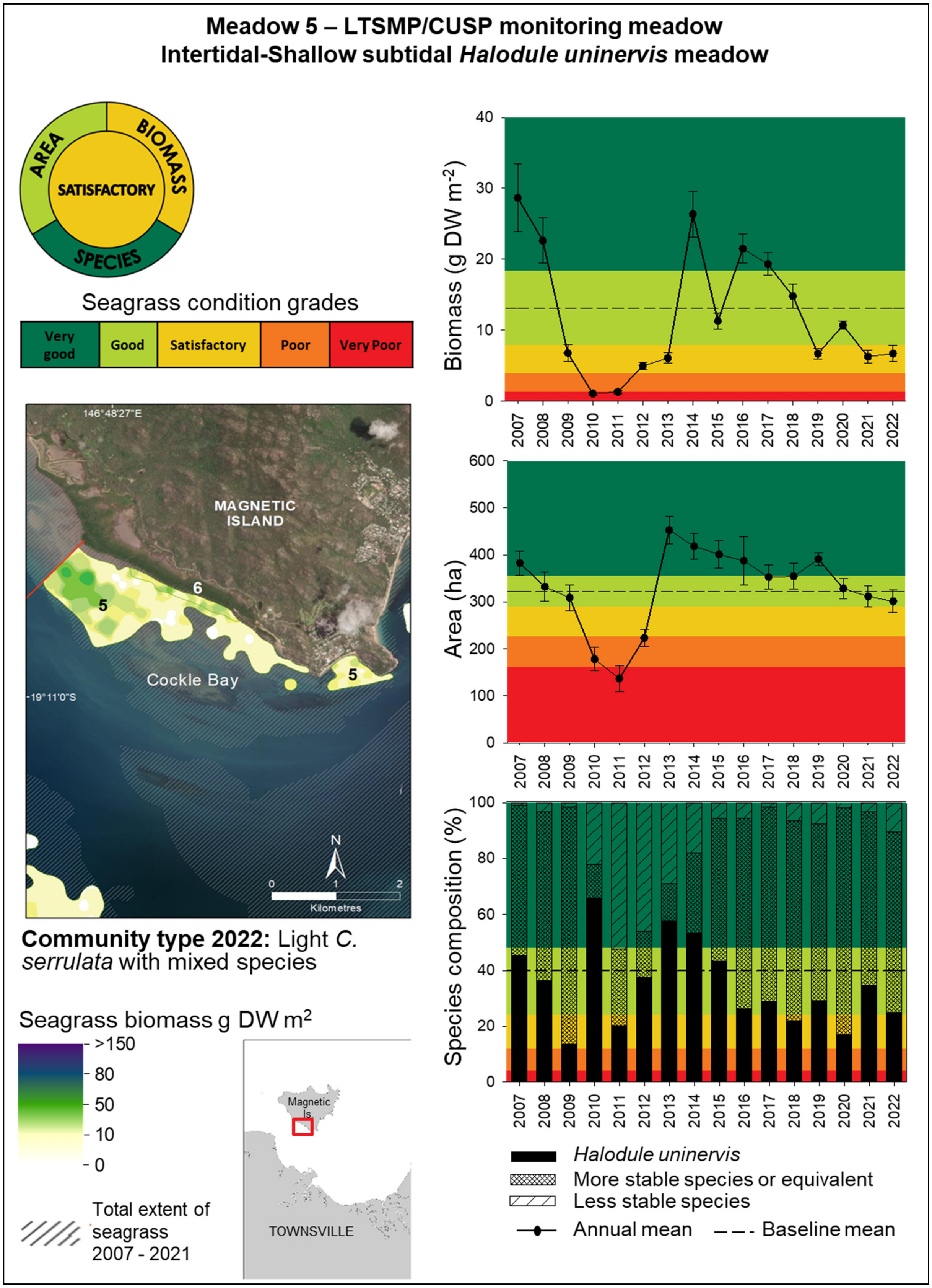

Figure 14. Changes in meadow area, biomass, and species composition for LTSMP seagrass Meadow 5 at Magnetic Island, 2007 – 2022. (biomass error bars = SE; area error bars = "R" reliability estimate).

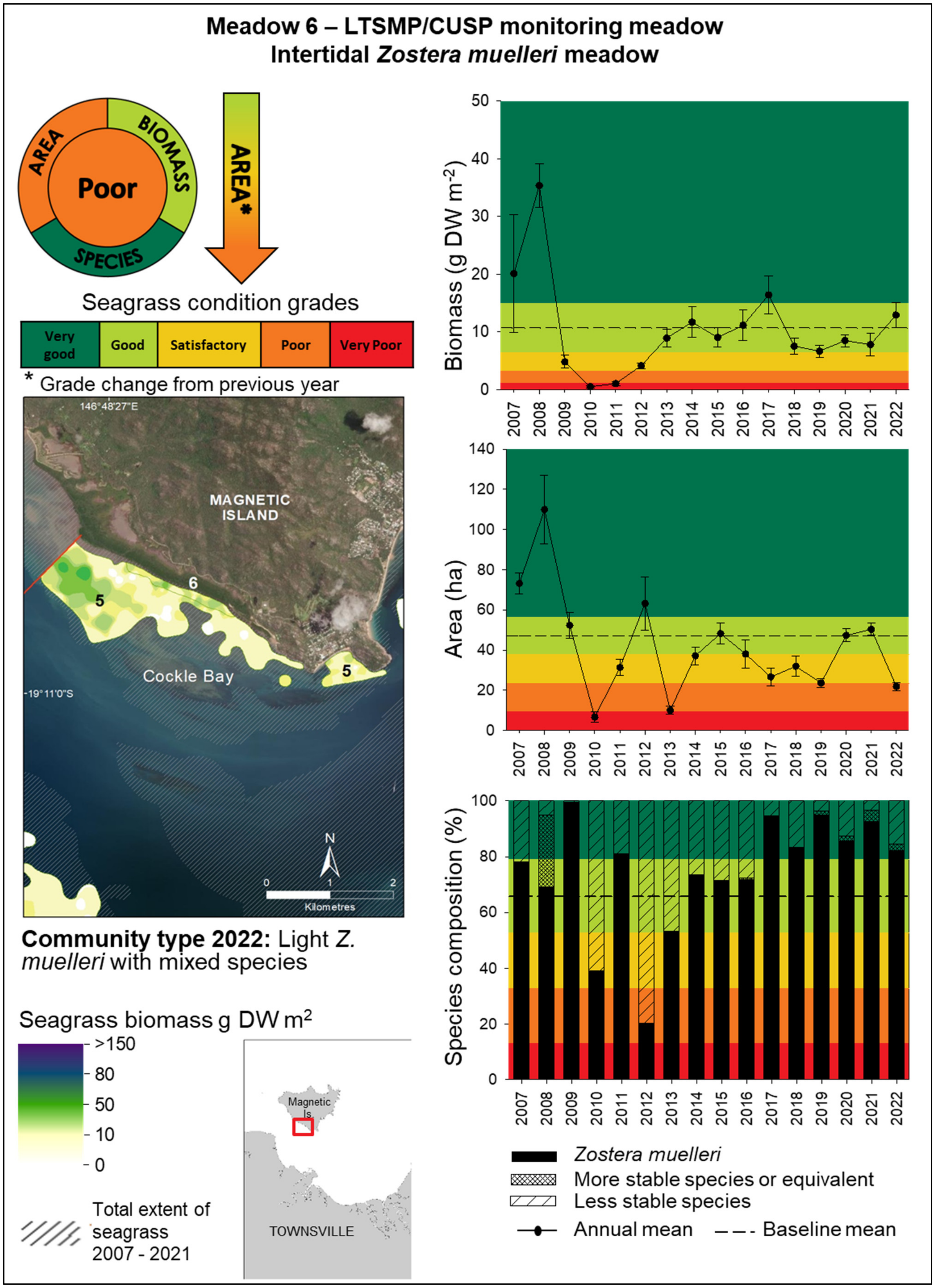

Figure 15. Changes in meadow area, biomass, and species composition for LTSMP seagrass Meadow 6 at Magnetic Island, 2007 – 2022. (biomass error bars = SE; area error bars = "R" reliability estimate).

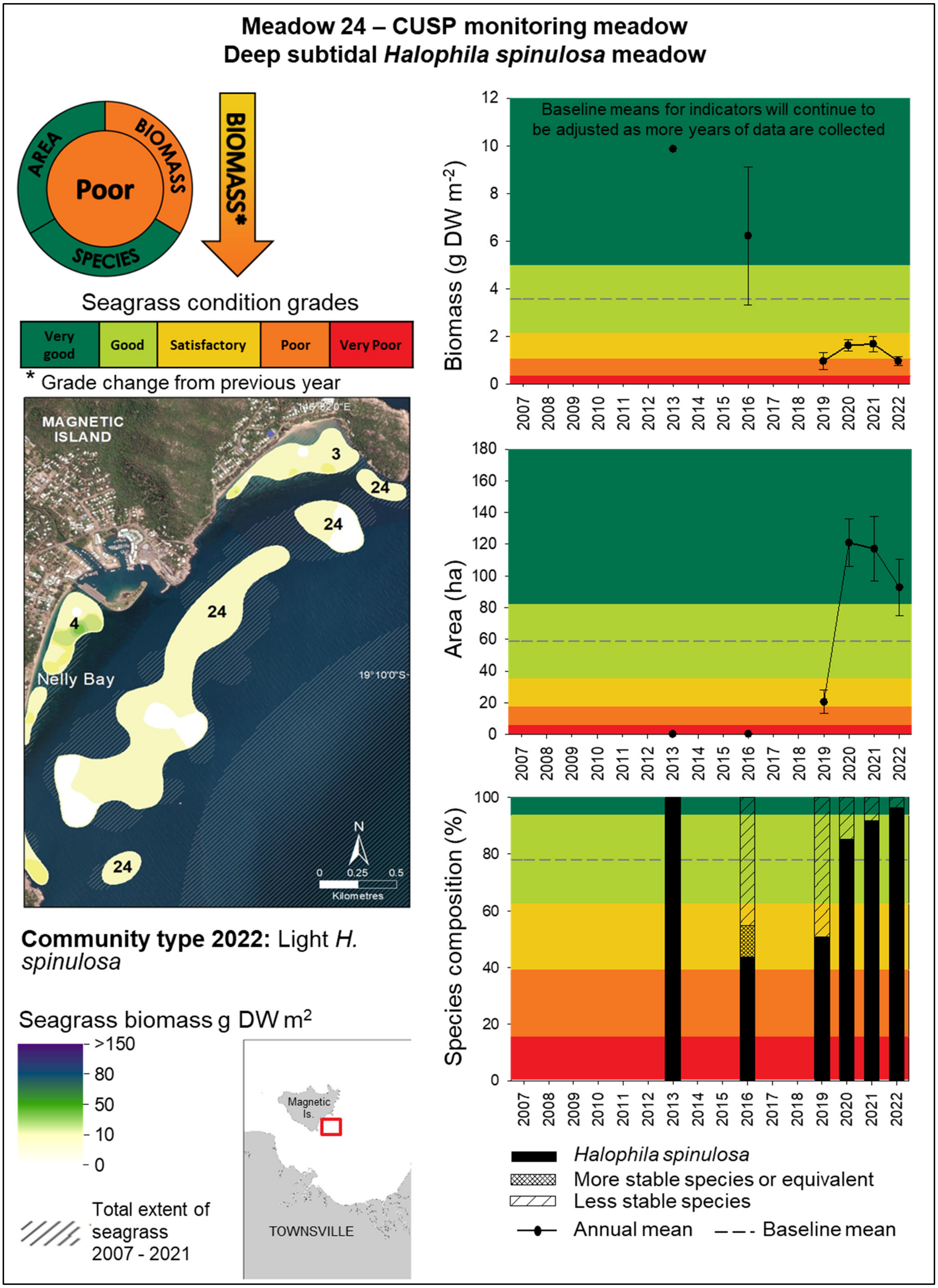

Figure 16. Changes in meadow area, biomass, and species composition for LTSMP seagrass Meadow 24 at Magnetic Island, 2007 – 2022. (biomass error bars = SE; area error bars = “R” reliability estimate).

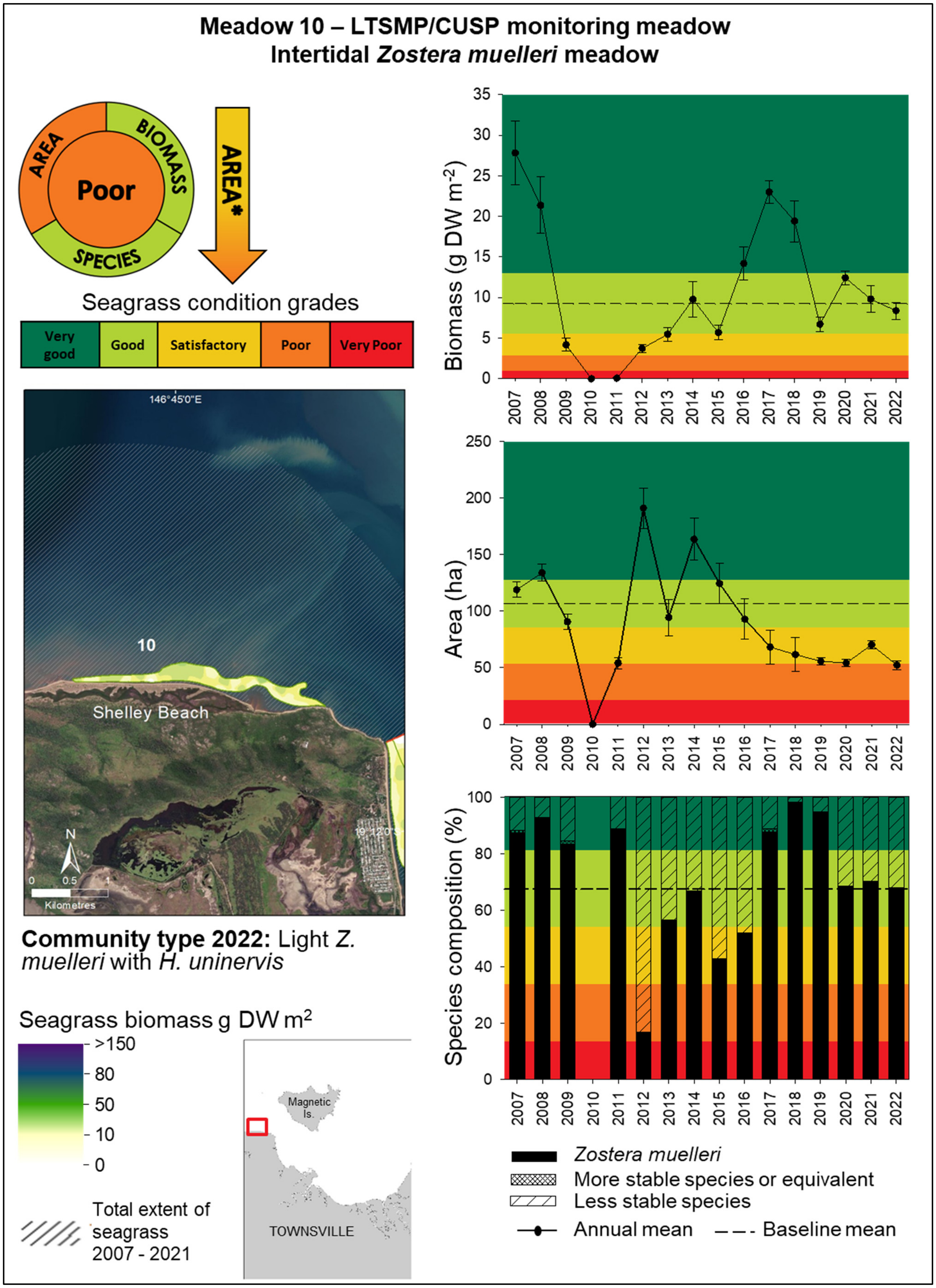

Figure 17. Changes in meadow area, biomass, and species composition for LTSMP seagrass Meadow 10 at Shelley Beach, 2007 – 2022. (biomass error bars = SE; area error bars = "R" reliability estimate).

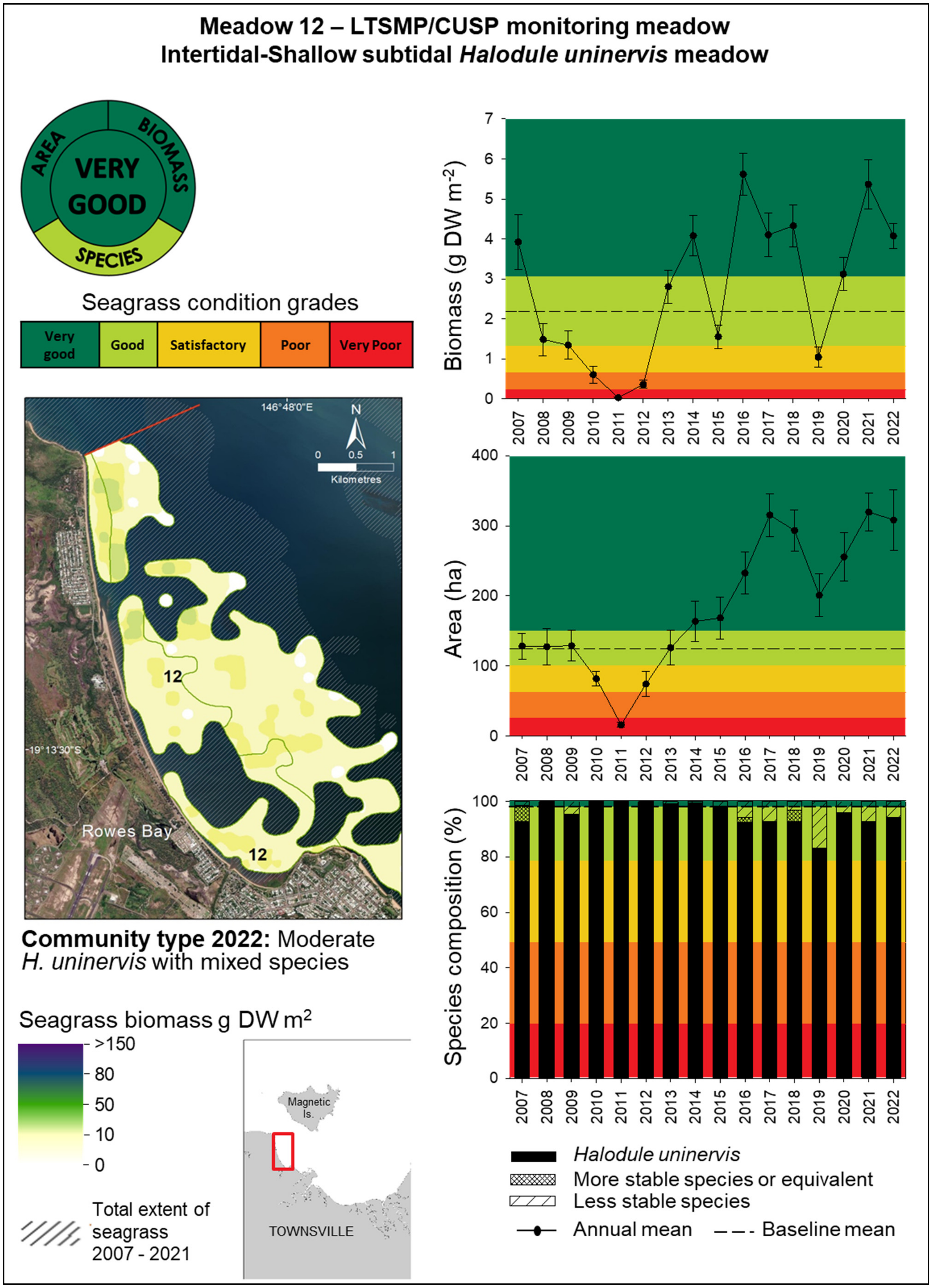

Figure 18. Changes in meadow area, biomass, and species composition for LTSMP seagrass Meadow 12, at Rowes Bay to Cape Pallarenda, 2007 – 2022. (biomass error bars = SE; area error bars = "R" reliability estimate).

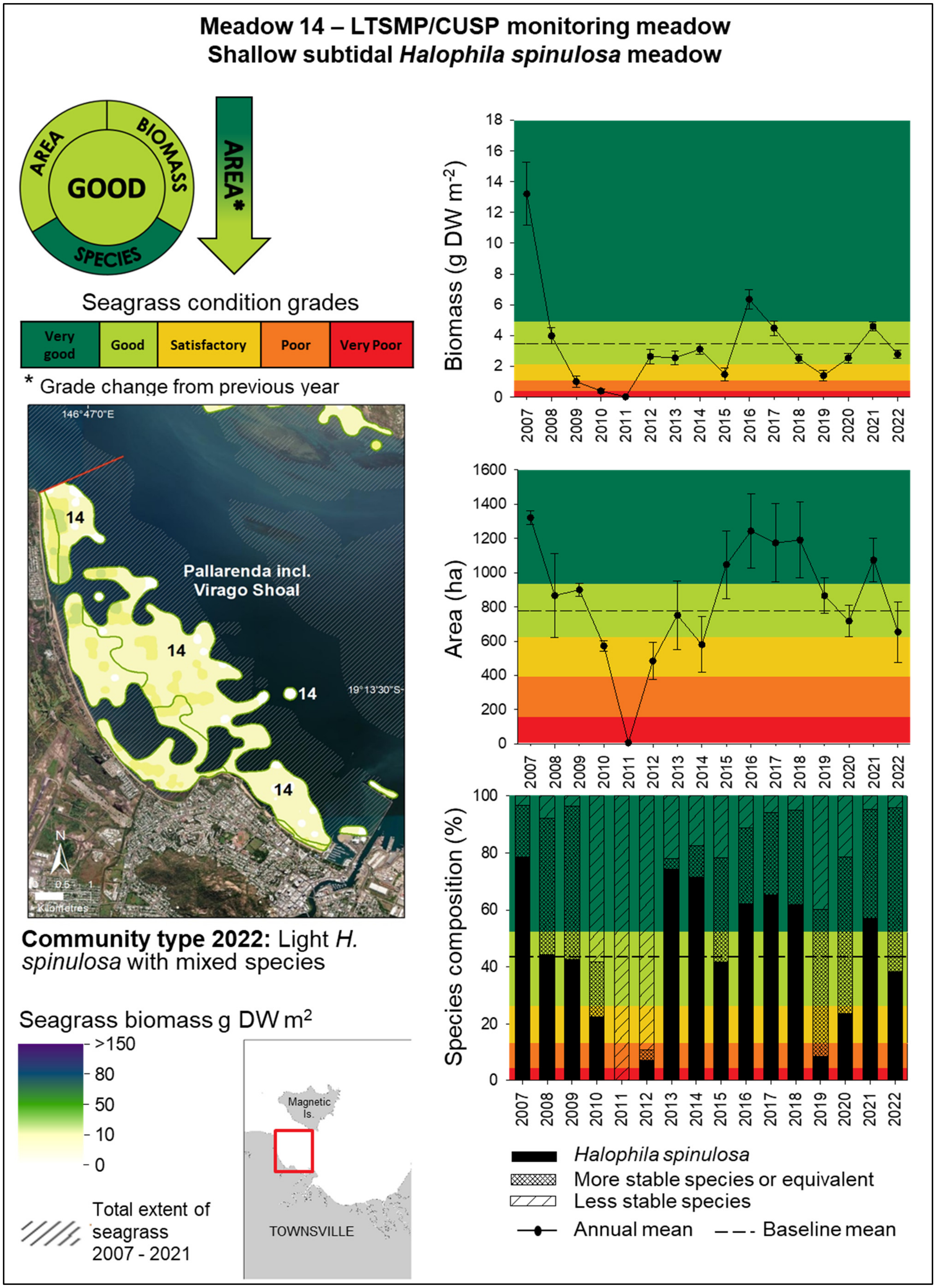

Figure 19. Changes in meadow area, biomass, and species composition for LTSMP seagrass Meadow 14 at the Strand to Cape Pallarenda, 2007 – 2022. (biomass error bars = SE; area error bars = "R" reliability estimate).

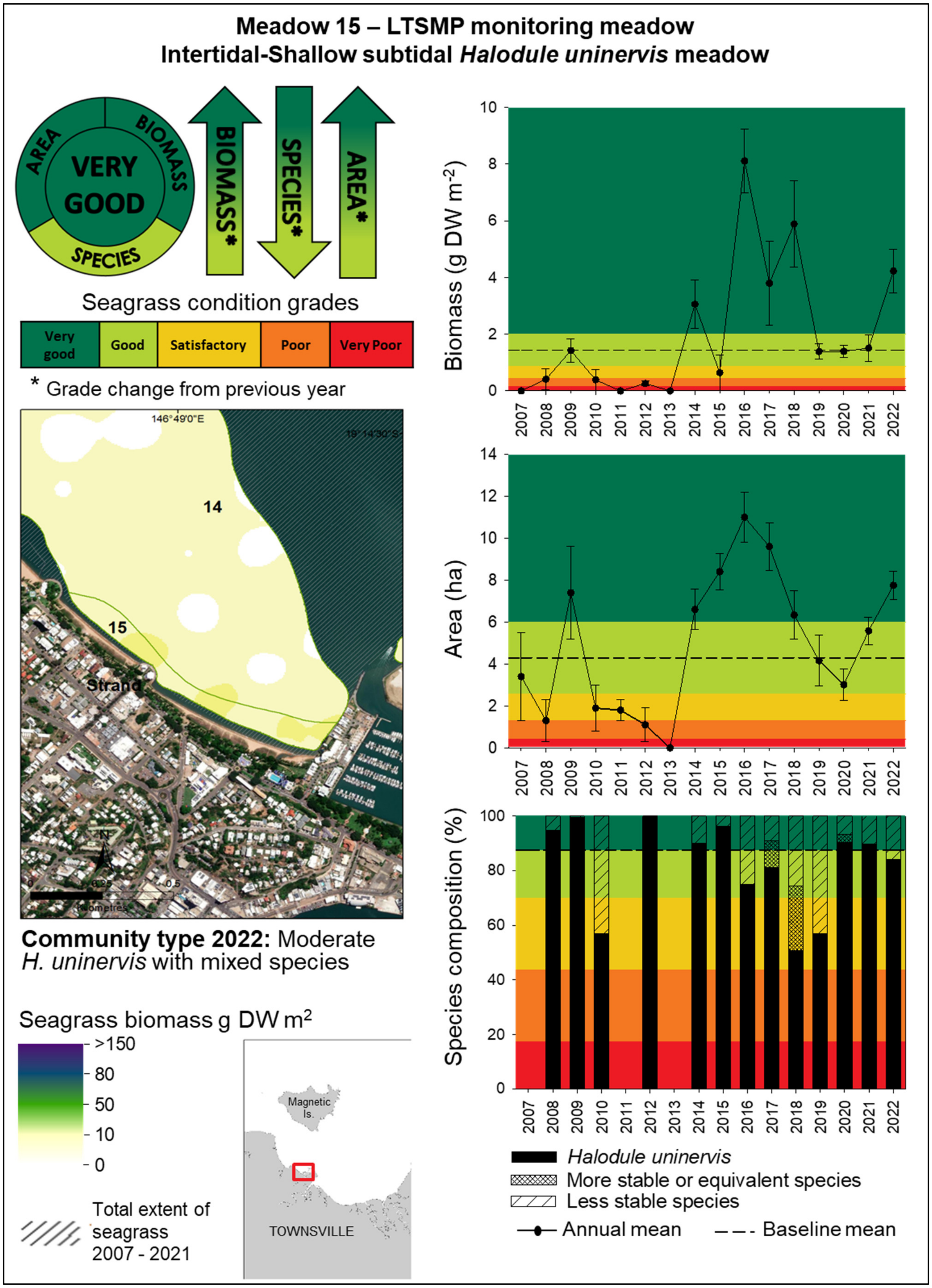

Figure 20. Changes in meadow area, biomass, and species composition for LTSMP seagrass Meadow 15 at the Strand, 2007 – 2022. (biomass error bars = SE; area error bars = "R" reliability estimate).

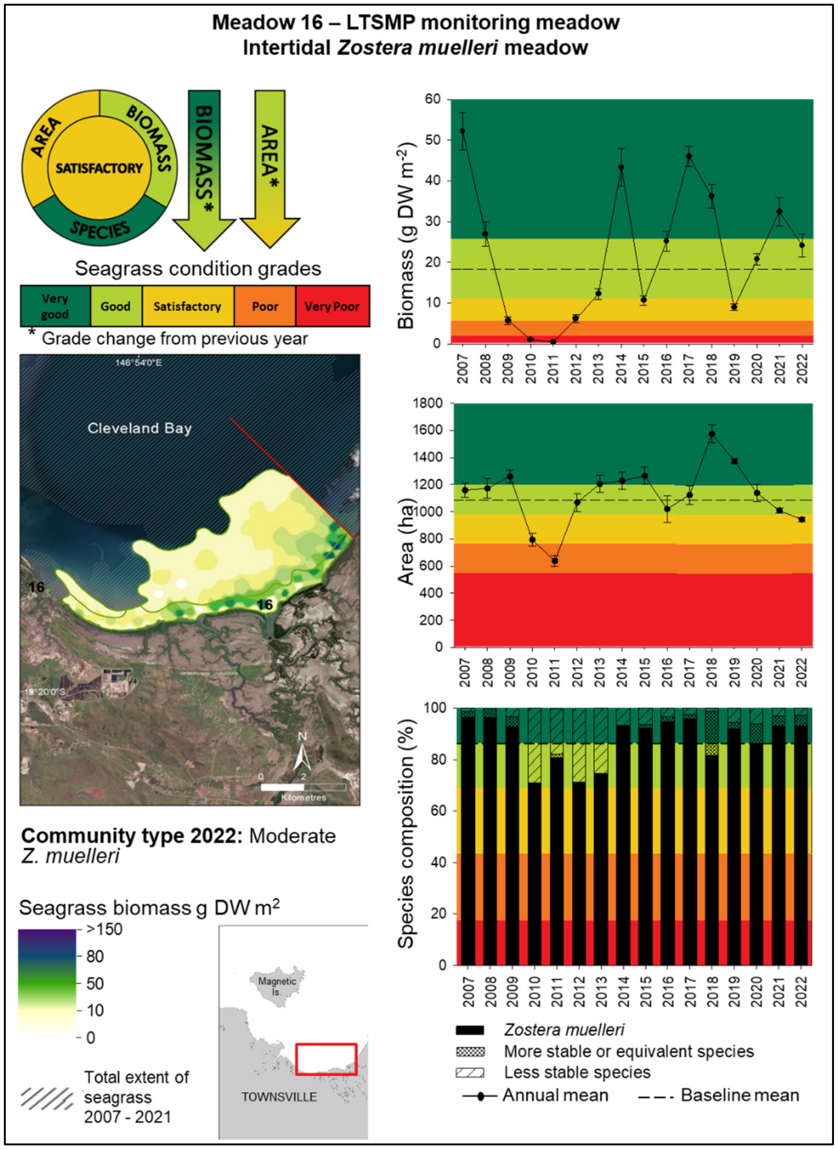

Figure 21. Changes in meadow area, biomass, and species composition for LTSMP seagrass Meadow 16 in Cleveland Bay, 2007 – 2022. (biomass error bars = SE; area error bars = "R" reliability estimate).

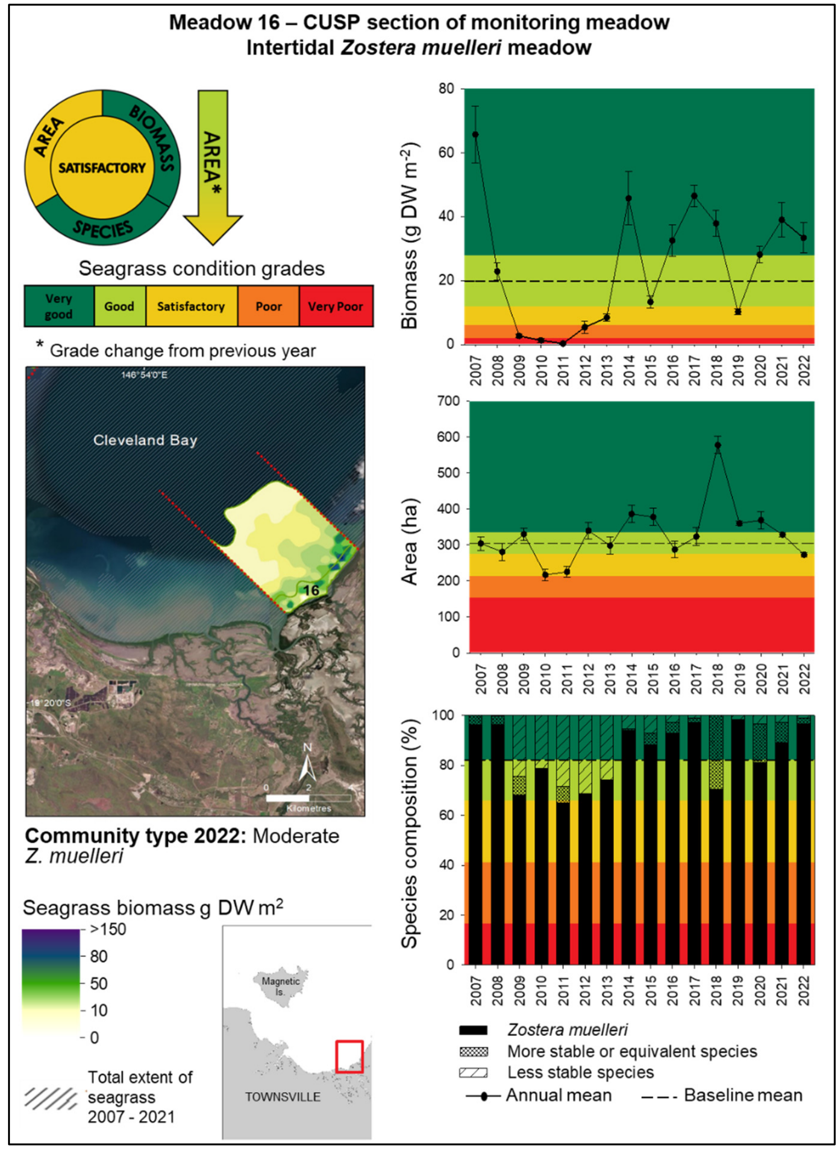

Figure 22. Changes in meadow area, biomass, and species composition for CUSP meadow section in Meadow 16 in Cleveland Bay, 2007 – 2022. (biomass error bars = SE; area error bars = "R" reliability estimate).

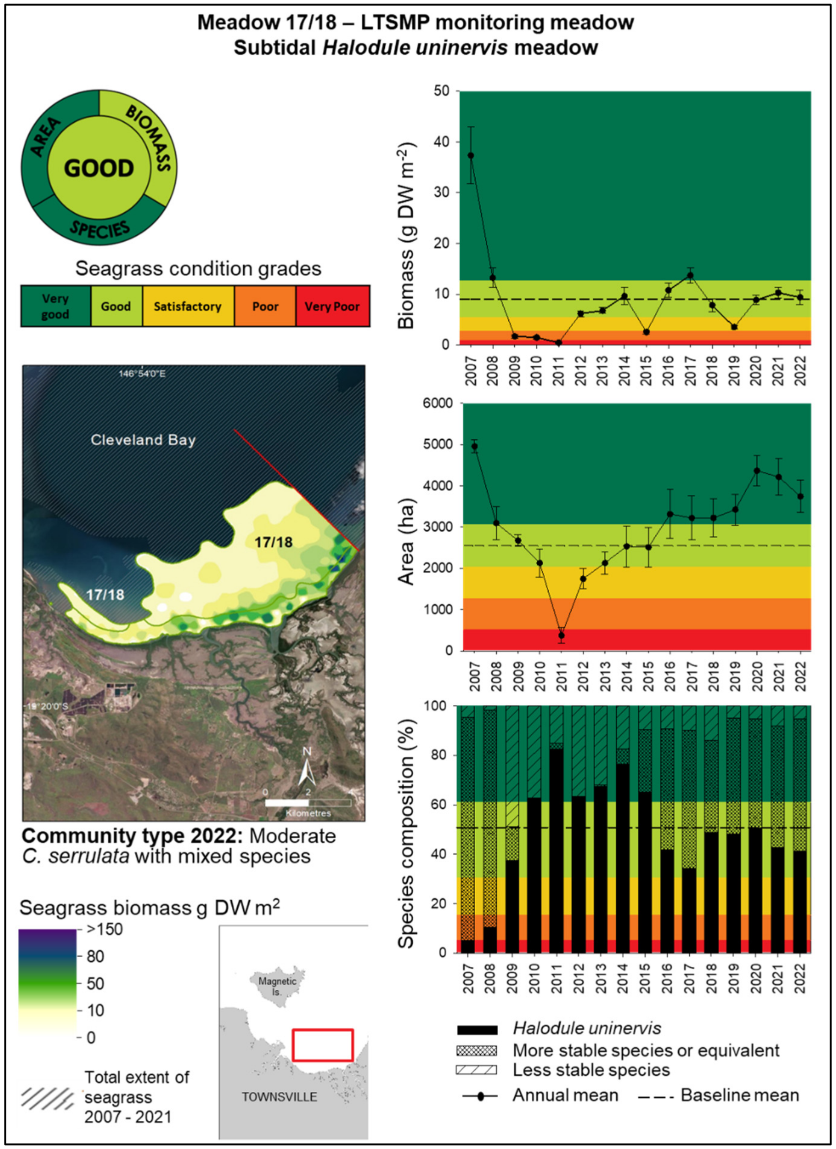

Figure 23. Changes in meadow area, biomass, and species composition for LTSMP seagrass Meadow 17/18 in Cleveland Bay, 2007 – 2022. (biomass error bars = SE; area error bars = “R” reliability estimate).

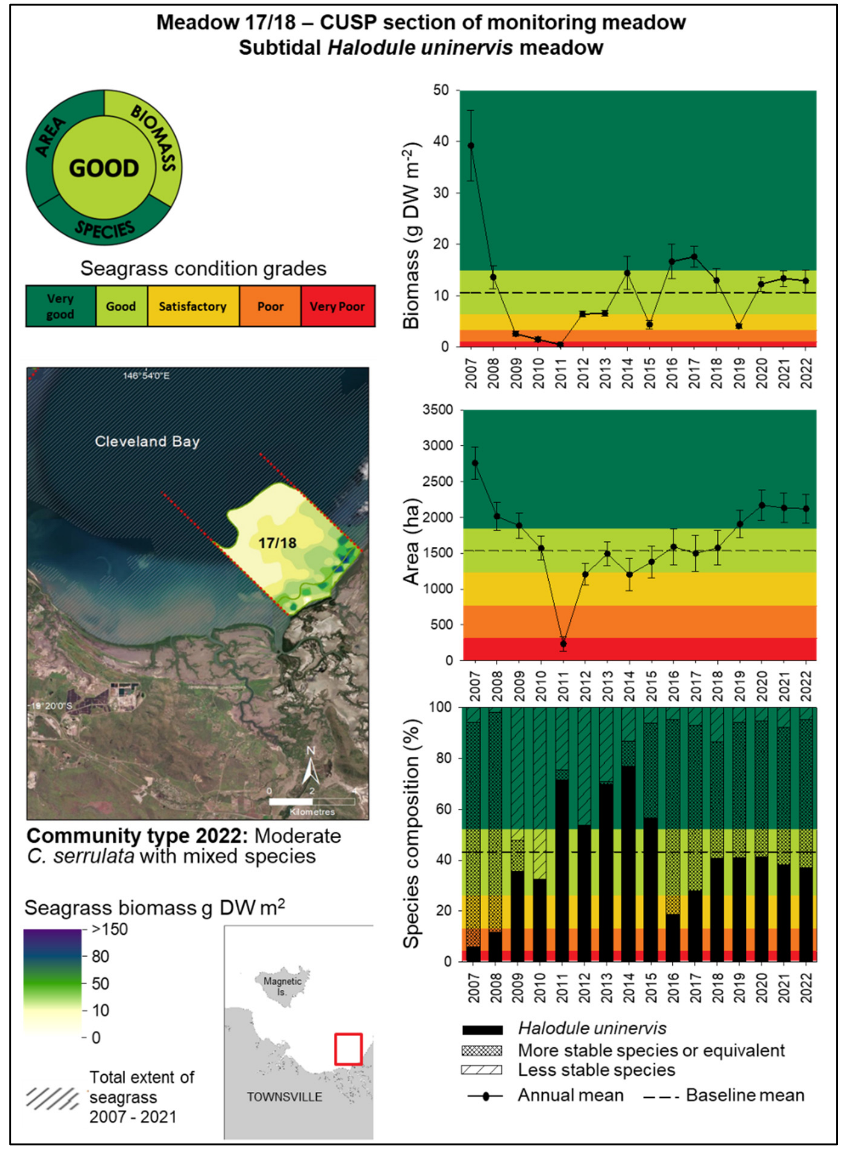

Figure 24. Changes in meadow area, biomass, and species composition for CUSP meadow section Meadow 17/18 in Cleveland Bay, 2007 – 2022. (biomass error bars = SE; area error bars = “R” reliability estimate).

5.3 Seasonal comparisons of Townville CUSP meadows

Seagrass meadows that form the CUSP are surveyed biannually (Table 1; Figure 5). Biannual surveys in tropical Queensland help track impacts from the wet season and seasonality (if any) in seagrass meadows and provide more frequent sampling for the CU Project.

In 2022, overall CUSP meadow area decreased by 16% From May to October 2022 (Figures 25 & 26). As a comparison in 2020 and 2021, meadow area increased by 19% and 5% respectively over the May to October period (Figure 25). Seagrass area and biomass change from previous 2022 and 2021 surveys varied at the individual meadow scale. The overall decrease in area of CUSP meadows between May and October 2022 was due to only four of the ten meadows decreasing in area between surveys: Cockle Bay (Meadow 5), Rowes Bay (Meadow 12), Pallarenda (Meadow 14) and Cleveland Bay (Meadow 16), a mix of intertidal and subtidal meadows. All other meadows increased in area between seasonal surveys (Figures 25 & 26).

Records of dugongs and their feeding trails (seen during intertidal helicopter surveys) were slightly higher in the October 2022 survey; 5.4% of intertidal sites, compared to 3.4% of sites in May 2022. In 2021, the occurrence of dugong feeding trails did not change between seasonal surveys, both surveys recording dugong feeding trails at approximately 3.5% of intertidal sites.

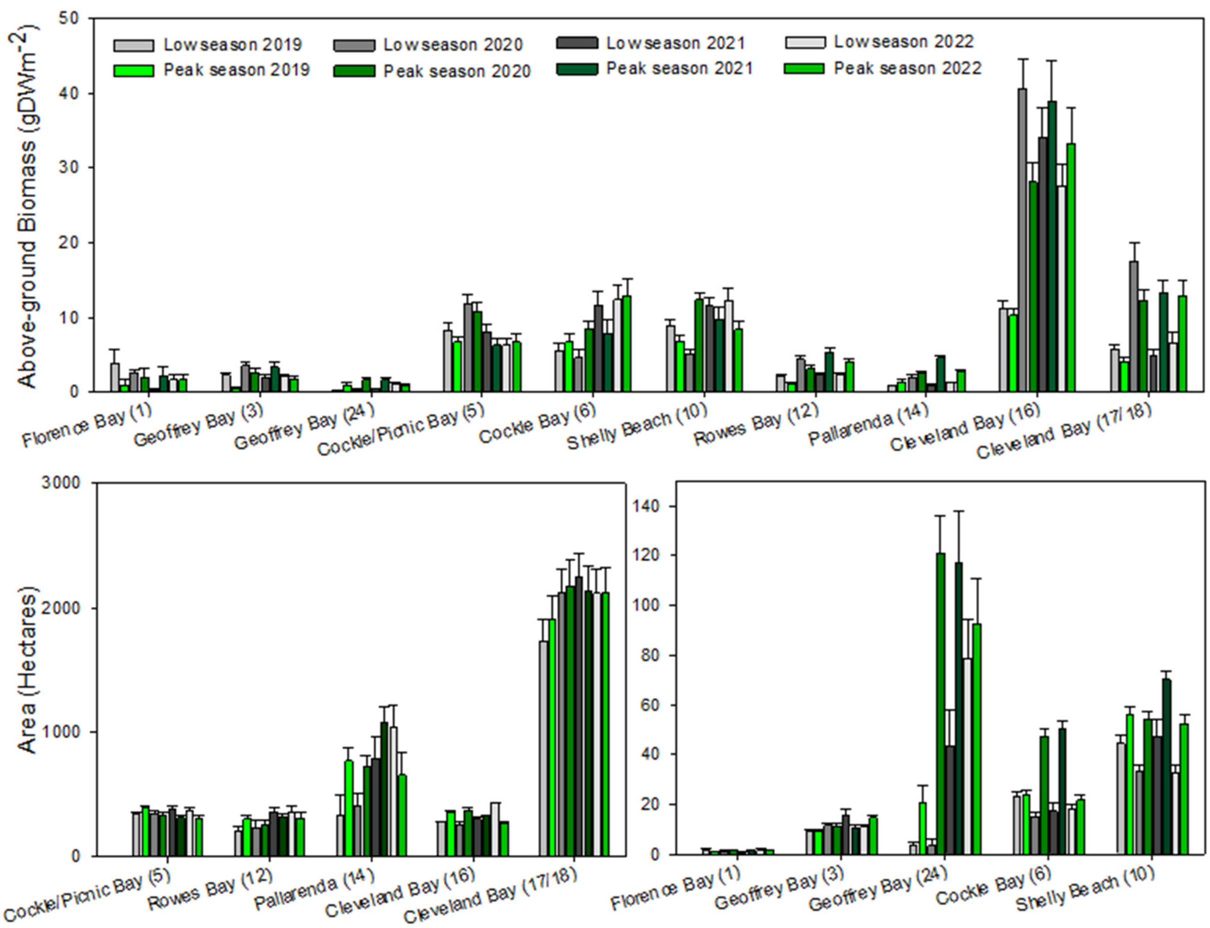

Figure 25. Seasonal meadow biomass and area in April/May and October/November surveys 2019 - 2022.

A)

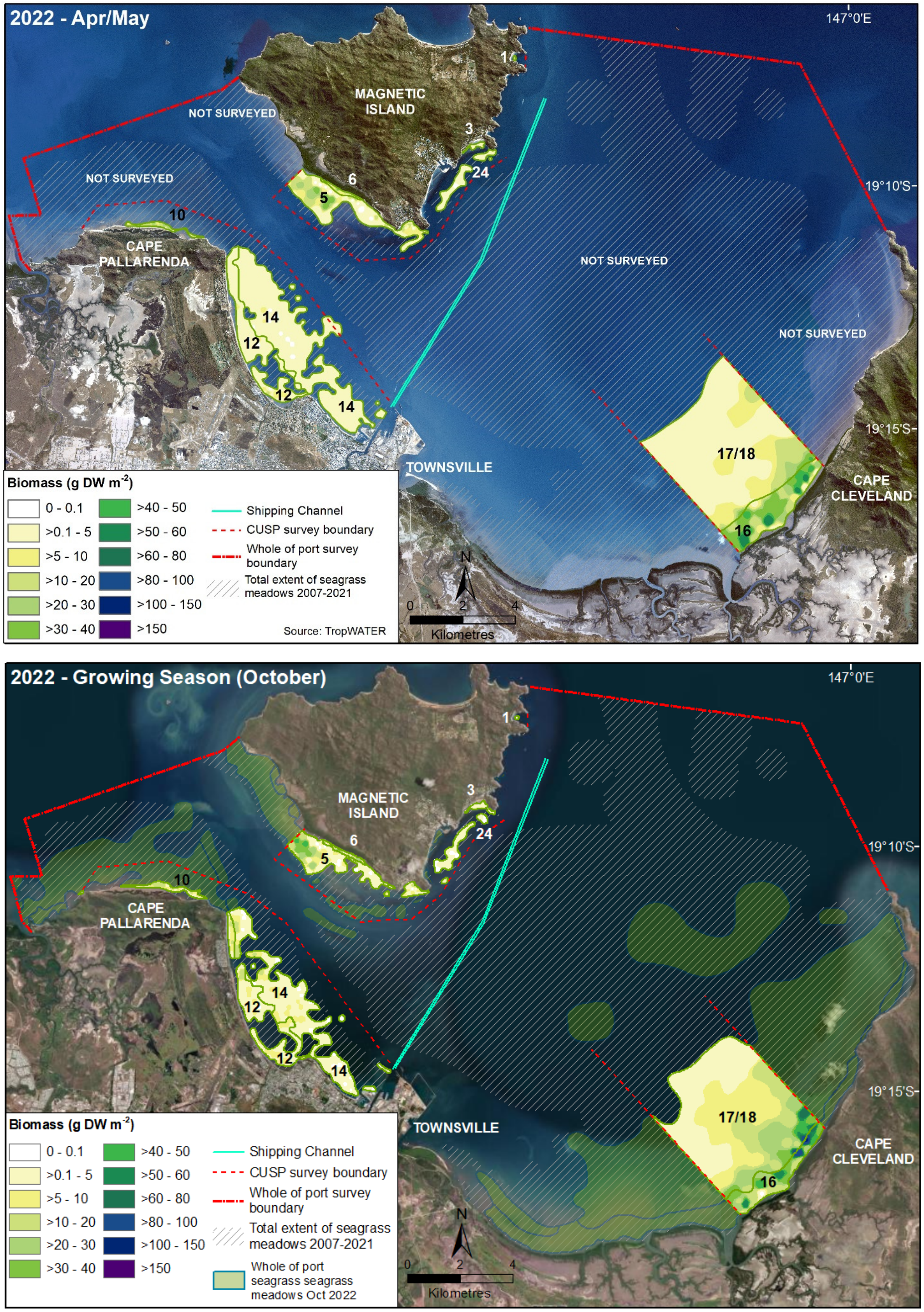

Figure 26. Seagrass density and distribution in the 2022 A) April/May and B) October/November surveys.

5.4 Whole-Of-Port Comparisons of Townsville Seagrass

Dry season whole-of-port surveys have been conducted seven times since the LTSMP program was established in 2007: 2007, 2013, 2016, 2019, 2020, 2021 and 2022. Seagrass meadow location and species composition has been similar around the port for coastal meadows in each of these surveys.

A total of 1,541 sites were assessed for seagrass condition as part of the October 2022 whole-of-port seagrass surveys, with seagrass present at 54% of sites. This is slightly lower than the previous two years which had seagrass at ~60% of sites in those two years. The whole-of-port seagrass footprint covered 12,306 ± 1,296 ha in 2022, a 39% decrease from 2021 (Figures 27 & 28). Most of the spatial footprint decrease was due to the smaller footprint of the deep-water Cleveland Bay meadow (Meadow 19) in 2022 compared to 2021.

Mean seagrass above-ground biomass has varied between each of the whole-of-port surveys (Figures 27 & 28). In 2019, above-ground biomass was the lowest for the program across all regions, but biomass has increased or remained stable since then.

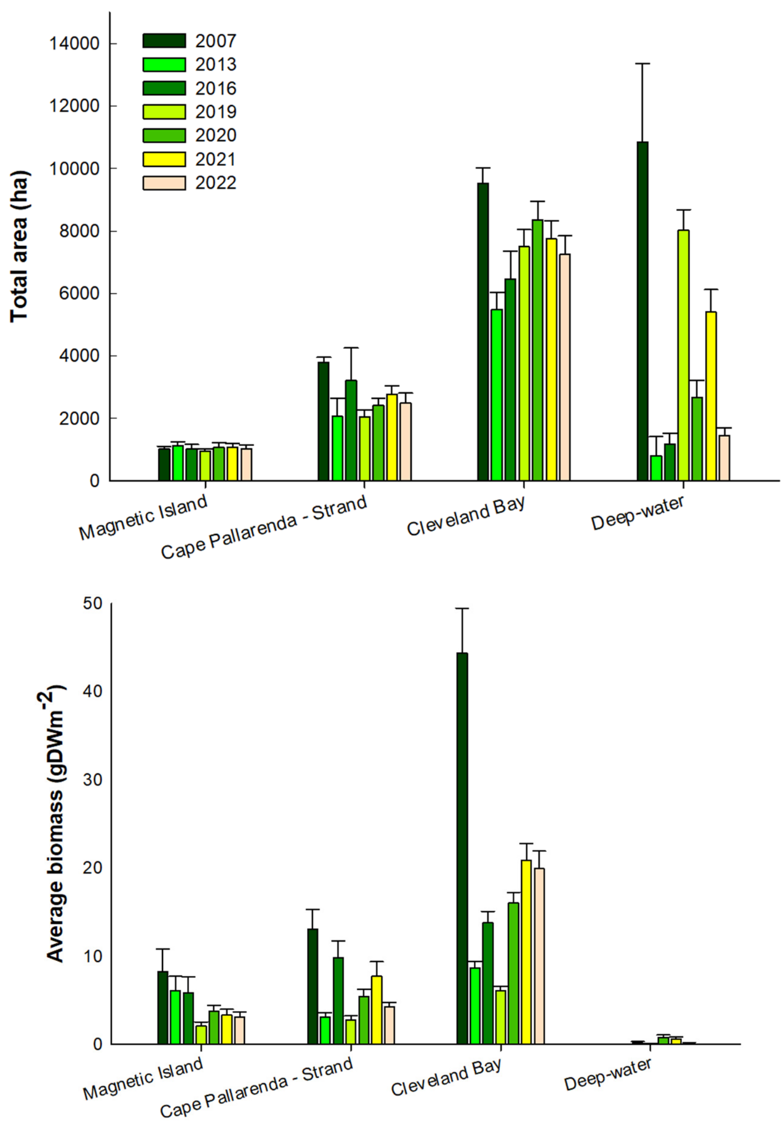

Figure 27. Comparison of whole-of-port meadow area and biomass in the four regions around Townsville in 2007, 2013, 2016, 2019, 2020, 2021 and 2022. (Biomass error bars = SE; area error bars = "R" reliability estimate).

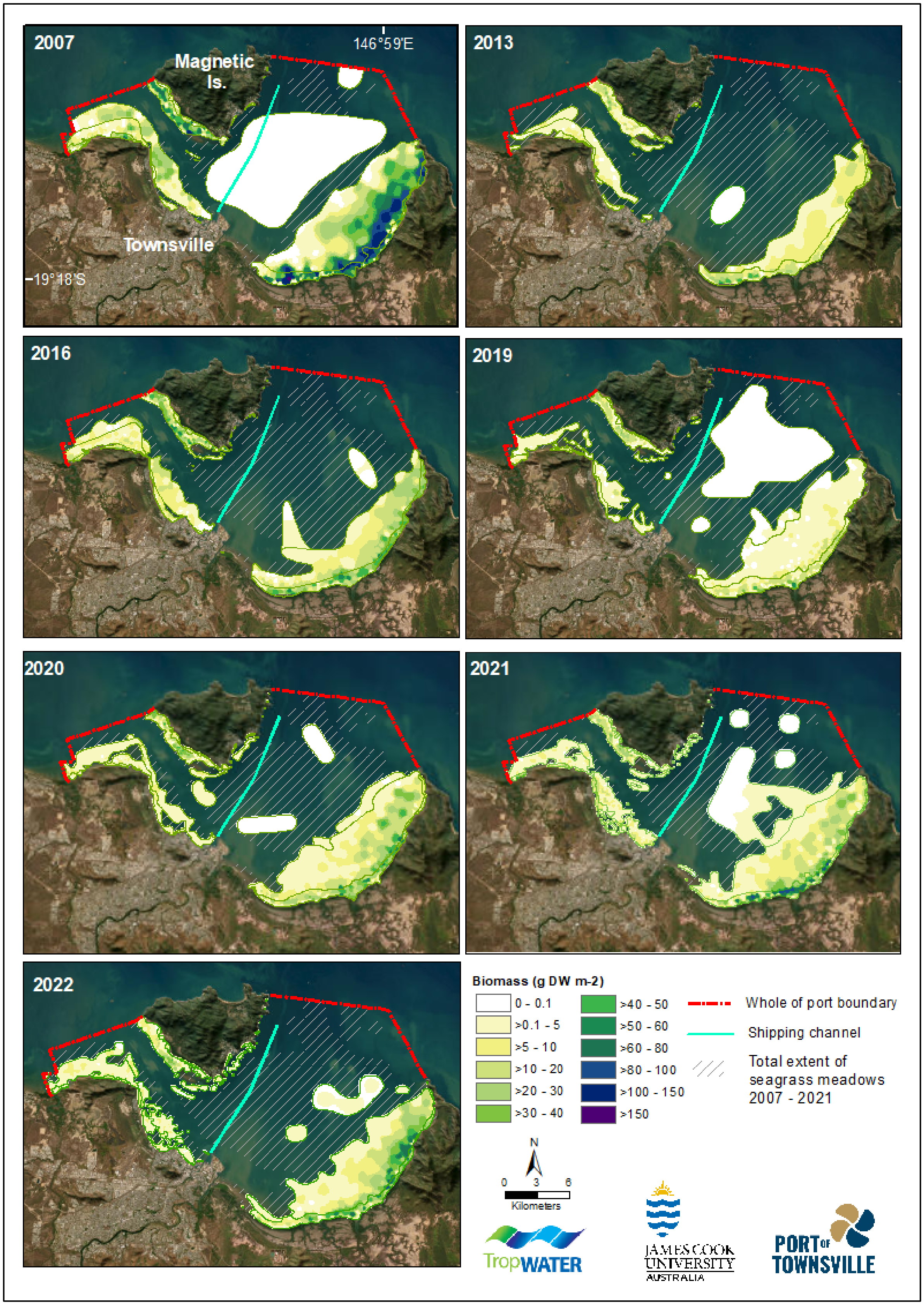

Figure 28. Comparison of whole-of-port seagrass biomass (g DWm^{-2}) and meadow extent; October 2007, 2013, 2016, 2019, 2020, 2021 and 2022.

5.5 Townsville Climate Patterns

5.5.1 Rainfall And River Flow

Rainfall in Townsville is seasonal with most of the rainfall typically occurring from December to April (Figure 29A). The 2021/22 total wet season rainfall was below average but late rainfall after the wet season caused the total annual rainfall to be above the long-term average. This followed two years of below average rainfall (Figure 29B). January, April, May, and July 2022 all had above average monthly rainfall. River flow from all three rivers surrounding Townsville (the Black River, Alligator Creek, and the Burdekin River) has been near to or below the long-term averages for the last three years (Figure 30A & B).

A)

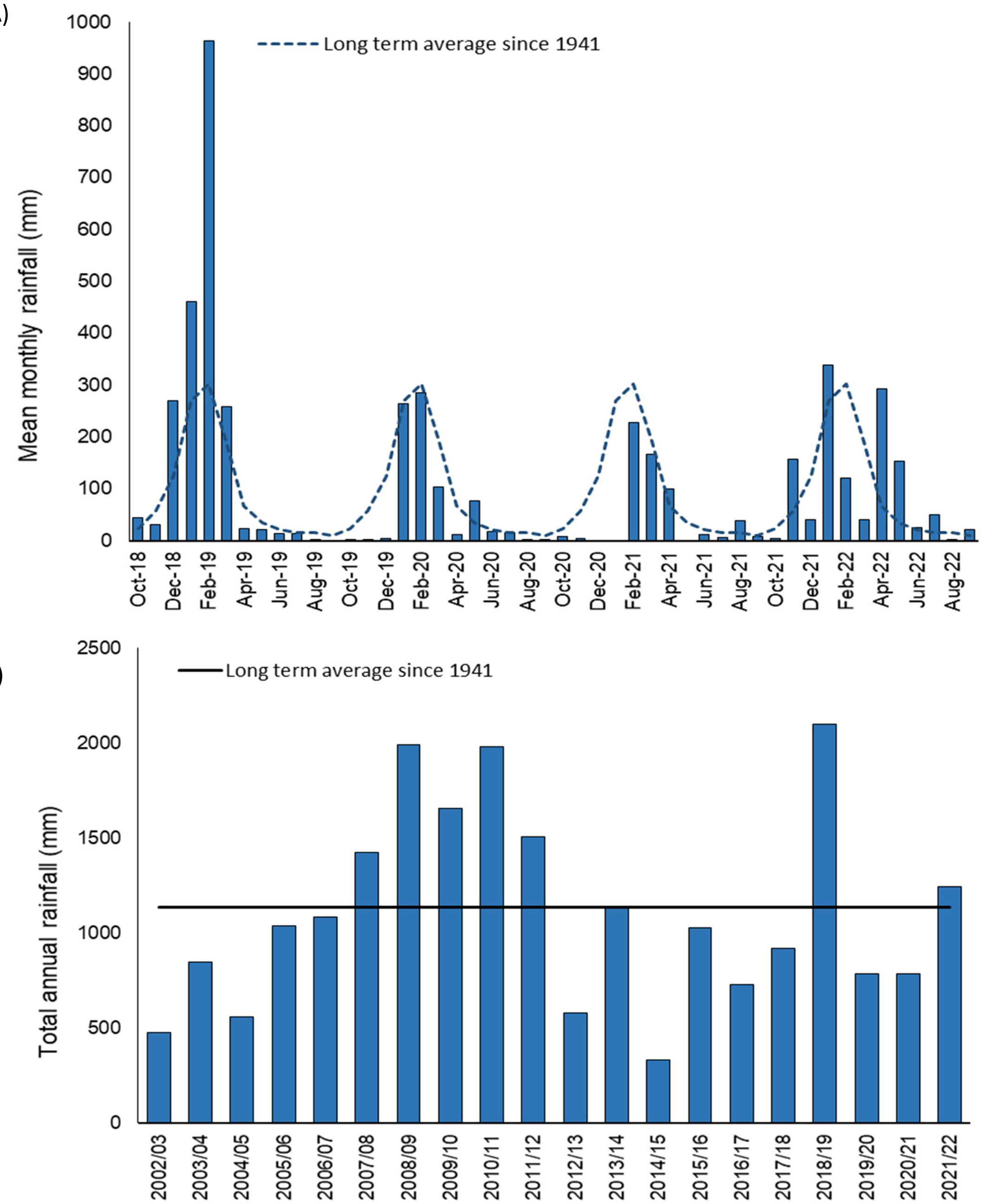

Figure 29. (A) Total monthly rainfall from October 2018 – September 2022 and (B) total annual rainfall from 2002/2003 to 2021/22 recorded at Townsville airport (Data from the Bureau of Meteorology, Station 032040 http://www.bom.gov.au).

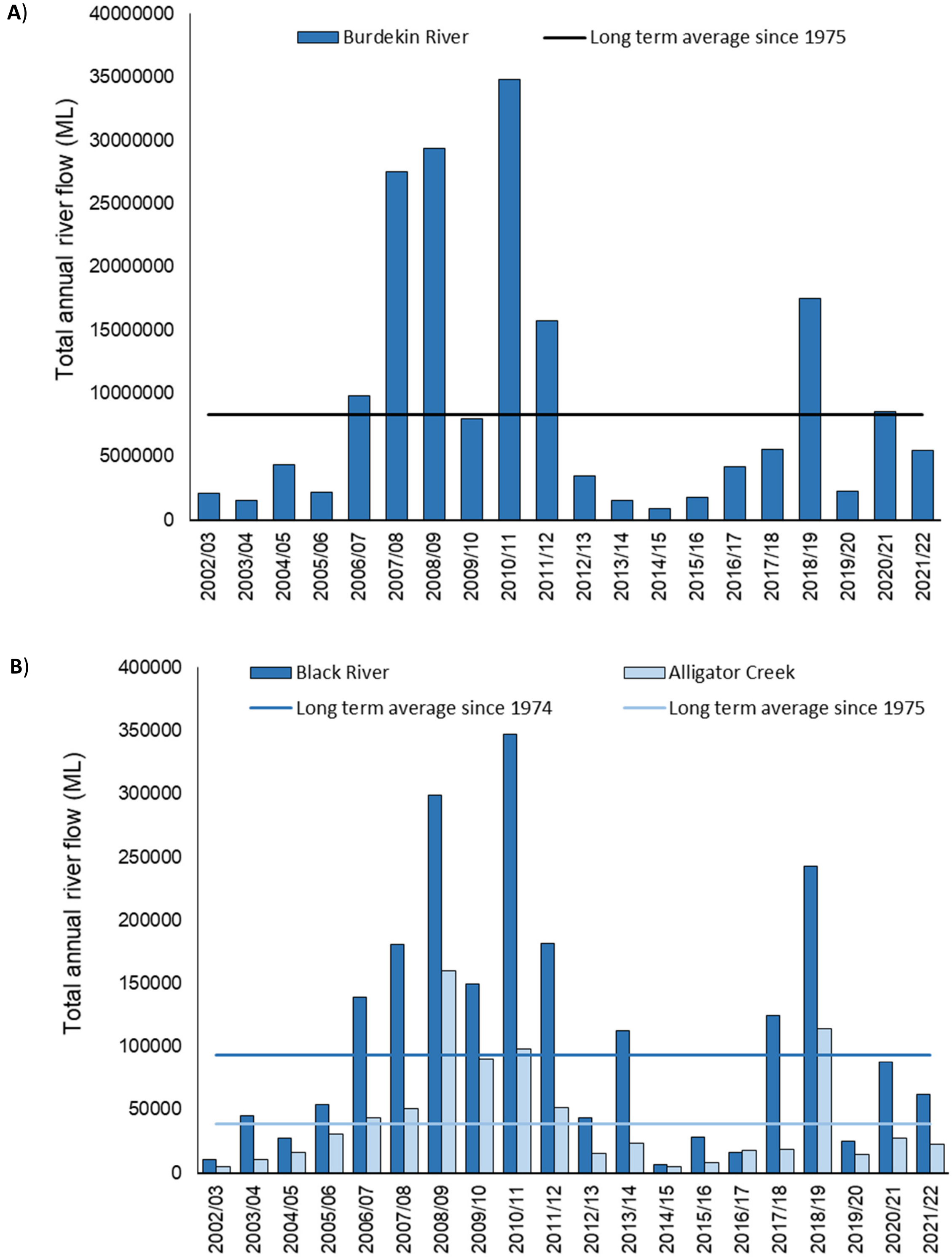

Figure 30. (A) Total annual flow of the Burdekin River from 2003/04 to 2021/22, and (B) total annual flow of the Black River and Alligator Creek from 2002/03 to 2021/22. (Department of Natural Resources, Mines and Energy, https://water-monitoring.information.qld.gov.au/).

5.5.2 Daily Global Solar Exposure

Daily global exposure is a measure of the total amount of solar energy falling on a horizontal surface in one day. Total solar radiation in Townsville during 2021/22 was above the long-term average (Figure 31).

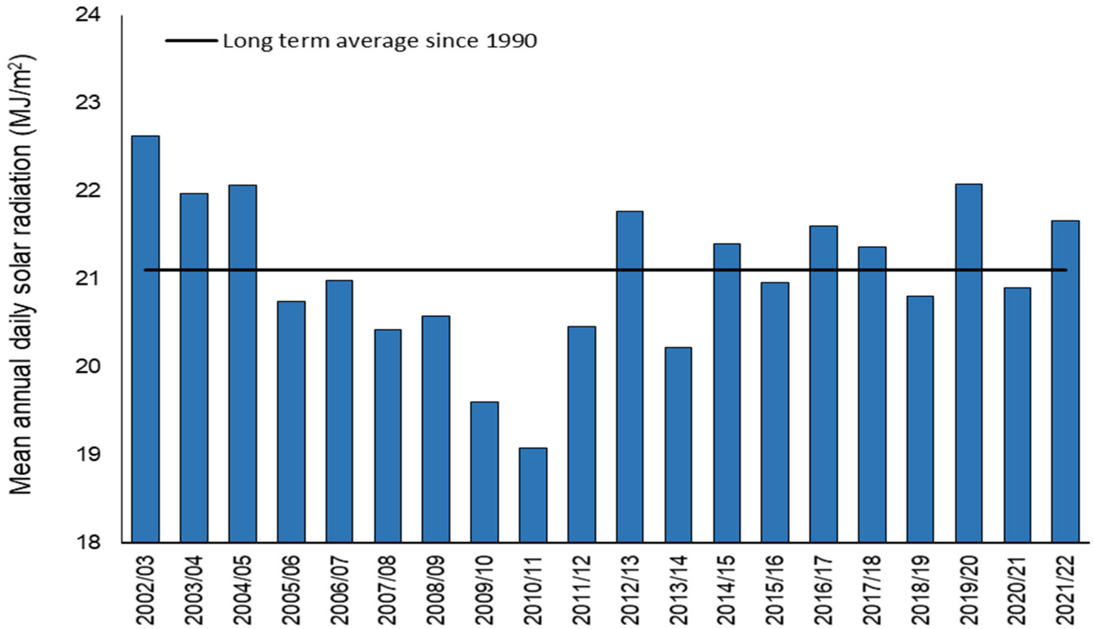

Figure 31. Mean annual daily solar radiation recorded at Townsville airport 2002/03 to 2021/22. (Data from the Bureau of Meteorology, Station 032040 http://www.bom.gov.au).

5.5.3 Air Temperature & Tidal Exposure of Seagrass Meadows

Mean annual daily maximum air temperature for 20222/22 was 29.9°C and has been above the long-term average of 29°C for the last ten years (Figure 32).

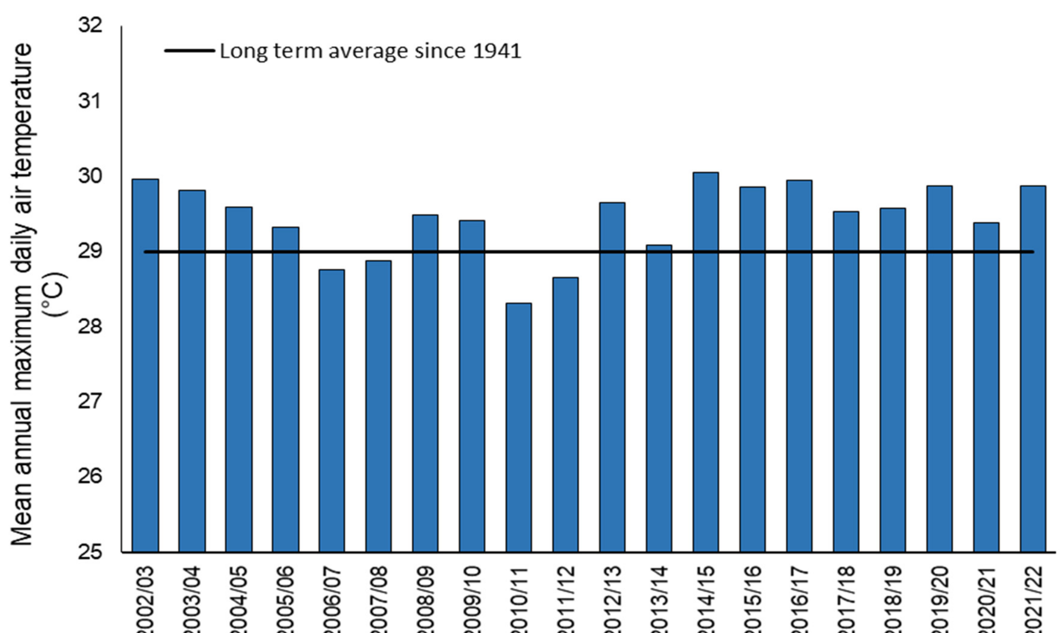

Figure 32. Mean annual maximum daily air temperature (°C) recorded at Townsville Airport, 2002/03 to 2021/22. (Data from the Bureau of Meteorology, Station 032040 http://www.bom.gov.au).

Total daytime exposure to air of intertidal seagrasses in Townsville is generally higher during the winter months and lower over summer/wet season (Figure 33A). The total time seagrass meadows were exposed to air in the months preceding the 2022 surveys (April and September) was lower than the long-term averages (Figure 33A). Total hours of tidal exposure in the one-month period prior to the two 2022 surveys were 4 hours for the post-wet survey, and 29 hours for the dry season survey: both below long-term averages (Figure 33A & B). The total hours of tidal exposure in the three-month period before dry season surveys has been below the long-term average for seven years (Figure 33B).

A)

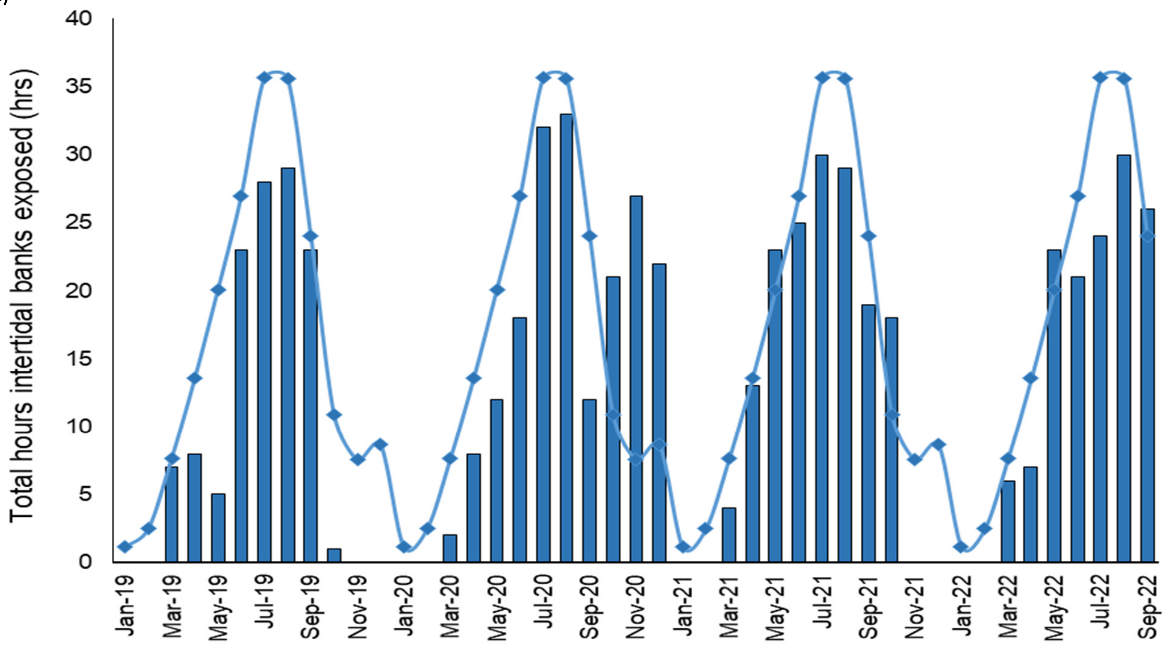

Figure 33A. Total monthly daytime intertidal exposure (<0.8m tidal height) Jan 2019 – December 2022 (Maritime Safety Queensland, www.msq.qld.gov.au).

B)

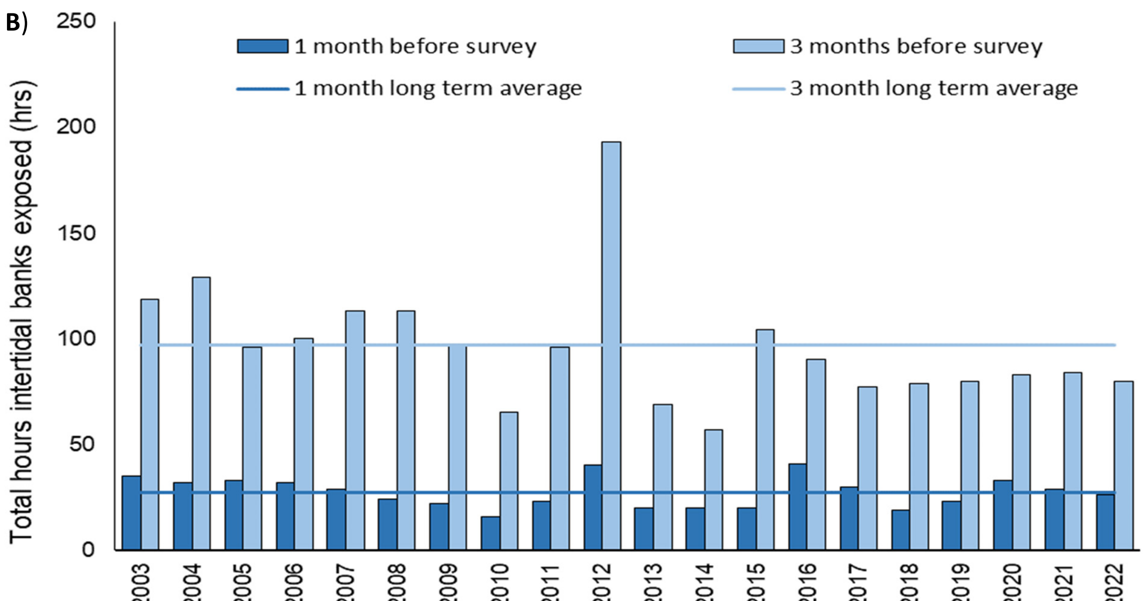

Figure 33B. Total daytime intertidal exposure (<0.8m tidal height) one month and three months prior to the growing season monitoring in Townsville (September 2022) (Maritime Safety Queensland, www.msq.qld.gov.au).

5.5.4 Photosynthetic Active Radiation (PAR) and Water Temperature

The Townsville seagrass program refers to benthic PAR and water temperature data from the CU Marine Water Monitoring Program (CU MWMP; GHD) to help inform seagrass habitat condition. The amount and quality of light reaching the seabed is a limiting factor and critical to the persistence and growth of seagrass. Monitoring PAR helps us understand seagrass change and potential causes of any observed change. For the CUSP, biologically relevant seagrass thresholds have been set at:

- Subtidal seagrass meadows dominated by *Halophila spinulosa* – 2.5 mol/m^2/day; 7 day rolling average; 28 consecutive days below threshold before impact.
- Intertidal seagrass meadows dominated by *Zostera muelleri* and *Halodule uninervis* - 6 mol/m^2/day; 14 day rolling average; 28 consecutive days below threshold before impact.

The MWMP has monitoring sites that are telemetered and some that are not telemetered (GHD 2022). Key or notable PAR data findings will be referred to in the discussion and not reported here as it will be part of the 2023 MWMP reporting.

6 DISCUSSION

Seagrass meadows in Townsville were in an overall satisfactory or better condition in 2022. An extensive footprint of seagrass was found in the greater port region. Nine of the twelve monitoring meadows were in a satisfactory or better condition while three meadows were in poor condition due to declines in meadow biomass or area. The species composition of all meadows was in good or very good condition. The presence of turtles and dugongs and their feeding trails in meadows throughout the survey area indicated herbivorous marine megafauna continue to make extensive use of the available seagrass habitat.

While an extensive footprint of seagrass was present in Townsville, declines in meadow biomass and/or area between October 2021 to October 2022 were recorded across most meadows. The fact that declines occurred throughout the entire region suggests regional scale drivers of change rather than localised declines associated with anthropogenic causes such as capital or maintenance dredging. Local environmental conditions through 2022 are likely to have driven the small declines in meadow biomass and/or area recorded in seagrass meadows throughout Townsville.

Through 2022 there were many periods when environmental conditions were not favourable for seagrass growth and persistence. As individual one-off events these unfavourable conditions are not likely to have impacted seagrass in the region, however, successive, and concurrent events during the year are likely to have caused cumulative stress to seagrass sufficient to cause the declines recorded in October 2022. Unfavourable environmental conditions in 2022 included a March heat wave, out of season above average rainfall, persistent elevated wind conditions (> 20 knots) coinciding with the above-average rainfall months, and low light conditions for significant periods of time (i.e., greater than 28 days) during the year at various times and sites. For example, Shelley Beach intertidal loggers (SB1 & SB2) recorded light levels less than 6 mol/m^2/day (14 day rolling average) for 105 days February-June, and 37 days August-September. Cleveland Bay intertidal loggers (CB1 & CB2) recorded light less than 6 mol/m^2/day (14 day rolling average) for 42 days June-August and 78 days August-October. There were many other occurrences like this at other intertidal and subtidal sites. The 2023 CU Marine Water Monitoring Program report will have the full details on PAR values at monitoring sites.

Local environmental conditions are a key factor in determining seagrass distribution, biomass, and health. One of the primary drivers of seagrass distribution, abundance and productivity is the availability of light (Chartrand et al. 2012; Collier et al. 2012b; Bjork et al. 1999). Studies conducted at Magnetic Island show increases in light are positively correlated with seagrass growth and that very low light intensities significantly contributed to the loss of seagrasses in 2011 (Collier et al. 2012a). Riverine and creek inputs, rainfall, and wind (causing resuspension of sediment leading to increased turbidity) all have an impact on the quantity and quality of light reaching the seagrass (GHD 2022; Jones et al. 2020; Bainbridge et al. 2012; Petus et al. 2014; Lambrechts et al. 2010). Throughout 2022, there were many 'out of season' periods, at various monitoring sites, that recorded sustained low light within the seagrass meadows, and which were likely to have impacted seagrass growth and survival. Daytime tidal exposure during these times, more specifically the time just before exposure and just after exposure is likely to have provided some relief to low light conditions allowing seagrass to persist, but not necessarily expand their footprint, particularly into deeper areas where further light limitation occurs.

Extreme and sustained periods of high within-canopy temperatures can also have an impact on seagrass. We reported in the May bi-annual seagrass program report (McKenna et al. 2022) that the March heatwave in Townsville did not reach high enough temperatures, or that high temperatures were not sustained for long enough to cause declines in Townsville seagrass species. The temperatures recorded in seagrass meadows by the CU MWMP during the March 2022 heatwave were within the range of temperatures previously recorded in the meadows (McKenzie et al. 2023). Studies in Townsville have shown local species can withstand temperatures of 35°C with no detrimental effects, but an impact is seen if 40°C is sustained (Collier and Waycott 2014). The optimum temperature for photosynthesis of *Halodule uninervis* and *Cymodocea serrulata* is 35°C (on average) and it must exceed 40°C for the plants to lose energy (Collier et al. 2017). Campbell et al. (2006) also found that the physiological functions of Townsville seagrass species are not impacted until temperature extremes of 40-45°C are reached for at least three days. Daytime tidal exposure during the March heatwave and in April following the heatwave were below the long-term average which may have provided some respite from the elevated temperatures.

The additional survey and reporting conducted in July 2022, also reported little physical evidence to suggest that the March heatwave and/or periods of low light recorded in May 2022 had an impact on Townsville seagrass at that time. It is possible however, that the declines in biomass and/or area recorded in most meadows by October 2022, could be a delayed response to these events particularly when combined with the other unfavourable environmental conditions that occurred during 2022. A similar delayed response of seagrass loss was seen after the 2019 Townsville floods. No losses were reported after the May 2019 survey but by October 2019 widespread declines in seagrass biomass and/or area were recorded throughout the region (McKenna et al. 2020). These delayed responses could be a result of seagrasses having depleted their energy stores during the year, impacting their ability to fully exploit more favourable growing conditions when they occurred later in the year.

Three seagrass meadows in the Townsville region have showed declining trends over recent years: the Cockle Bay intertidal reef top Meadow 5, Cleveland Bay intertidal *Z. muelleri* Meadow 16 and the Shelley Beach intertidal *Z. muelleri* Meadow 10. For the two *Z. muelleri* meadows, the downward trend in area is likely due to the encroachment of other neighbouring meadows of different species mixes as well as expansion of mangroves into some areas that previously contained seagrass. Both these meadows share a seaward boundary with an adjacent meadow that are extending further shoreward outcompeting the *Z. muelleri* meadows. The inshore boundary of the two *Z. muelleri* meadows are also retracting as stands of mangroves grow further out into the mudbank (the Cleveland Bay meadow) and sand banks shift and expand (the Shelley Beach meadow).

The Cockle Bay reef top meadow may be experiencing a localised disturbance contributing to the declining trends in meadow area and biomass. The Great Barrier Reef Marine Park Authority's Marine Monitoring Program (MMP) has also reported that seagrass abundance has progressively declined at their Cockle Bay sites since 2015 and that there has been a shift to colonising species dominating their sites (McKenzie et al. 2023). Our field observations over the past decade suggest that the reef top has changed to be dominated by unconsolidated rubble rather than consolidated rubble/rock and hard coral making the landscape more difficult for seagrass to colonise and persist. While the exact cause of these changes is not clear it is unlikely to be associated with capital or maintenance dredging in the area as changes predate the start of the CU project and light levels recorded in the meadow through the CU MWMP have not fallen below biologically relevant thresholds during the project.

Bi-annual seagrass monitoring indicates that the seasonal signal in biomass in Townsville seagrasses may not be particularly strong or consistent compared with some other Queensland locations. There are mixed results depending on meadow depth and type (seagrass community), with the clearest seasonal signal occurring in deeper meadows, the outer margins of subtidal meadows and those dominated by *Halophila* species (i.e., the deep-water Cleveland Bay Meadow 19). For seagrass area, the seasonal signal is slightly stronger than biomass and is mainly driven by growth and expansion of colonising *Halophila* species in the peak season surveys.

The deep-water *Halophila* meadows in Townsville continued to be highly variable from year to year. These deeper meadows and their species are ephemeral and are generally only present for part of the year (Chartrand et al. 2017; York et al 2015). *Halophila* species generally germinate and grow from a recruitment of seeds, or a sediment seed bank that can remain dormant in the sediment for parts of the year or between years until environmental conditions are suitable for growth (Chartrand et al. 2017; York et al 2015; Rasheed et al. 2014; Hammerstrom et al. 2006; Hammerstrom and Kenworthy 2003; McMillan 1991). *Halophila* fruits were found in abundance in the 2022 dry season survey.

The condition of seagrass meadows in Townsville reflected local environmental related changes. Long term monitoring at other locations in the Queensland wide seagrass monitoring network reflected similar results. In Gladstone local weather-related changes in seagrass were recorded with some meadows being impacted by high rainfall events, whereas seagrass in Cairns, Clairview and Abbot Point were in good condition with generally favourable local weather conditions (Rasheed et al. 2023; Reason et al. 2023; Smith et al. 2023).

Seagrass meadows in Townsville were in an overall satisfactory or better condition in 2022. While some indicators of seagrass condition in some meadows may mean they are more susceptible to future pressures than previously, their good spatial coverage and species composition indicates they have levels of resilience and a capacity to return to better overall meadow condition if favourable environmental conditions are present through 2023.

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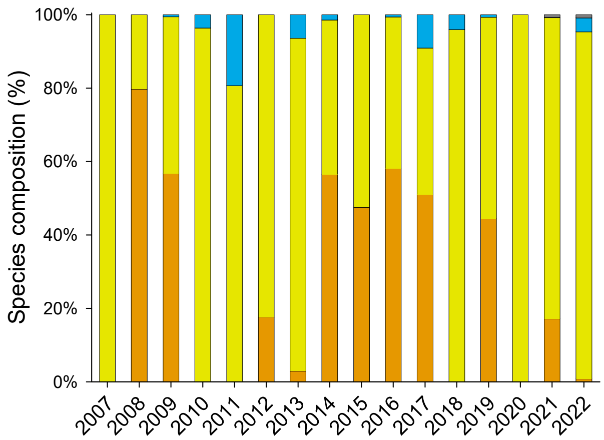
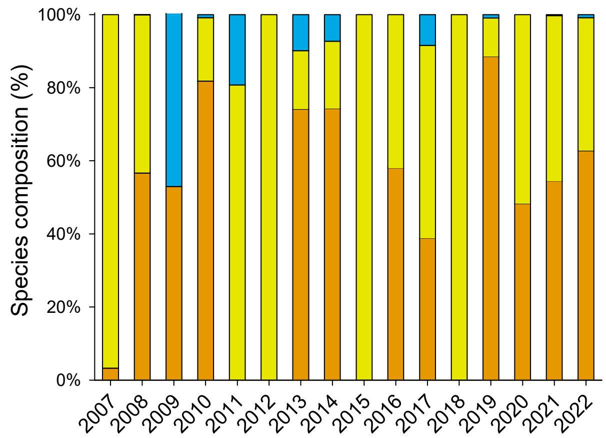
8 APPENDICES

Appendix 1. Detailed meadow species composition; 2007-2022

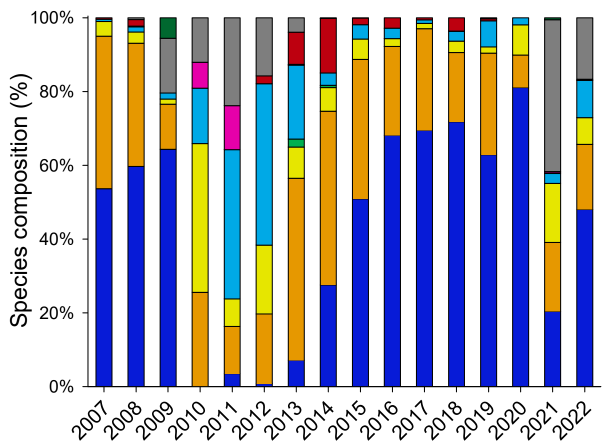
Meadow 3



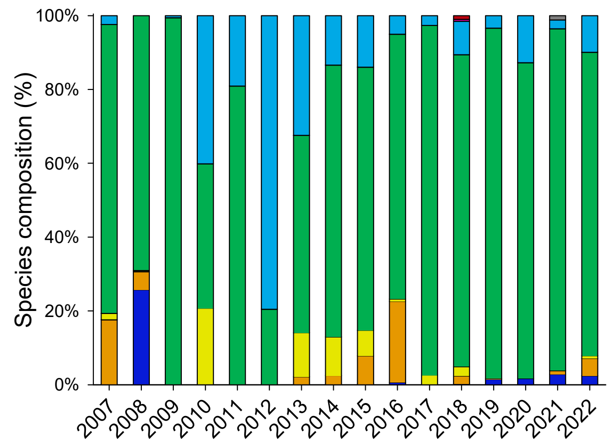
Meadow 4



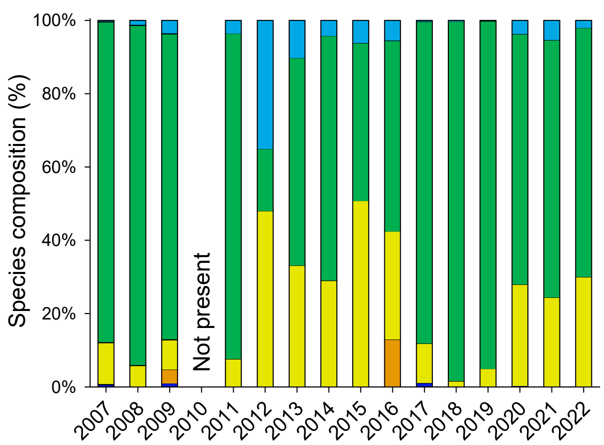
Meadow 5



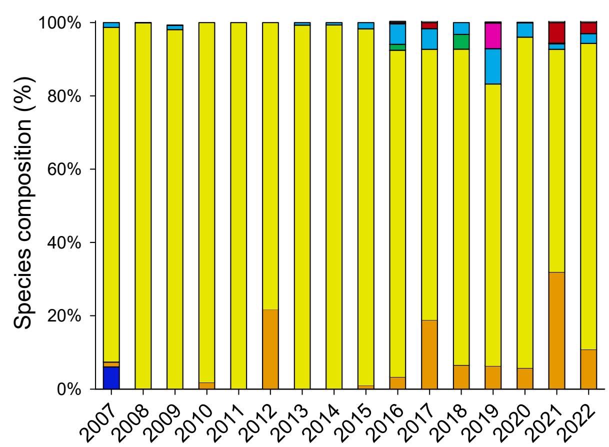
Meadow 6



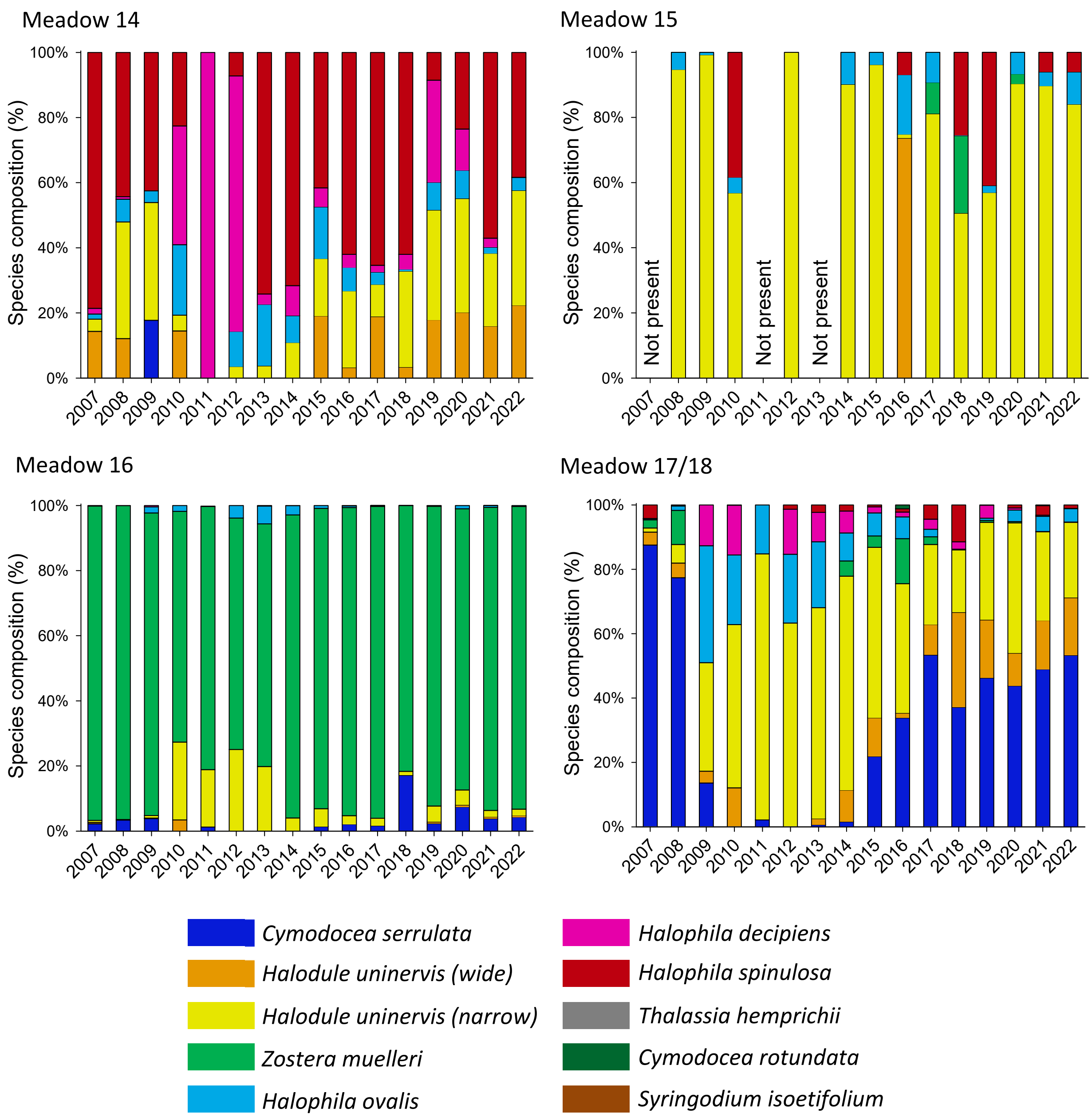
Meadow 10



Meadow 12

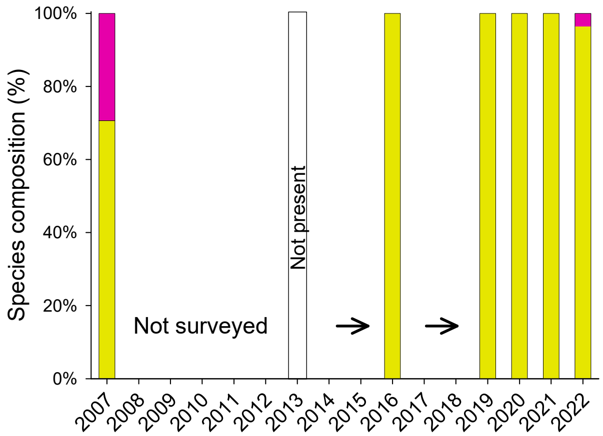


- *Cymodocea serrulata*
- *Halodule uninervis (wide)*
- *Halodule uninervis (narrow)*
- *Zostera muelleri*
- *Halophila ovalis*
- *Halophila decipiens*
- *Halophila spinulosa*
- *Thalassia hemprichii*
- *Cymodocea rotundata*
- *Syringodium isoetifolium*

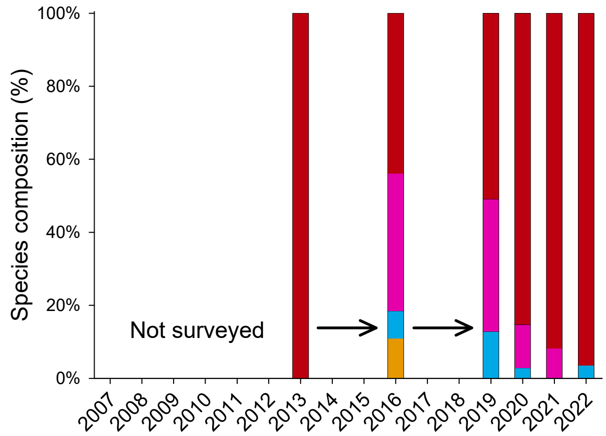

Meadow 14
Meadow 15
Meadow 16
Meadow 17/18
Species composition (%)
0%
20%
40%
60%
80%
100%
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Not present
Not present
Not present
Cymodocea serrulata
Halodule uninervis (wide)
Halodule uninervis (narrow)
Zostera muelleri
Halophila ovalis
Halophila decipiens
Halophila spinulosa
Thalassia hemprichii
Cymodocea rotundata
Syringodium isoetifolium

Meadows 1, 24 and deep-water meadow 19 were surveyed as part of whole-of-port surveys; 2007, 2013, 2016. From 2019 they have been surveyed annually: 2019, 2020, 2021 & 2022.

Meadow 1



Meadow 24



Deep-water Meadow 19