PORT OF TOWNSVILLE
SEAGRASS MONITORING PROGRAM 2021

McKenna S, Van De Wetering C and Wilkinson J

Report No. 22/05

February 2022

PORT OF TOWNSVILLE SEAGRASS MONITORING PROGRAM 2021

A Report for the Port of Townsville Limited

Report No. 22/05

February 2022

Prepared by Skye McKenna,
Chris Van De Wetering and Juliette Wilkinson

Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)
James Cook University
PO Box 6811
Cairns Qld 4870
Phone: (07) 4232 2023
Email: skye.mckenna@jcu.edu.au
Web: www.tropwater.com

Information should be cited as:

McKenna S, Van De Wetering C and J Wilkinson 2022, 'Port of Townsville Seagrass Monitoring Program: 2021,' James Cook University Publication, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), Cairns.

For further information contact:

Skye McKenna
Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)
James Cook University
skye.mckenna@jcu.edu.au
PO Box 6811
Cairns QLD 4870

This publication has been compiled by the Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University.

Acknowledgments:

This project was funded by the Port of Townsville Limited (PoTL). We wish to thank TropWATER staff and volunteers for their assistance in the field.

KEY FINDINGS

Seagrass Condition 2021

Good

LTSMP meadows

Good

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 15^{th} year of the LTSMP and the 3^{rd} year of the CUSP. Key findings for the 2021 surveys include:

- Seagrass in monitoring meadows were in good condition with the footprint, species composition and density of seagrass at expected levels measured against baselines.

- Total seagrass area within the port limits covered 17,146 ha in 2021. An 18% increase from the same time last year. Within this total footprint:
    - LTSMP meadows covered 7,074 ha
    - CUSP meadows covered 4,417 ha

- Ten of the eleven seagrass species that are known to occur in the Townsville region were present in areas surveyed in 2021. This included the first record of *Halophila tricostata* in the LTSMP in the deeper areas of Cleveland Bay.

- 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.

- So far seasonal assessments suggest the seasonal signal in seagrass density and area in Townsville is not as strong or consistent as other areas in Queensland.

- The healthy condition of Townsville's seagrass indicates they were in a resilient state leading into 2022.

IN BRIEF

Seagrasses have been monitored annually in the Port of Townsville since 2007 through the Long-Term Seagrass Monitoring Program (LTSMP). The LTSMP has mapped up to 25,000 ha (2007) of coastal and deep-water seagrass in the broader Townsville area. 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 established LTSMP and is designed to assess and monitor seagrass habitat 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 also includes expanded areas of seagrass in assessments to meet regulatory requirements and conditions associated with the CU Project. This report presents the results of the 15th year of the LTSMP and the 3rd year of the CUSP.

Since 2019 seagrass monitoring occurs twice a year in Townsville; once post-wet season in April/May when seagrasses typically show diminished growth – their "low season", then again in the dry season (September-November) when seagrasses are likely at the peak of distribution and abundance. During this dry season survey, all seagrasses within the broader port limits are surveyed, not just the LTSMP and CUSP monitoring meadows. In 2021 two seagrass habitat surveys were conducted in the Port of Townsville:

- April/May 2021 post-wet season survey focusing on the coastal CUSP meadows only and,
- September/October 2021 dry season whole-of-port survey that encompassed the CUSP and LTSMP monitoring meadows, as well as all seagrass within the broader port area.

Seagrasses in the Port of Townsville were in good condition in 2021, similar to 2020. All three condition indicators (seagrass biomass, area and species composition) were graded as satisfactory or better for all monitoring meadows in both programs (Figure 1).

The whole-of-port seagrass footprint covered 17,146 ha in 2021 of which the LTSMP meadows covered 7,074 ha, the CUSP meadows covered 4,417 ha (Figure 1) and the deep-water *Halophila* meadow (Meadow 19) covered 5,405 ha. Total area of LTSMP meadows was the highest recorded since the initial baseline in 2007 (Figure 2).

Seagrass meadow biomass in all monitoring meadows was in satisfactory or better condition in 2021 and the species composition of all monitoring meadows was in good or very good condition.

The deep-water meadow (Meadow 19) that is surveyed annually in Cleveland Bay, is highly variable from year to year in biomass, area and footprint. Between 2020 and 2021 the deep-water meadow increased in area by over 100% to 5,405 ha while biomass was similar between years. Of note in 2021 was the sighting of *Halophila tricostata* in the deeper areas of Cleveland Bay. This species has not been recorded previously in the LTSMP program, although has previously been recorded in the region.

Tropical seagrasses generally follow a seasonal pattern where above-ground biomass and meadow extent (area) diminish in the wet/post-wet season ("low" season), reaching a peak in distribution and density in the late spring (i.e. growing season) (Chartrand et al. 2017; Erftemeijer and Herman 1994; McKenzie 1994; Rasheed 1999; 2004; Unsworth et al. 2010; York et al. 2015). For the CUSP bi-annual monitoring, early results and the original baseline surveys in 2007/2008 (Rasheed and Taylor 2008) suggest that the seasonal signal in seagrass biomass in Townsville seagrasses may not be particularly strong or consistent compared with some other Queensland locations. There appears to be mixed results depending on meadow depth and type (seagrass community), with the clearest seasonal signal occurring in deeper meadows and those dominated by *Halophila* species. 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 dry season surveys.

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.

Seagrasses in Townsville continue to be in healthy condition in 2021. The maintenance of healthy seagrass coincides with a period of stable climate conditions over the past two years that has likely facilitated seagrass growth and increased plant reserves. The prolonged period of good seagrass health provides Townsville seagrass with a good level of resilience leading into 2022.

The Townsville LTSMP is incorporated into the broader Queensland Ports seagrass monitoring program using the consistent state-wide monitoring methodology (see www.tropwater.com.au). This enables direct comparisons with regional and state-wide trends to put local changes into context.

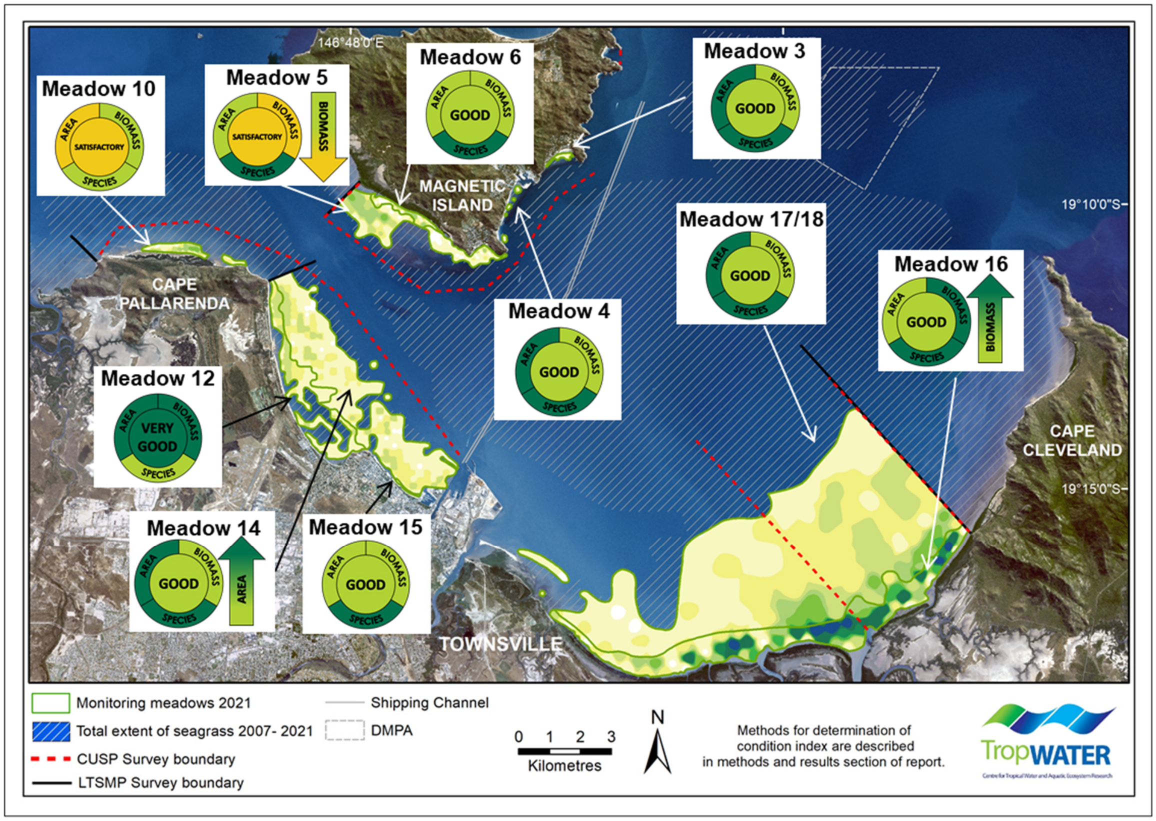


Figure 1. Seagrass condition for meadows monitored as part of the Long-Term Seagrass Monitoring Program (LTSMP). For CUSP meadow condition see results section 3.2

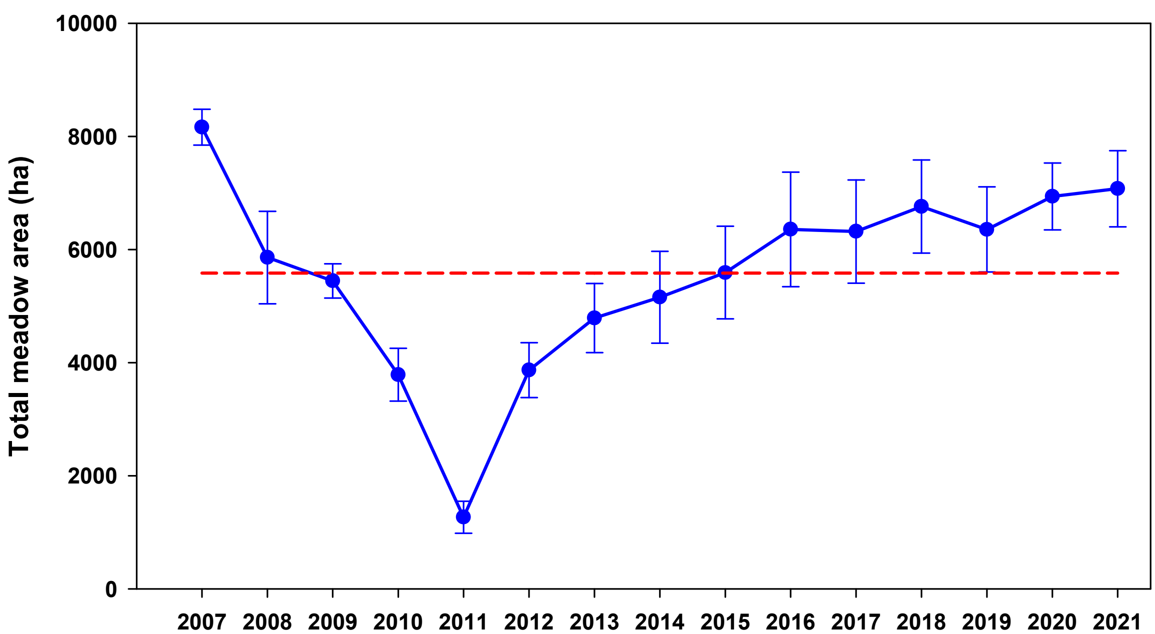


Figure 2. Total area of the Long-term seagrass monitoring program meadows (LTSMP); 2009-2021 (error bars = “R” reliability estimate), (red dashed line = long-term average).

TABLE OF CONTENTS

1 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, 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).

1.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program is established in the majority of 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 3).

Figure 3. 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

1.2 Port of Townsville Seagrass Monitoring Programs

1.2.1 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.

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 4) were selected for annual monitoring, with broader whole-of-port mapping occurring in some years (2007, 2008, 2013, 2016, 2019, 2020 & 2021). 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 (Figures 1 & 4). 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 (Figure 3). 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).

1.2.2 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 surrounding Townsville, Cleveland Bay and Magnetic Island before, during and after the planned works. The CUSP includes the monitoring meadows that form the LTSMP, but also includes expanded areas of seagrass in assessments to meet regulatory requirements and conditions associated with the CU Project (Figure 4). 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 15th year of the LTSMP, and the 3rd year of the CUSP and compares the results with previous surveys.

2 METHODS

2.1 Sampling approach

Methods for assessing seagrass in the Townsville region follow those of the established seagrass program for Townsville and other Queensland ports (Bryant et al. 2016; Wells and Rasheed 2017). 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.

The LTSMP monitors ten seagrass meadows annually between September – November (Table1, Figure 1 & 4). The majority of these meadows or meadow sections also form the CUSP (Table 1, Figure 4). Table 1 provides details on what meadows are assessed in each program.

The CUSP monitoring meadows are a mix of replicated reference and impact locations which will provide data appropriate to assess seagrass condition before, during and after the capital dredge campaign within and outside of the zones of impact (if applicable) and zones of influence (ZoI) (Table 1). For each meadow community/species type and habitat type (intertidal/subtidal) there is an appropriate corresponding reference/impact meadow. Meadow-scale monitoring also allows for assessments along a gradient of impact. The design allows for analysis of seagrass change in relation to historical data and nearby marine water monitoring sites. The larger meadow-scale monitoring also allows a better ability to assess the impacts of larger scale natural events such as flood/wind/wave driven suspension of sediments in Cleveland Bay. The network of monitoring meadows that form the CUSP is also extensive enough, that if the dredge plume footprint shifts from the modelling, seagrass meadows can easily be re-assigned as reference or impact meadows.

Seagrass assessments for the LTSMP occur annually between September – November, while assessments for the CUSP occur twice a year; once post-wet season (April/May) when seagrasses typically show diminished growth – their "low season", then again in the dry season (September - November) when seagrasses are generally at the peak of distribution and abundance. This survey coincides with the LTSMP survey. The CUSP surveys complement the LTSMP by providing more frequent and economical evaluations of seagrass.

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 4). 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 4).
- *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 will form reference and impact regions for the CU Project (Figure 4).

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)
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)
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)

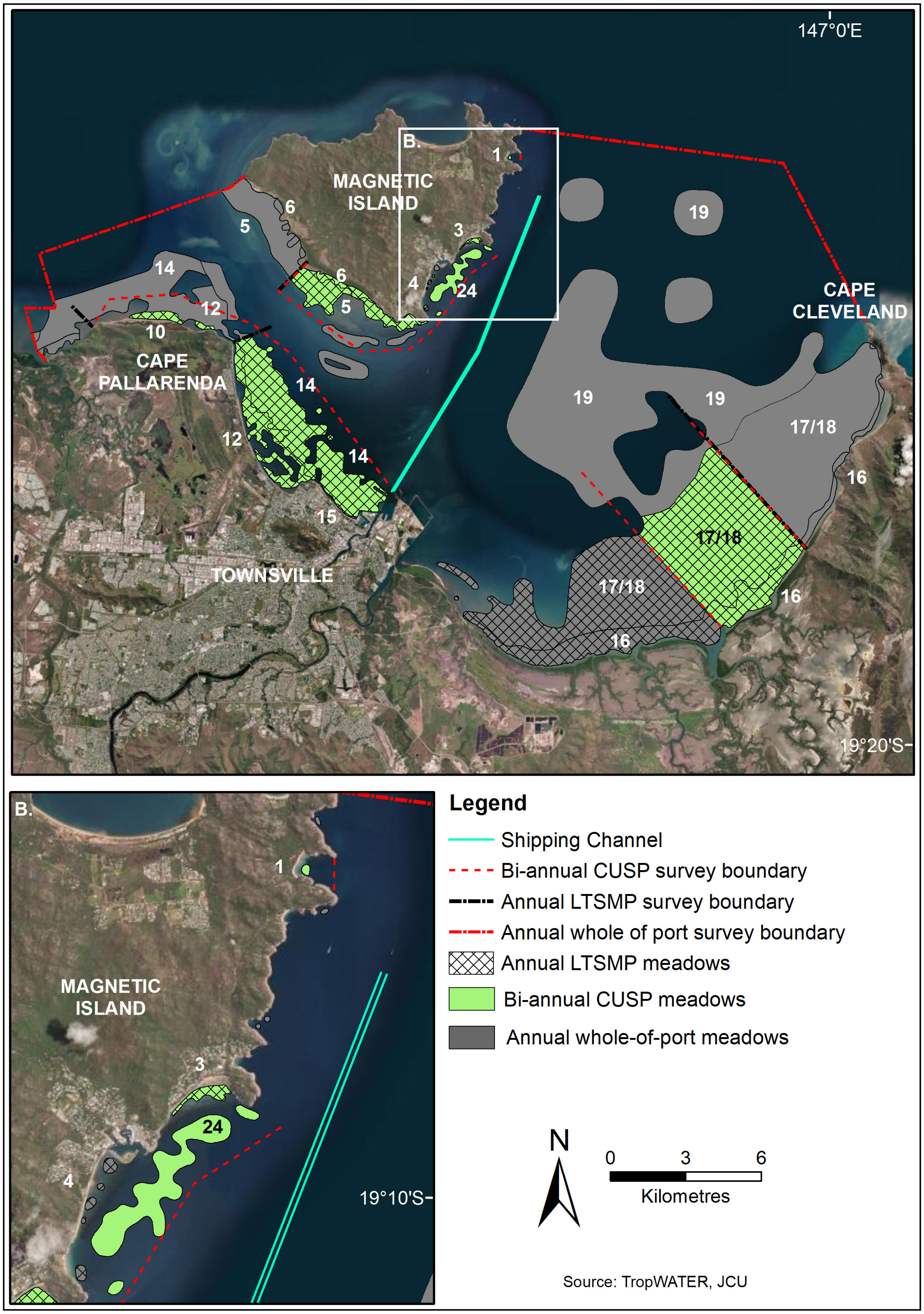


Figure 4. Location and survey extent of meadows assessed in annually surveyed LTSMP meadows, biannually surveyed CUSP meadows, and at the whole-of-port of port scale.

2.2 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 5):

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*: boat-based free diving or 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 5. The different seagrass monitoring techniques: helicopter aerial surveillance, boat based free divers and digital, live feed camera systems.

Seagrass above-ground biomass was determined using a "visual estimate of biomass" technique (see Kirkman, 1978; Mellors, 1991). A 0.25 m^2 quadrat was placed randomly three times at each site. For each quadrat, an observer assigned a biomass rank made in reference to a series of quadrat photographs of similar seagrass habitats for which the above-ground biomass had previously been measured. Two separate ranges were used:

low biomass and high biomass. The relative proportion of the above-ground biomass (i.e. percentage) of each seagrass species within each quadrat was also recorded. At the completion of ranking, the observer also ranked a series of photos of calibration quadrats that represented the range of seagrass observed during the survey. These calibration quadrats had previously been harvested and the actual biomass determined in the laboratory. A separate regression of ranks and biomass from the calibration quadrats was generated for each observer and applied to the biomass ranks given in the field. Field biomass ranks were converted into above-ground biomass in grams dry weight per square metre (g DW m^2) using each individual observers regression equation.

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.

2.3 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.

Meadows were described using a standard nomenclature system developed for Queensland's seagrass meadows. Seagrass community type was determined using the dominant and other species' percent contribution to mean meadow biomass (for all sites within a meadow) (Table 2). Community density was based on mean biomass of the dominant species within the meadow (Table 3).

Table 2. Nomenclature for Queensland seagrass community types.

Community type	Species composition
Species A	Species A is 90-100% of composition
Species A with Species B	Species A is 60-90% of composition
Species A/Species B	Species A is 40-60% of composition

Table 3. Density categories and mean above-ground biomass ranges for each species used in determining seagrass community density.

Density	Mean above ground-biomass (grams dry weight per metre square (g DW m^{-2}))				
	H. uninervis **(narrow)**	***H. ovalis H. decipiens***	***H. uninervis*** **(wide)** ***C. serrulata C. rotundata S. isoetifolium***	***T. hemprichii H. spinulosa***	***Z. muelleri***
Light	< 1	< 1	< 5	< 15	< 20
Moderate	1.1 – 3.9	1.1 – 4.9	5.1 – 24.9	15 - 35	20.1 – 59.9
Dense	> 4	> 5	> 25	> 35	> 60

Isolated seagrass patches
The majority of area within the meadow consists of unvegetated sediment interspersed with isolated patches of seagrass.

Aggregated seagrass patches
The meadow consists of numerous seagrass patches but still features substantial gaps of unvegetated sediment within the boundary.

Continuous seagrass cover
The majority of meadow area consists of continuous seagrass cover with a few gaps of unvegetated sediment.

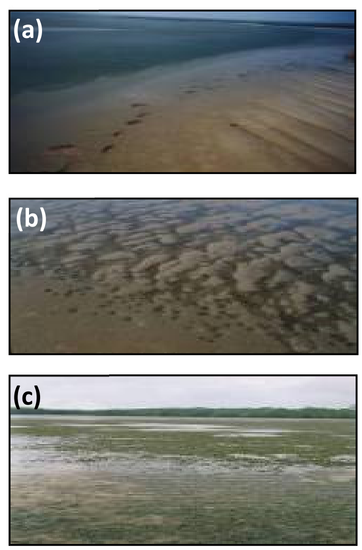


Figure 6. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover

Seagrass meadow boundaries were determined from a combination of techniques. Exposed inshore boundaries were mapped directly from helicopter and guided by recent satellite imagery of the region (Source: ESRI; Google Earth) and previous surveys. Subtidal boundaries were interpreted from a combination of subtidal survey sites, the distance between sites, field notes, depth contours and recent satellite imagery.

Meadow area was determined using the calculate geometry function in ArcGIS®. Meadows were assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 4). 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 4. Mapping precision and methodology for seagrass meadows in Townsville, 2021.

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;

2.4 Seagrass condition assessments, index and meadow baselines

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. Baselines were informed by annual means calculated over the first ten years of monitoring (2007 – 2016) (Figure 7). The ten-year period incorporates a range of conditions present in Townsville, including El Niño and La Niña periods, and extreme rainfall and river flow events (Bryant and Rasheed 2018).

The baseline condition for the new 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 (six years for Meadow 1 and five 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.

A condition index has been developed for all the seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to their baselines. Seagrass condition for each indicator in Townsville 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). The flow chart in Figure 8 summarises the methods used to calculate seagrass condition. See Appendix 1 and 2 for full details of score calculation.

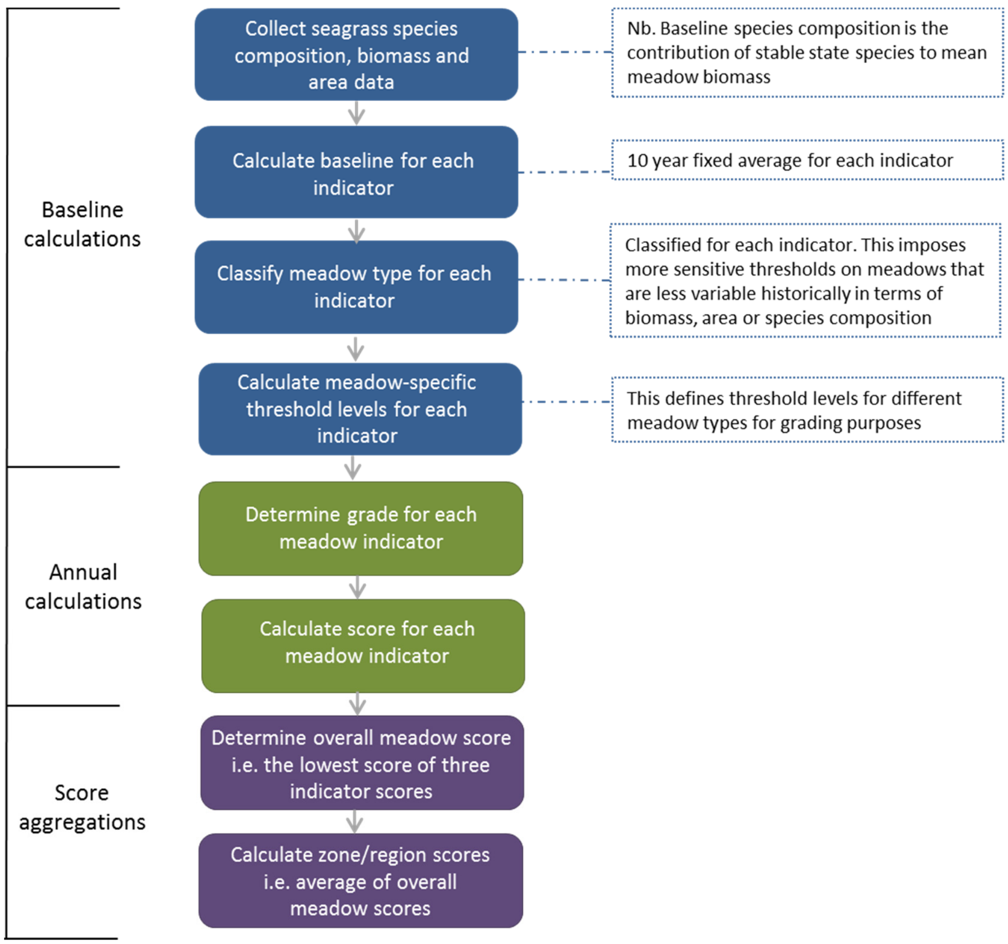


Figure 7. Flow chart to develop Townsville grades and scores.

2.5 Statistical design and analysis specific to the CU 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 plume modelling is validated and 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 in to analysis. As the dredging campaign had not begun at the time of the monitoring reported here, no statistical analysis in terms of assessing CU Project influences has been conducted on the data from these surveys.

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

2.6 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.

3 RESULTS

3.1 Seagrass presence and species throughout Port of Townsville

In 2021 two monitoring surveys were conducted in the Port of Townsville as part of both the LTSMP and CUSP:

- <u>April/May 2021</u>; post-wet season survey focusing on the coastal CUSP meadows only (Figures 4 & 25A):
    - A total of 1,046 sites were assessed for seagrass condition with seagrass present at 60% of sites;
    - The CUSP seagrass meadow footprint covered 4,201 ± 475;
    - Deep-water meadows (e.g. Meadow 19) are not surveyed in the post-wet season survey.
- <u>September-October 2021</u>; 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 4 & 27):
    - A total of 1,577 sites were assessed for seagrass condition in this whole-of-port seagrass survey with seagrass present at 61% of sites.
    - The whole-of-port seagrass footprint covered 17,146 ± 1,721 ha of which the:
        - LTSMP meadows covered 7,074 ± 672 ha
        - CUSP meadows covered 4,417 ± 444 ha.
        - The deep-water *Halophila* meadow (Meadow 19) covered 5,405 ± 719 ha.

Eleven seagrass species have historically been identified in the LTSMP (Figure 8). With the exception of *Syringodium isoetifolium*, all species (ten) were present in the 2021 surveys (Figure 8). *Syringodium isoetifolium* was last found in the program in 2015. Of note was the sighting of *Halophila tricostata* in the deeper areas of Cleveland Bay (Figure 8). This species has not been recorded in the LTSMP to date, although has previously been recorded in the region.

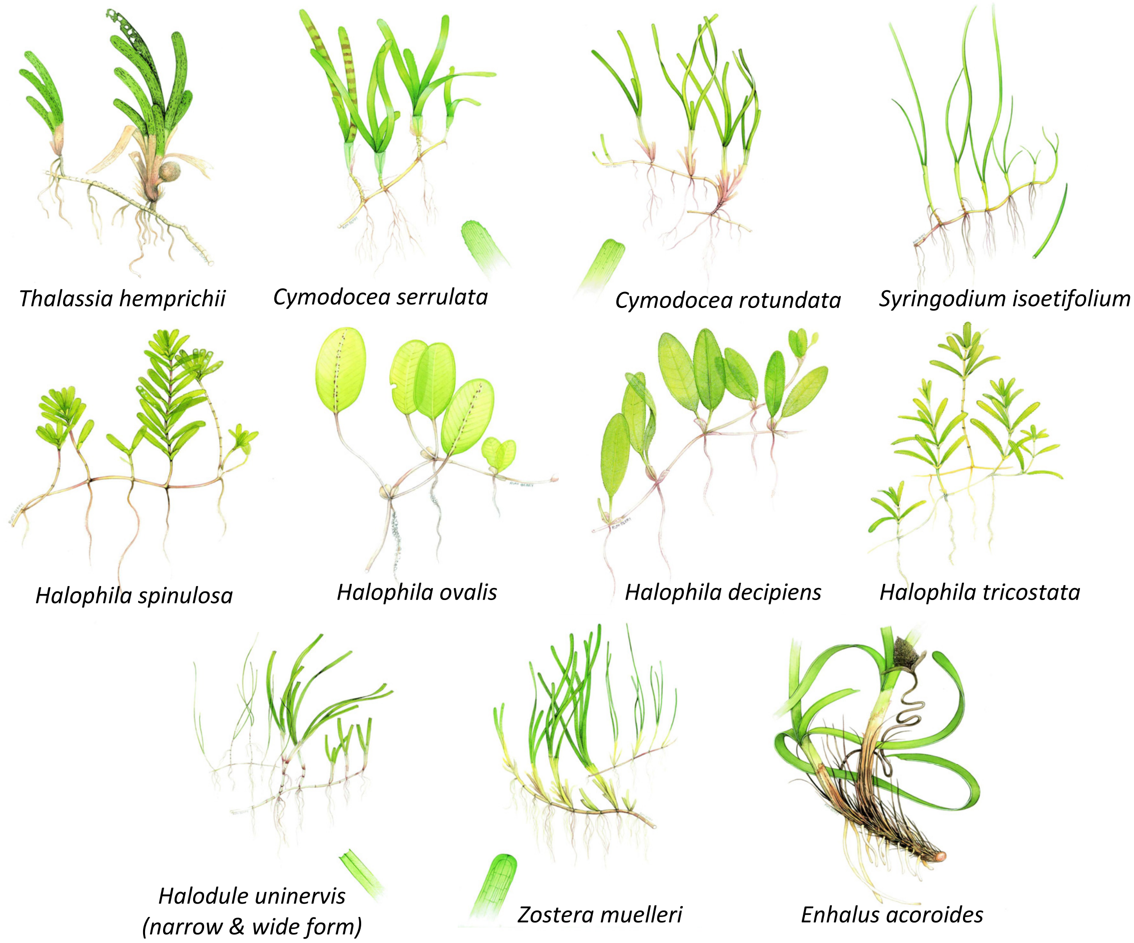


Figure 8. Seagrass species identified in the Townsville Long-term Seagrass Monitoring Program (LTSMP).

3.2 Seagrass condition in the Townsville LTSMP and CUSP monitoring meadows

3.2.1 Seagrass distribution, abundance and composition throughout the Port of Townsville

The overall condition of seagrass monitoring meadows in the Townsville LTSMP and CUSP was good in 2021 (Table 5). This was similar to 2020. All three seagrass condition indicators (seagrass biomass, area and species composition) were graded as satisfactory or better for all monitoring meadows in both programs (Table 5).

Seagrass meadow area in all monitoring meadows was of satisfactory or better condition in both programs (Table 5). Total meadow area for the LTSMP meadows was similar between 2020 and 2021 (Figure 9). Individual monitoring meadow area ranged from 1.6 ha in the subtidal *H. uninervis* Florence Bay meadow (Meadow 1; Figure 11) to 4,212 ha for the subtidal *H. uninervis* Cleveland Bay meadow (Meadow 17/18; Figure 21). The biggest spatial changes at the meadow level between 2020 and 2021 occurred in the Cape Pallarenda to Strand region:

- The intertidal/shallow subtidal *H. uninervis* meadow between Cape Pallarenda and Kissing Point (LTSMP/CUSP Meadow 12) increased to its largest recorded area so far in the program; 320ha (Figure 17);

- The shallow subtidal *H. spinulosa* meadow, between Cape Pallarenda and Breakwater Marina (LTSMP/CUSP Meadow 14) adjacent to meadow 12, expanded in footprint by 50% changing in condition from good to very good for area (Figure 18);

Some meadows did decline in area between years, but these declines were not large enough for meadows to change condition from the previous year or be classed as less than satisfactory (Table 5).

Seagrass meadow biomass in all monitoring meadows was in satisfactory or better condition in 2021 (Table 5). For all but one meadow (Meadow 5; Cockle Bay Reef), seagrass meadow biomass maintained a good or very good condition in 2021. The Cockle Bay Reef meadow (Meadow 5) biomass changed from good to satisfactory condition in 2021 (Figure 13). Monitoring meadow biomass ranged from 1.51 g DW m^{-2} in the intertidal/shallow subtidal *H. uninervis* meadow along the Strand (Meadow 15) to 38.93 g DW m^{-2} in the intertidal *Z. muelleri* meadow in Cleveland Bay (CUSP section of Meadow 16). These density ranges were similar to 2020.

The species composition of all monitoring meadows was in good or very good condition (Table 5). Species composition in meadows ranged from monospecific meadows to multispecific (up to eight species) meadows. Seagrass meadows mostly consisted of aggregated patches or continuous cover of seagrass, with a light to moderate cover of seagrass. There were a couple of meadows that had a dense cover of seagrass for the meadow composition type (Table 3): the intertidal/shallow subtidal *H. uninervis* meadow between Cape Pallarenda and Kissing Point (LTSMP/CUSP Meadow 12) and the intertidal/shallow subtidal *H. uninervis* meadow at Picnic Bay (LTSMP Meadow 4).

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, is highly variable from year to year in biomass, area and footprint. Between 2019 and 2020 the deep-water meadow area decreased by ~70% (Figures 26 & 27). Between 2020 and 2021 the deep-water meadow increased in area again by over 100% to 5,405 ± 719ha (Figures 26 & 27). Such large shifts in deep-water seagrass is not unusual. Seagrass biomass in the meadow has been similar over the past couple of years (Figures 26 & 27). Of note was the sighting of *Halophila tricostata* in the deeper areas of Cleveland Bay (Figure 8). This species has not been recorded in the LTSMP program to date, although has previously been recorded in the region.

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.

Table 5. Condition scores for seagrass indicators (biomass, area and species composition) for the LTSMP and CUSP meadows; September/October 2021 survey.

Meadow	Region	LTSMP/CUSP	Biomass	Area	Species Composition	LTSMP Overall Meadow Score	CUSP Overall Meadow Score
1	Magnetic Island	CUSP	0.85	0.89	1.0		0.85
3		LTSMP & CUSP	0.72	0.86	1.0	0.72	0.72
4		LTSMP	0.79	0.90	1.0	0.79	
5		LTSMP & CUSP	0.59	0.72	0.99	0.59	0.59
6		LTSMP & CUSP	0.68	0.79	0.97	0.68	0.68
24		CUSP	0.56	0.95	0.88		0.56
10	Cape Pallarenda - Strand	LTSMP & CUSP	0.77	0.58	0.77	0.58	0.58
12		LTSMP & CUSP	0.96	1.0	0.80	0.88	0.88
14		LTSMP & CUSP	0.83	0.89	0.99	0.83	0.83
15		LTSMP	0.76	0.83	0.88	0.76	
16	Cleveland Bay	LTSMP	0.88	0.68	0.97	0.68	
16 (CUSP meadow section)		CUSP	0.89	0.83	0.98		0.83
17/18		LTSMP	0.79	0.93	0.97	0.79	
17/18 (CUSP meadow section)		CUSP	0.82	0.89	0.98		0.82
LTSMP - Overall Score for the Port of Townsville 2021						**0.73**	
CUSP - Overall Score for the Port of Townsville 2021							**0.73**

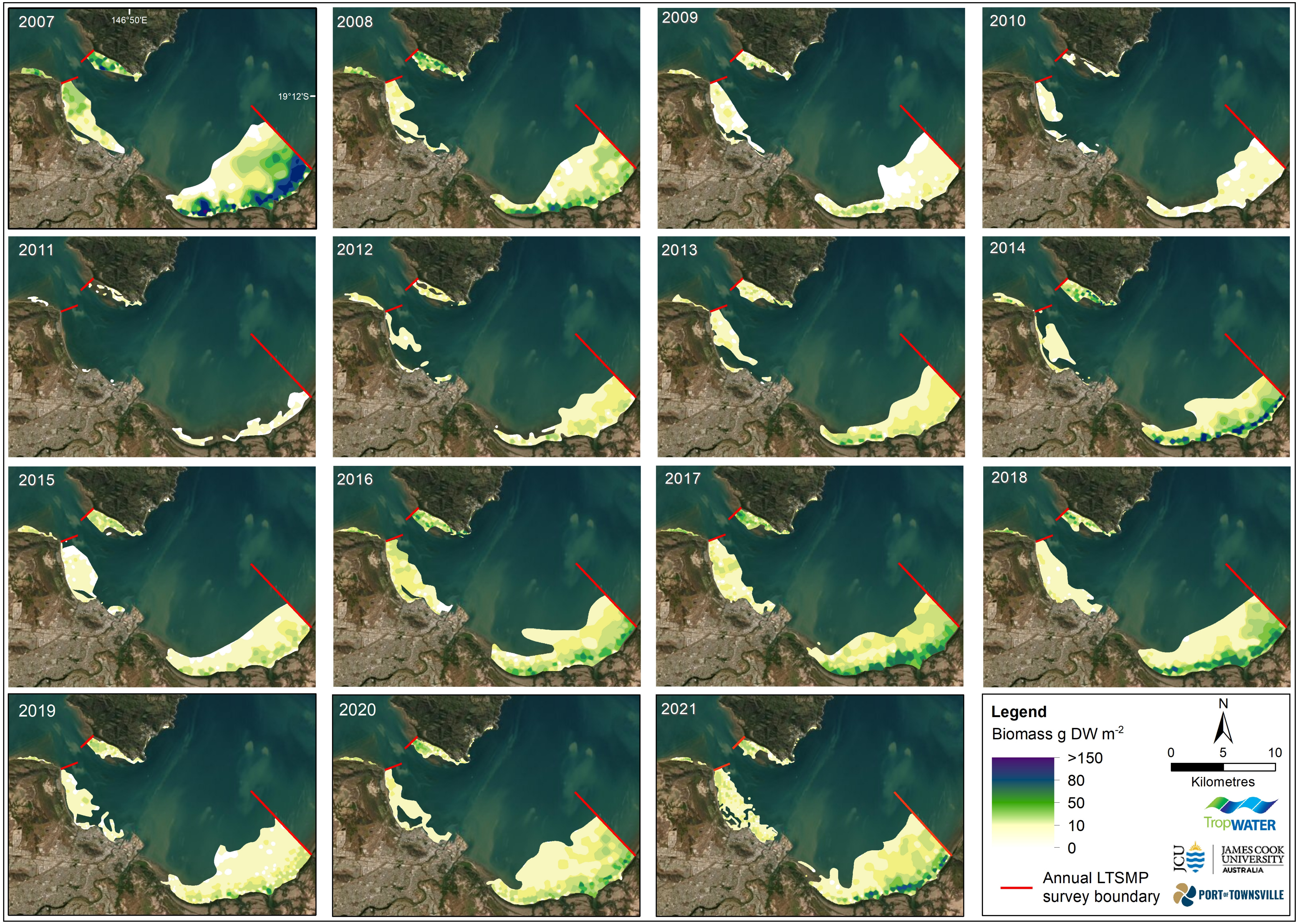


Figure 9. Long-term Seagrass monitoring meadow location and spatial extent from 2007 – 2021.

3.2.2 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 4, 10-15). These meadows range from intertidal to deep-water (>8m below MSL) meadows. All meadows in this area were of satisfactory or better condition in 2021 (Table 5).

The area of all monitoring meadows around Magnetic Island was rated as good or very good compared to their historical baselines (Table 5; Figures 10-15). Between 2019 and 2020, the largest spatial increase in seagrass around the island was the expansion of the subtidal Geoffrey Bay *H. spinulosa* meadow (Meadow 24) to its largest recorded area since 2013 (Figure 15). In 2021, this meadow maintained an extensive footprint from Geoffrey Bay down to Nelly Bay. Similarly, all other meadows around Magnetic Island maintained a similar footprint to that of 2020.

Seagrass meadow biomass (density) was in satisfactory or better condition for all Magnetic Island monitoring meadows (Table 5). The intertidal Cockle Bay meadow (Meadow 5) was the only meadow that decreased in condition from good in 2020 to satisfactory in 2021 (Figure 13). This decrease in biomass occurred relatively evenly across the meadow (Figure 13 & 27). Individual meadow biomass ranged from 1.69 g DW m^{-2} to 7.82 g DW m^{-2} around the Island.

Species composition at all meadows was also above baseline conditions, with a species mix that reflected a very good condition in all meadows (Table 5; Appendix 3). The only notable change in species composition that occurred around the island was in the Cockle Bay Reef meadow (Meadow 5) where there was a substantial increase in the contribution of *Thalassia hemprichii* to the meadow (Appendix 3). There was a corresponding decrease in the presence of *Cymodocea serrulata* in the meadow. These two stable species are very similar in biomass, so it is unlikely that this shift in dominant species was the cause of the biomass decline seen in the meadow.

3.2.3 Cape Pallarenda-Strand seagrass meadows

There are four monitoring meadows that make up the Cape Pallarenda-Strand region (meadows 10, 12, 14, 15) (Figures 16-19). All meadows in this area were of satisfactory or better condition in 2021 (Table 5).

The biggest spatial changes between 2020 and 2021 across all monitoring meadows occurred in this region. The intertidal/shallow subtidal *H. uninervis* meadow between Cape Pallarenda and Kissing Point (LTSMP/CUSP Meadow 12) increased to its largest recorded area in the program; 320ha (Figure 17). Most of the expansion of this meadow occurred at the deeper margins of the meadow and through the middle of the meadow where historically it has been patchy (Figure 17).

The meadow adjacent to Meadow 12: the shallow subtidal *H. spinulosa* meadow, between Cape Pallarenda and Breakwater Marina (LTSMP/CUSP Meadow 14) also expanded in its distribution by up to 50%, changing in condition from good in 2020 to very good in 2021 for area (Figure 18). Most of the expansion of this meadow also occurred at the deeper margins of the meadow, with the meadow extending out to 5.2m below mean sea level.

Meadow biomass across all meadows in this region remained in satisfactory or better condition, similar to 2020 (Figures 16-19). For Meadow 12, along with area, there was a corresponding increase in meadow biomass to one of the highest meadow densities recorded for the meadow in the program; 5.36 g DW m^{-2}. Much of the biomass increase occurred in the northern half of the meadow where higher density, continuous cover seagrass occurred (Figure17). There were no other notable changes in meadow biomass for the other meadows in the region.

Species composition for all four meadows in the region was in good or very good condition in 2021 (Table 5). Species composition has been relatively stable in the inshore *H. uninervis* meadow (12) (Figure 17). In 2021 there was a higher proportion of *H. uninervis* 'wide' morphological form in the meadow which likely contributed to the increase in meadow biomass (Appendix 3). Species composition in the adjacent subtidal *H. spinulosa* meadow has also been stable but the dominant species has switched through the years between *H. spinulosa* and *H. uninervis* (Figure 18; Appendix 3). At the time of the surveys, *H. spinulosa* was fruiting in this area (see images below).

For the intertidal Shelley Beach *Z. muelleri* meadow (10), species composition has been in good or very good condition since 2017. Similarly species composition in the 'Strand' meadow (15) has been in very good condition for the last two years, with *H. uninervis* the dominant species over these years (Figure 19; Appendix 3). At the time of the surveys, we recorded many dugong feeding trails in this relatively small inshore meadow, not an uncommon sight.

Halophila fruit collected from fruiting plants and in the tideline wrack along The Strand October 2021

3.2.4 Cleveland Bay seagrass meadows

There are two monitoring meadows in Cleveland Bay; the intertidal *Z. muelleri* meadow (16) and the shallow subtidal *H. uninervis* meadow (17/18) (Figures 20-23). These meadows are the largest coastal meadows in Townsville (Figure 27). For the CUSP, only a section of these large meadows is monitored biannually. Both meadows were in an overall good condition in 2021 in both programs (Table 5; Figures 20-23).

At the intertidal *Z. muelleri* meadow (16), biomass has been on an upward trajectory the last two years changing in condition from satisfactory in 2019, to very good condition in 2021 (Figures 20, 21). Density 'hotspots' returned to the meadow with areas of the meadow recording biomasses over 60 g DW m^{-2}. The distribution of this meadow has been in good or very good condition since 2012 and species composition has been in very good condition 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 in 2020 and has remained in good condition through 2021 (Table 5; Figures 22, 23). The area of this meadow has also been on an upward trajectory over the last several years. Much of this increase has been the result of meadow expansion at the deeper margins of the meadow (Figure 27). The species composition in the meadow has been stable since 2018. *Halodule uninervis* accounts for around 50% of the meadow biomass.

3.2.5 Cleveland Bay deep-water seagrass meadow

Whole-of-port surveys that incorporate deep-water seagrasses in Townsville have been conducted in 2007, 2008, 2013, 2016, May and October 2019, October 2020 and October 2021. The Cleveland Bay deep-water meadow (Meadow 19) is the primary deep-water meadow in the monitoring program. In 2019, the extent of this variable deep-water meadow was the largest recorded since 2007; 8,023 ha (Figure 27). In 2020, this area decreased by nearly 67% to 2,329 ha, and becoming fragmented (Figure 27). In 2021, the meadow increased again to a significant footprint of 5,405 ha. Meadow biomass has been of low density and similar the last couple of years. Of note in 2021 was the sighting of *H. tricostata* in the deeper areas of Cleveland Bay. This species has not been recorded in the LTSMP to date, although has previously been recorded in the region.

Seagrass (*H. decipiens* and *H. tricostata*) was recorded to 14m below mean sea level in the deep-water meadow (Meadow 19).

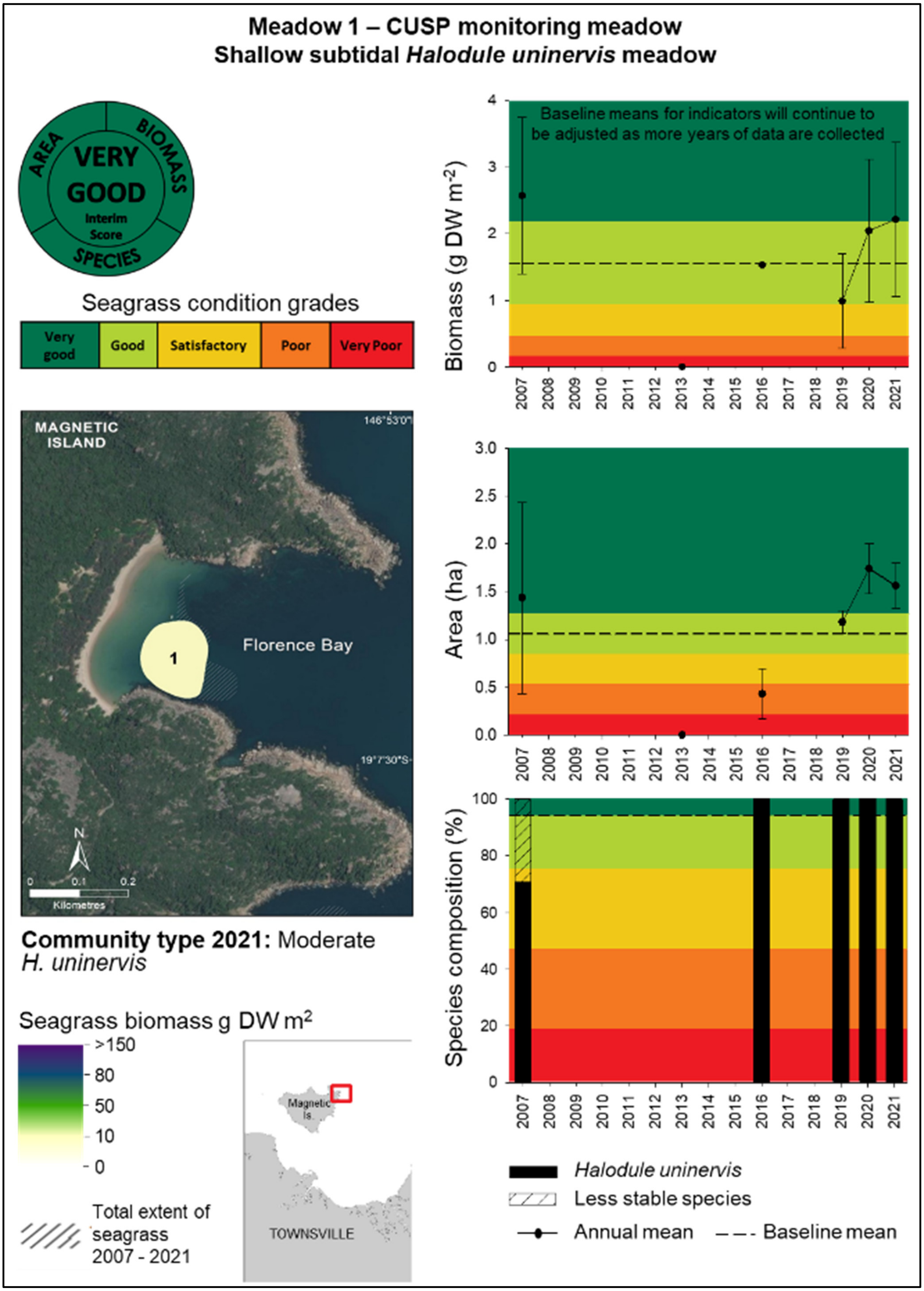


Figure 10. Changes in meadow area, biomass and species composition for seagrass Meadow 1 at Magnetic Island, 2007 – 2021. (biomass error bars = SE; area error bars = “R” reliability estimate).

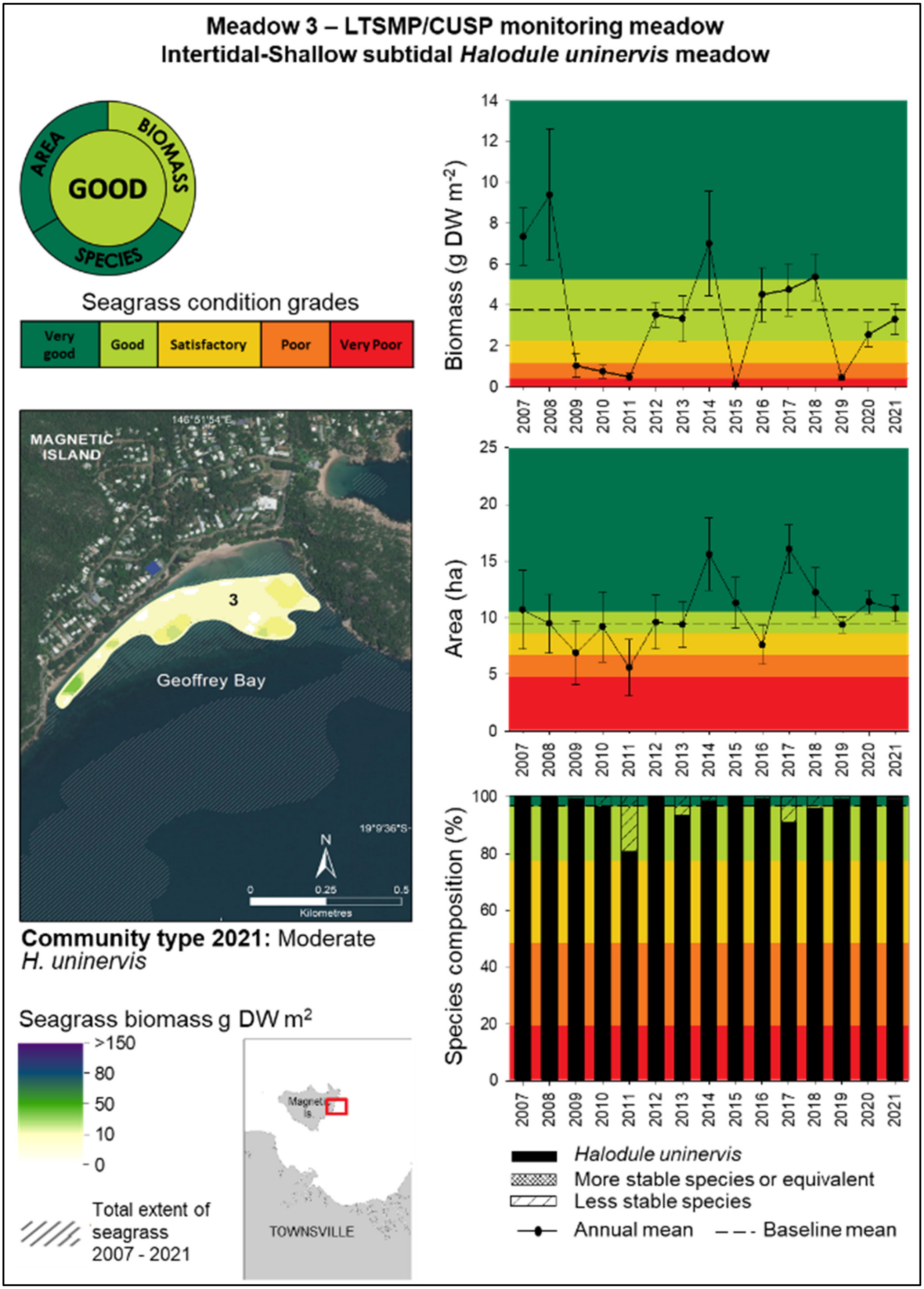


Figure 11. Changes in meadow area, biomass and species composition for seagrass Meadow 3 at Magnetic Island, 2007 – 2021. (biomass error bars = SE; area error bars = "R" reliability estimate).

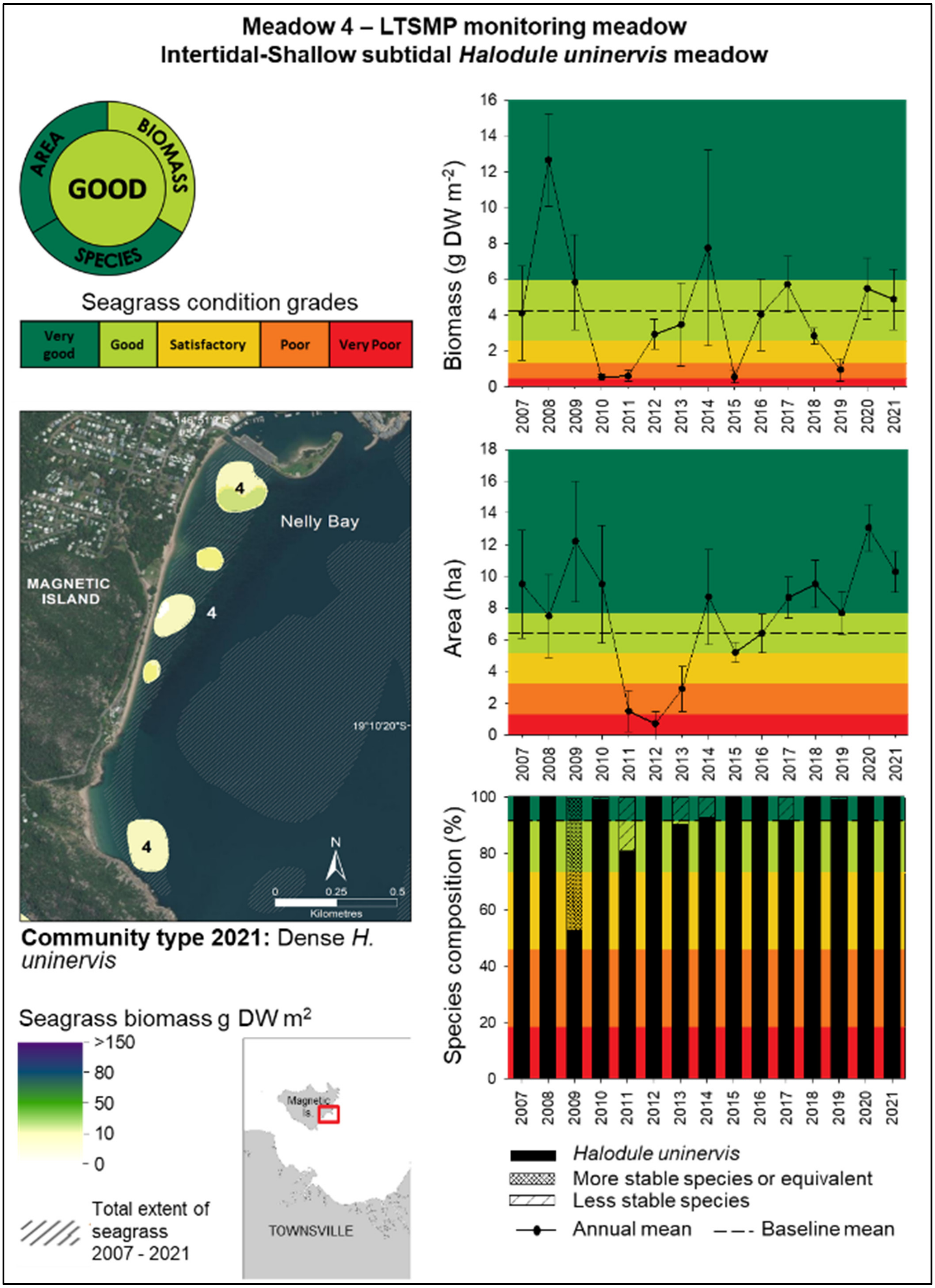


Figure 12. Changes in meadow area, biomass and species composition for LTSMP seagrass Meadow 4 at the Strand, 2007 – 2021. (biomass error bars = SE; area error bars = "R" reliability estimate).

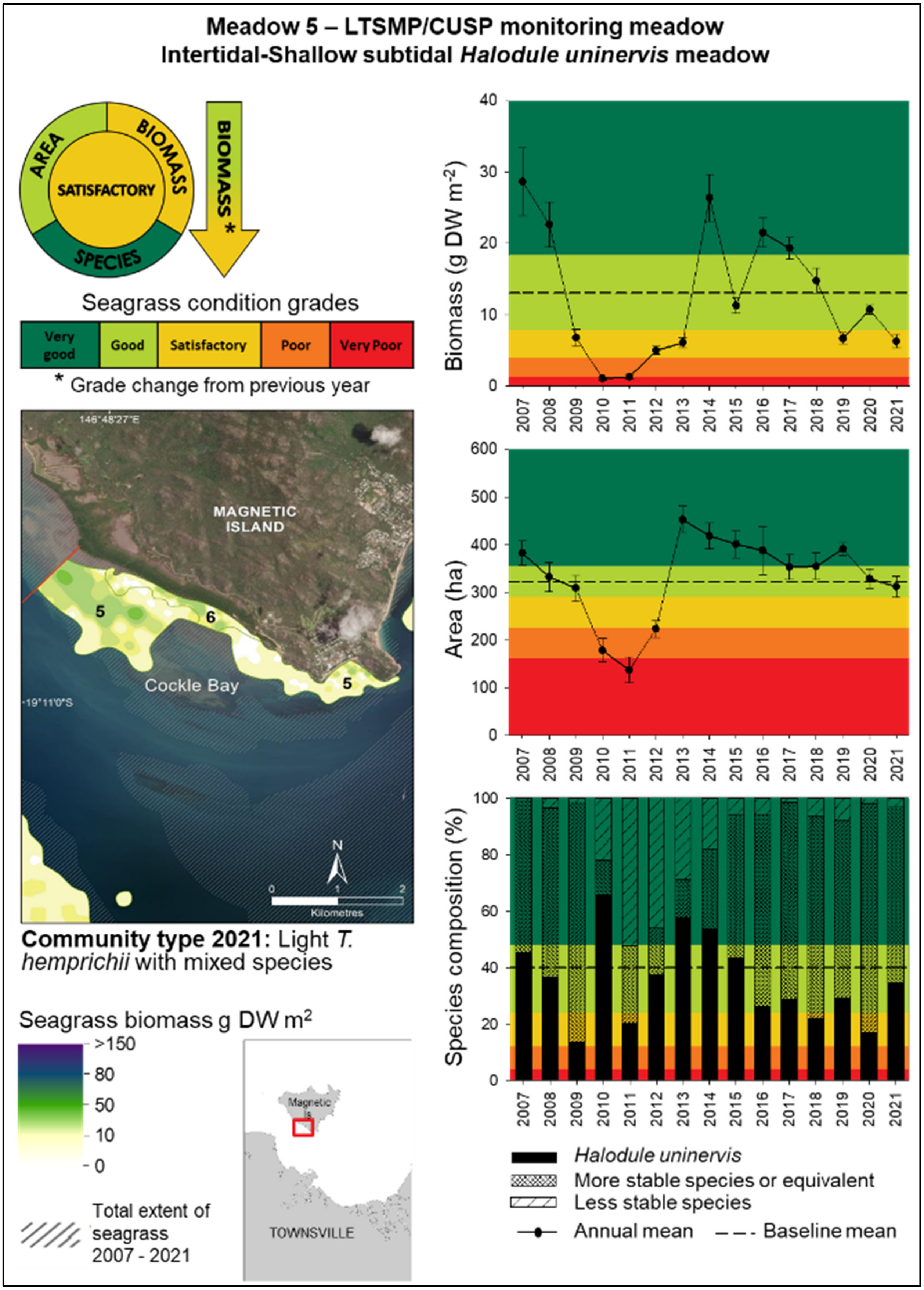


Figure 13. Changes in meadow area, biomass and species composition for seagrass Meadow 5 at Magnetic Island, 2007- 2021. (biomass error bars = SE; area error bars = "R" reliability estimate).

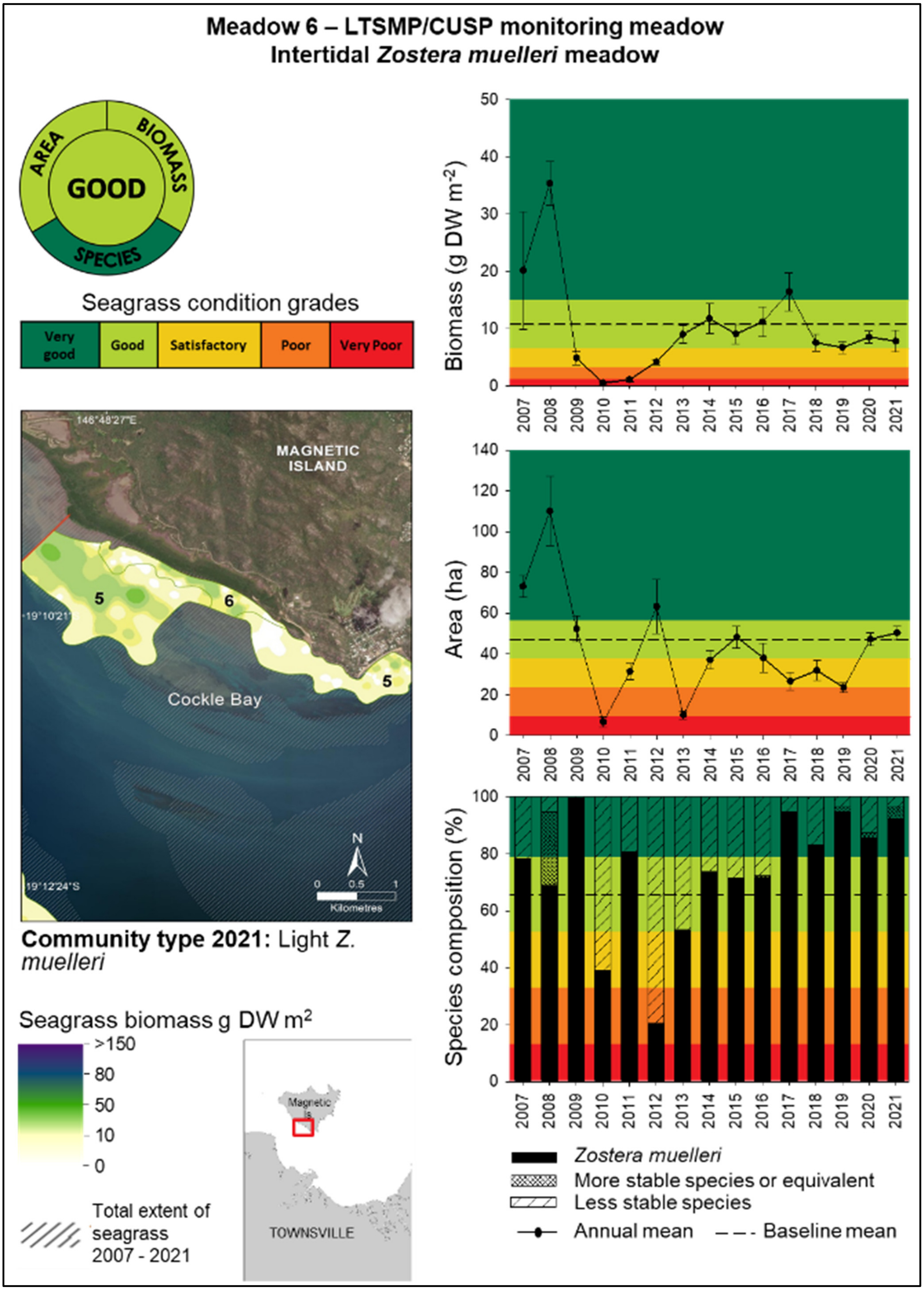


Figure 14. Changes in meadow area, biomass and species composition for seagrass Meadow 6 at Magnetic Island, 2007 – 2021. (biomass error bars = SE; area error bars = "R" reliability estimate).

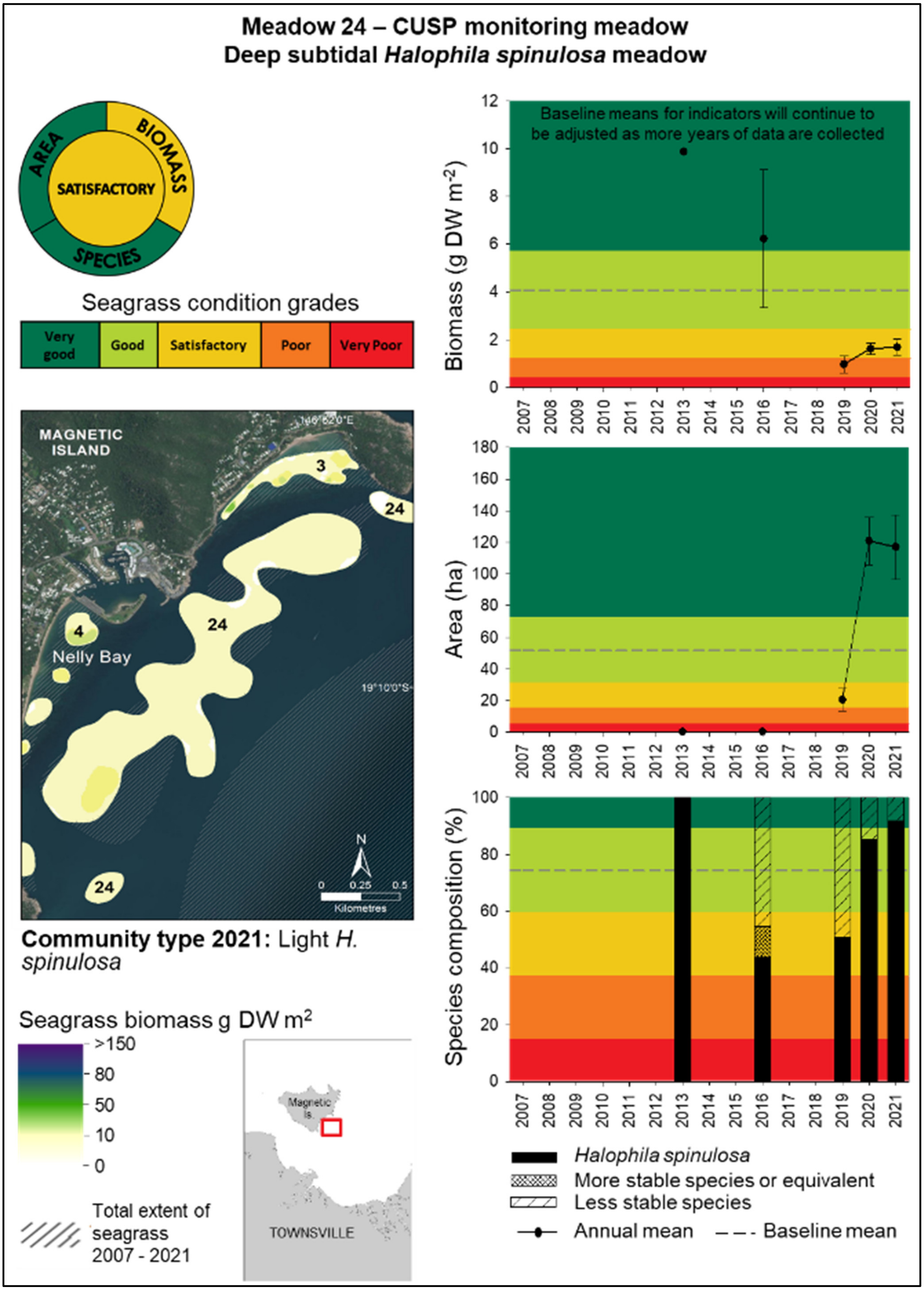


Figure 15. Changes in meadow area, biomass and species composition for seagrass Meadow 24 in Geoffrey Bay, 2007 – 2021. (biomass error bars = SE; area error bars = "R" reliability estimate).

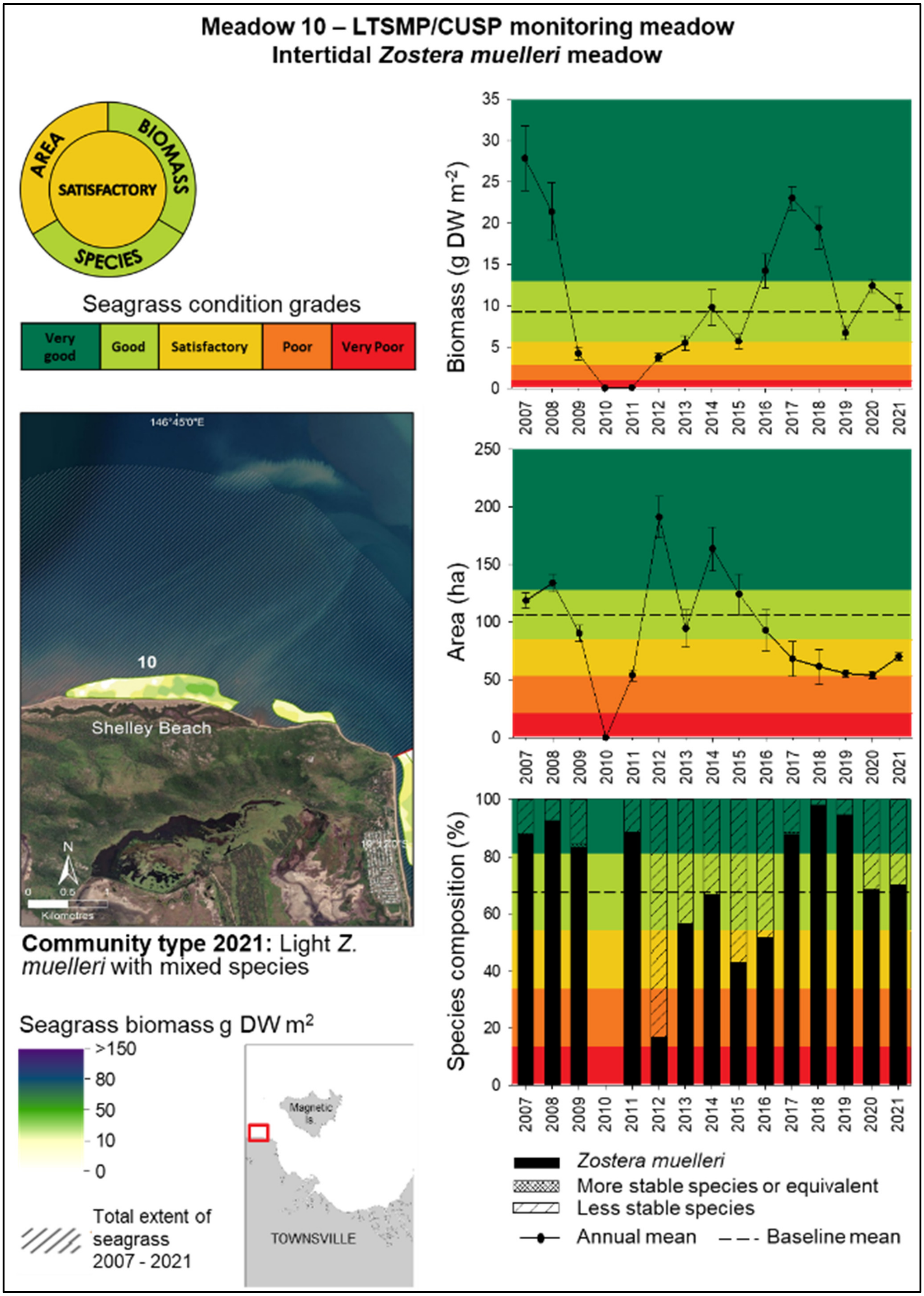


Figure 16. Changes in meadow area, biomass and species composition for seagrass Meadow 10 in Shelley Beach, 2007 – 2021. (biomass error bars = SE; area error bars = "R" reliability estimate).

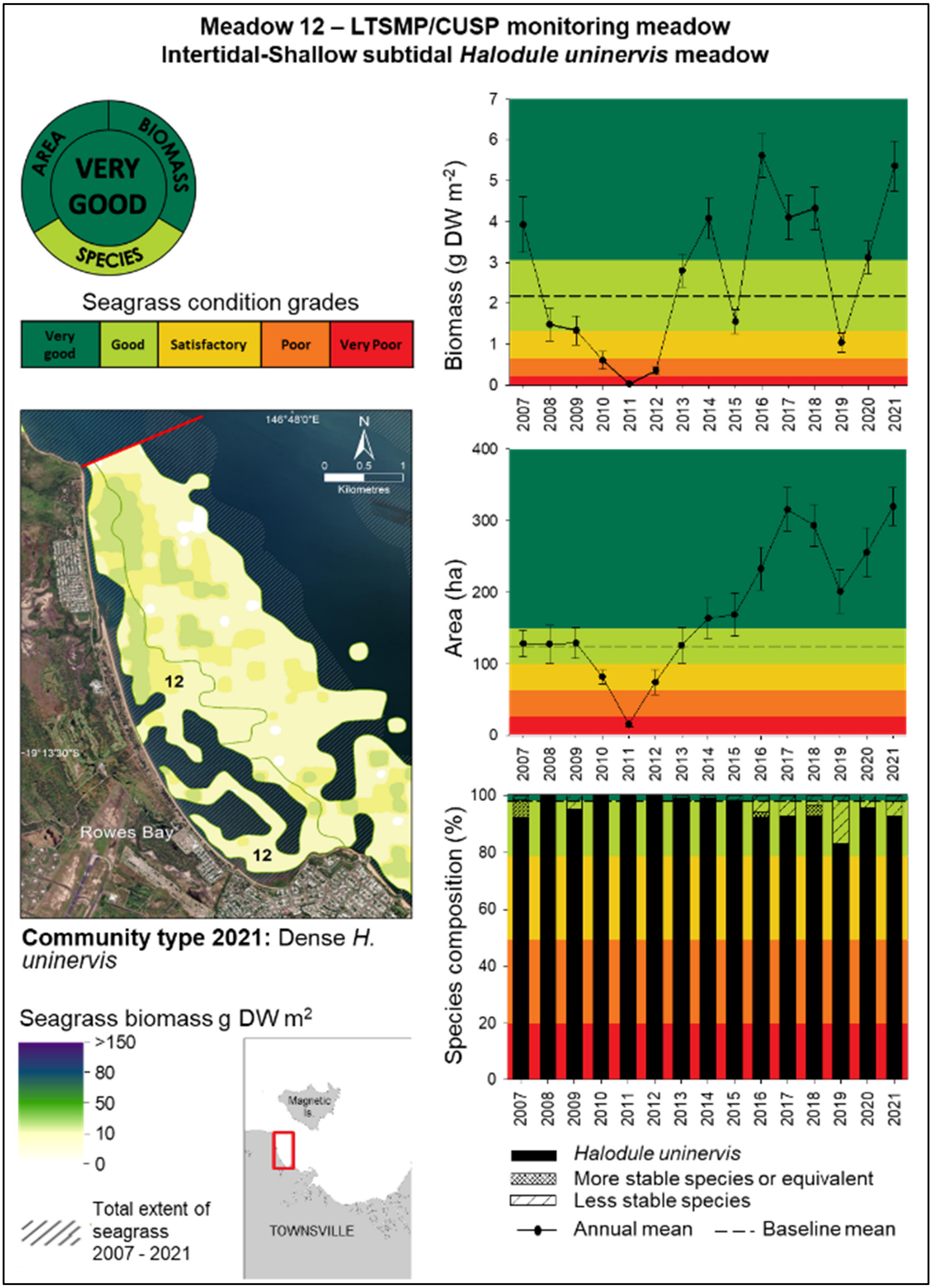


Figure 17. Changes in meadow area, biomass and species composition for seagrass Meadow 12, in Rowes Bay, 2007 – 2021. (biomass error bars = SE; area error bars = "R" reliability estimate).

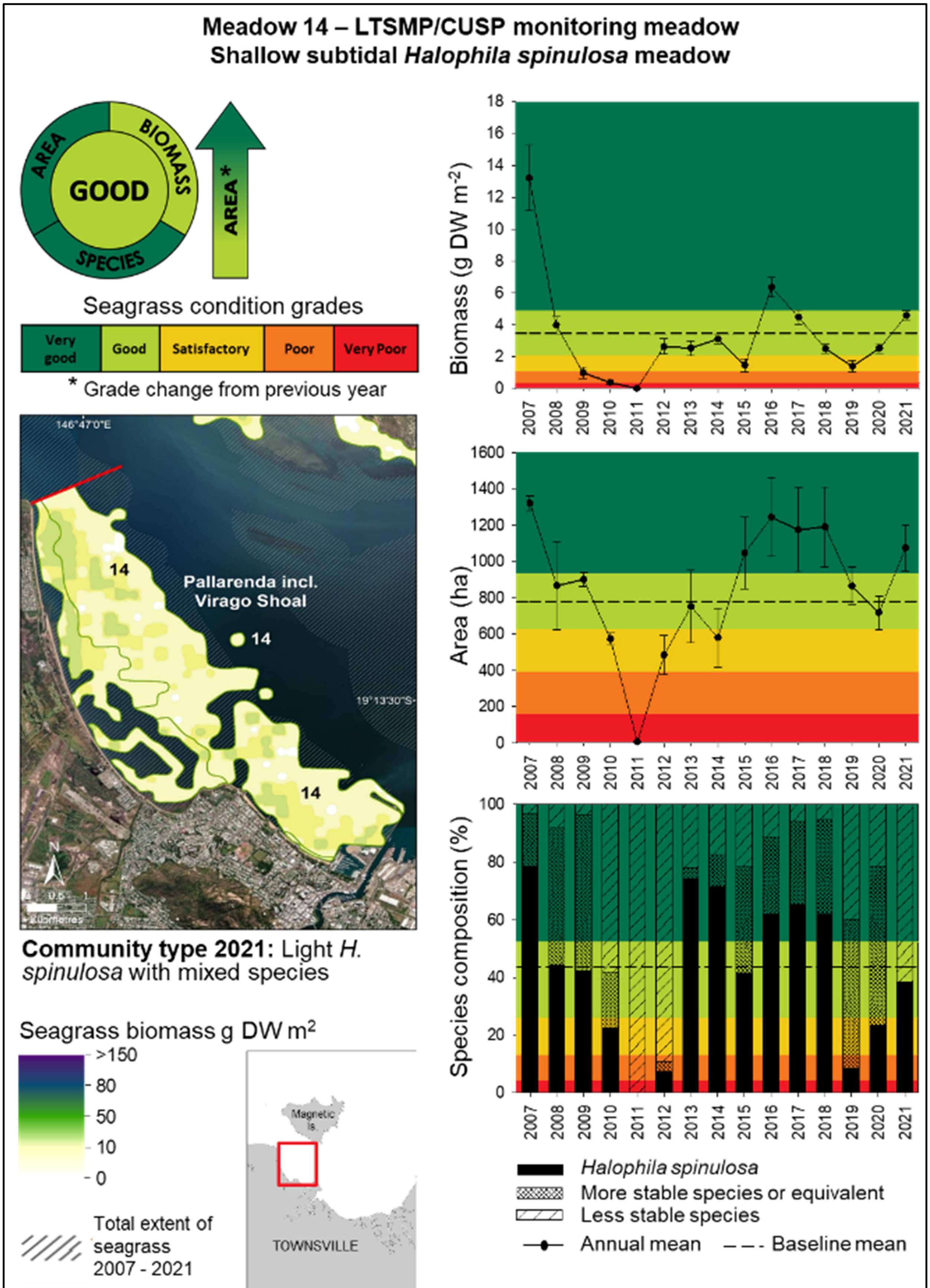


Figure 18. Changes in meadow area, biomass and species composition for seagrass Meadow 14 at Pallarenda, Virago Shoal and the Strand, 2007 – 2021. (biomass error bars = SE; area error bars = "R" reliability estimate).

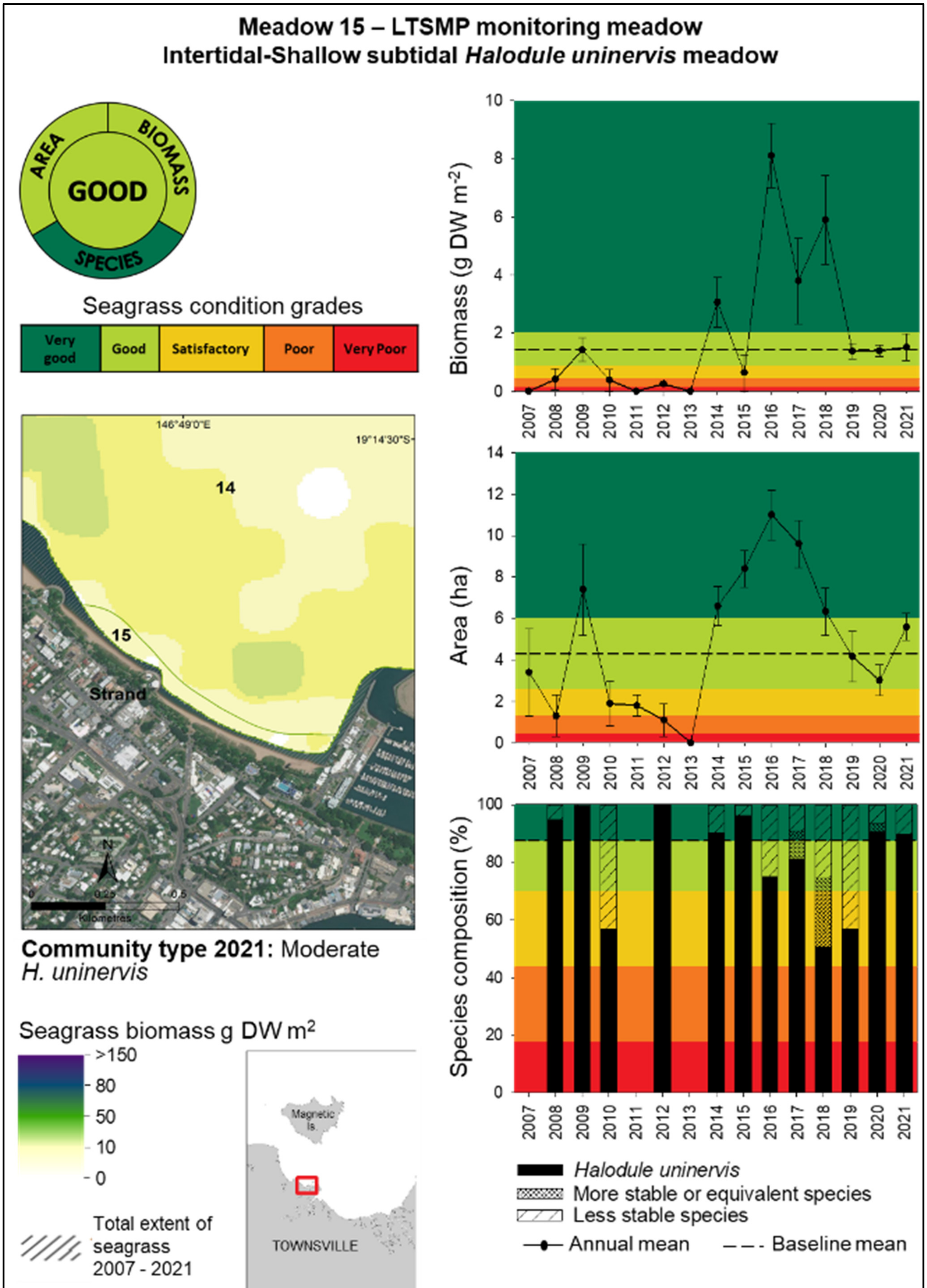


Figure 19. Changes in meadow area, biomass and species composition for LTSMP seagrass Meadow 15 at the Strand, 2007 – 2021. (biomass error bars = SE; area error bars = “R” reliability estimate

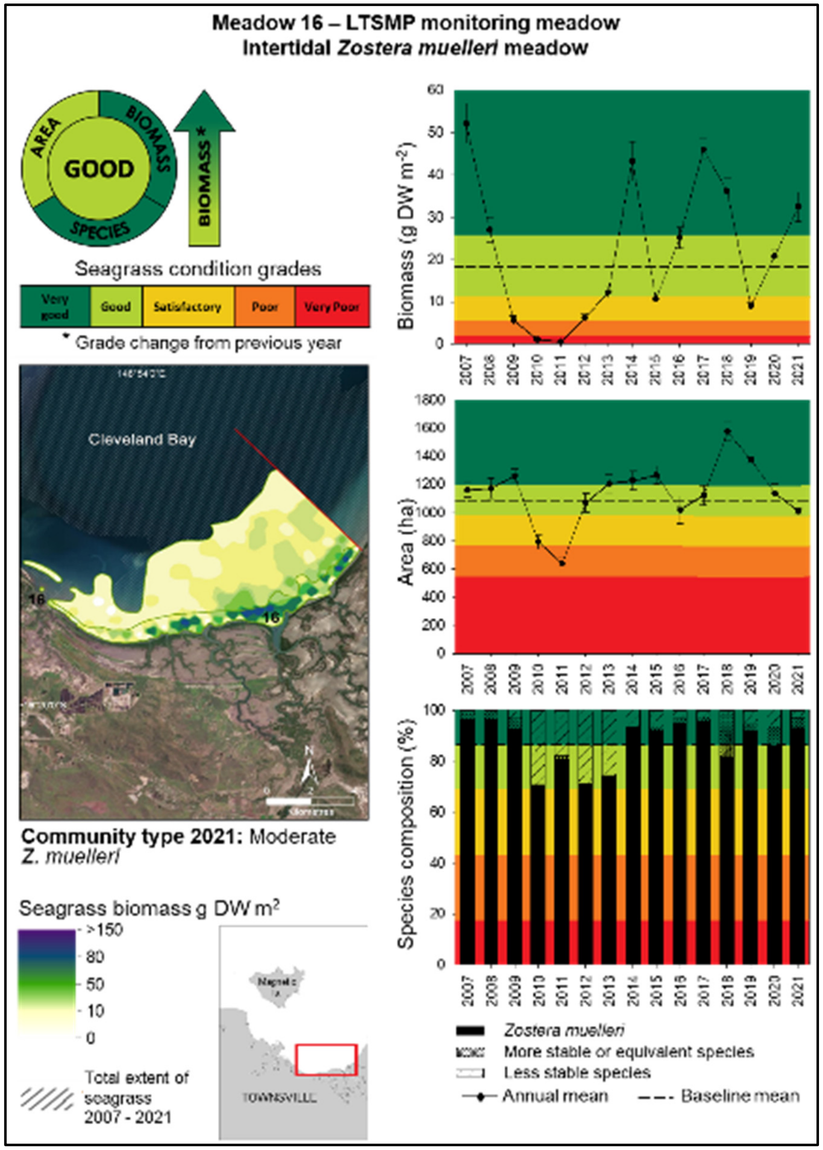


Figure 20. Changes in meadow area, biomass and species composition for LTSMP seagrass Meadow 16 in Cleveland Bay, 2007 – 2021. (biomass error bars = SE; area error bars = "R" reliability estimate).

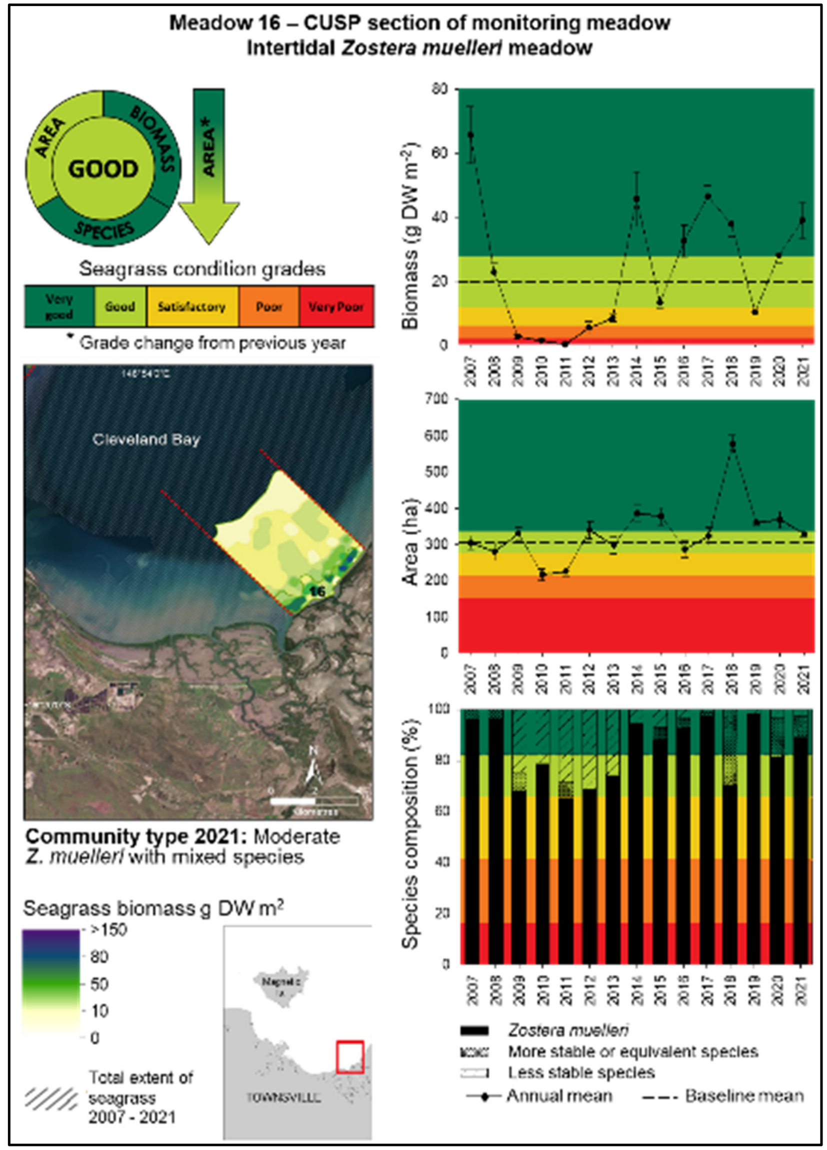


Figure 21. Changes in meadow area, biomass and species composition for CUSP seagrass Meadow 16 in Cleveland Bay, 2007 – 2021. (biomass error bars = SE; area error bars = "R" reliability estimate).

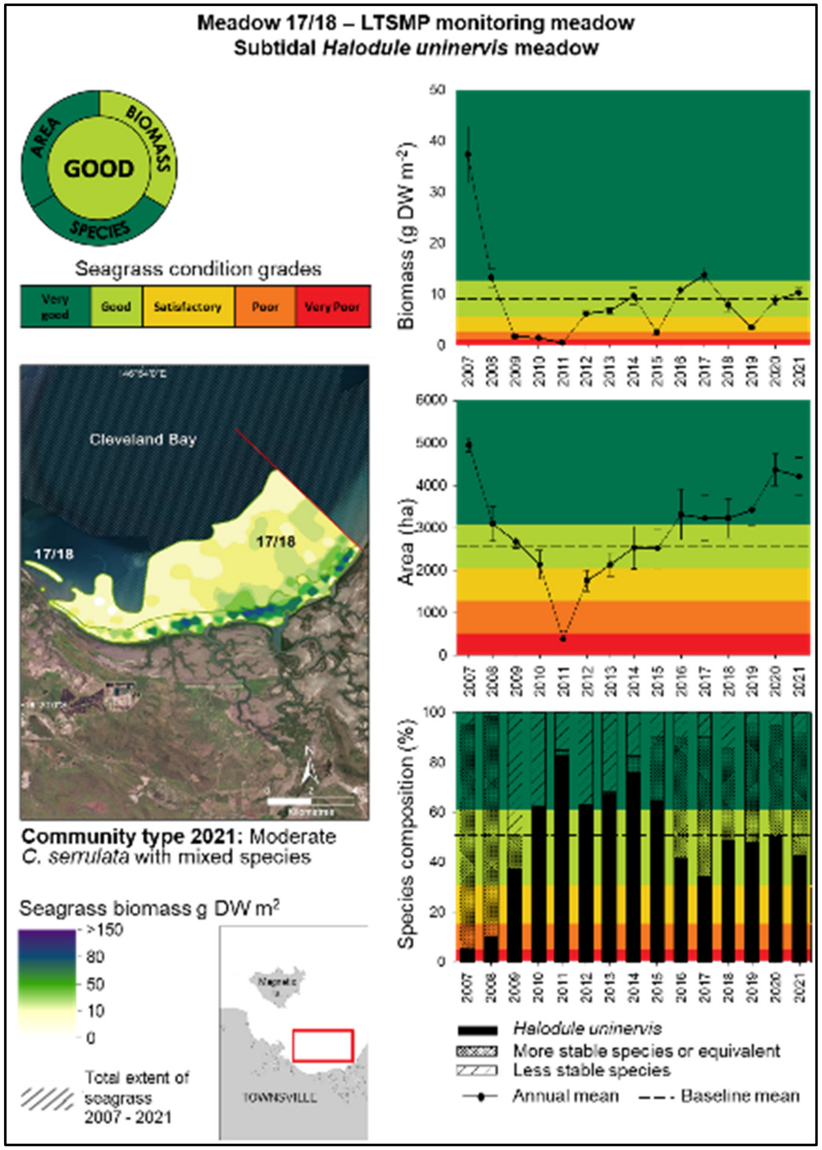


Figure 22. Changes in meadow area, biomass and species composition for LTSMP seagrass Meadow 17/18 in Cleveland Bay, 2007 – 2021. (biomass error bars = SE; area error bars = "R" reliability estimate).

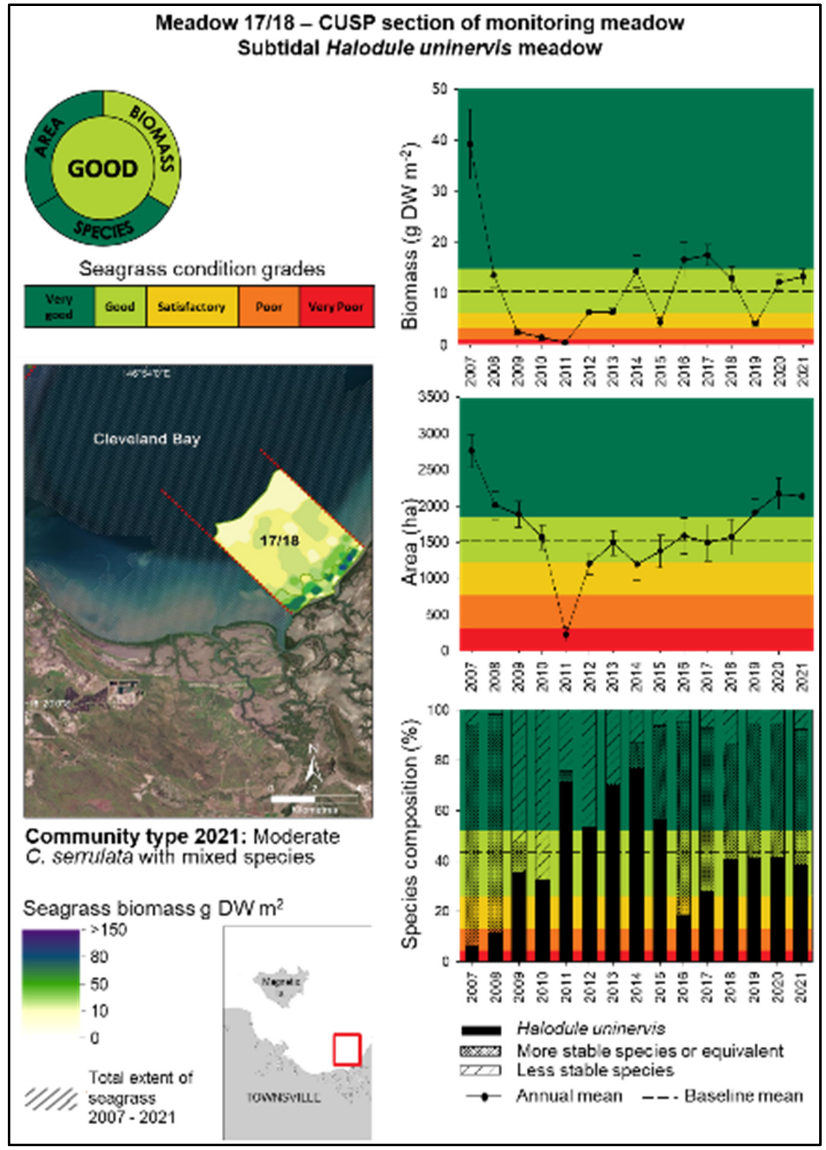


Figure 23. Changes in meadow area, biomass and species composition for CUSP seagrass Meadow 17/18 in Cleveland Bay, 2007 – 2021. (biomass error bars = SE; area error bars = "R" reliability estimate).

3.3 Seasonal comparisons of Townville CUSP meadows

Seagrass meadows that form the CUSP are surveyed biannually (Table 1; Figure 4). Biannual surveys help determine if there is seasonality in seagrass meadows. For the CUSP monitoring, program results and the original baseline surveys in 2007/2008 (Rasheed and Taylor 2008) suggest that the seasonal signal in seagrass biomass (density) in Townsville seagrasses may not be particularly strong or consistent compared with some other Queensland locations. There appears to be mixed results depending on meadow depth and type (seagrass community), with the clearest seasonal signal occurring in deeper meadows and those dominated by *Halophila* species. 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 dry season surveys.

In 2021, CUSP meadow area increased by 5% from April to October (Figures 24, 25). In comparison there was a 19% increase over the same periods in 2020. The biggest changes in meadow distribution occur in subtidal meadows that contain the seasonal and ephemeral *Halophila* species (Figures 24, 25). The seasonal presence of these species in the dry season, resulted in fragmented subtidal meadows combining to form more continuous meadows in the growing season in 2021 (i.e. meadows 14 and 24; Figure 25).

Records of dugongs and their feeding trails were higher overall in 2021 compared to 2020 for both post-wet and dry season surveys. 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 sites. In contrast, individual animal sightings were different between seasons with zero animals sighted in the post-wet season survey, compared to animals being consistently sighted during the field work in the 2021 dry season survey.

Another seasonal difference noted in 2021 was fruiting in plants. *Cymodocea serrulata* was fruiting in the post-wet season survey, with no fruits seen in the dry season survey. In contrast *Halophila* fruits were seen throughout the dry season survey and no fruits recorded in the post-wet survey.

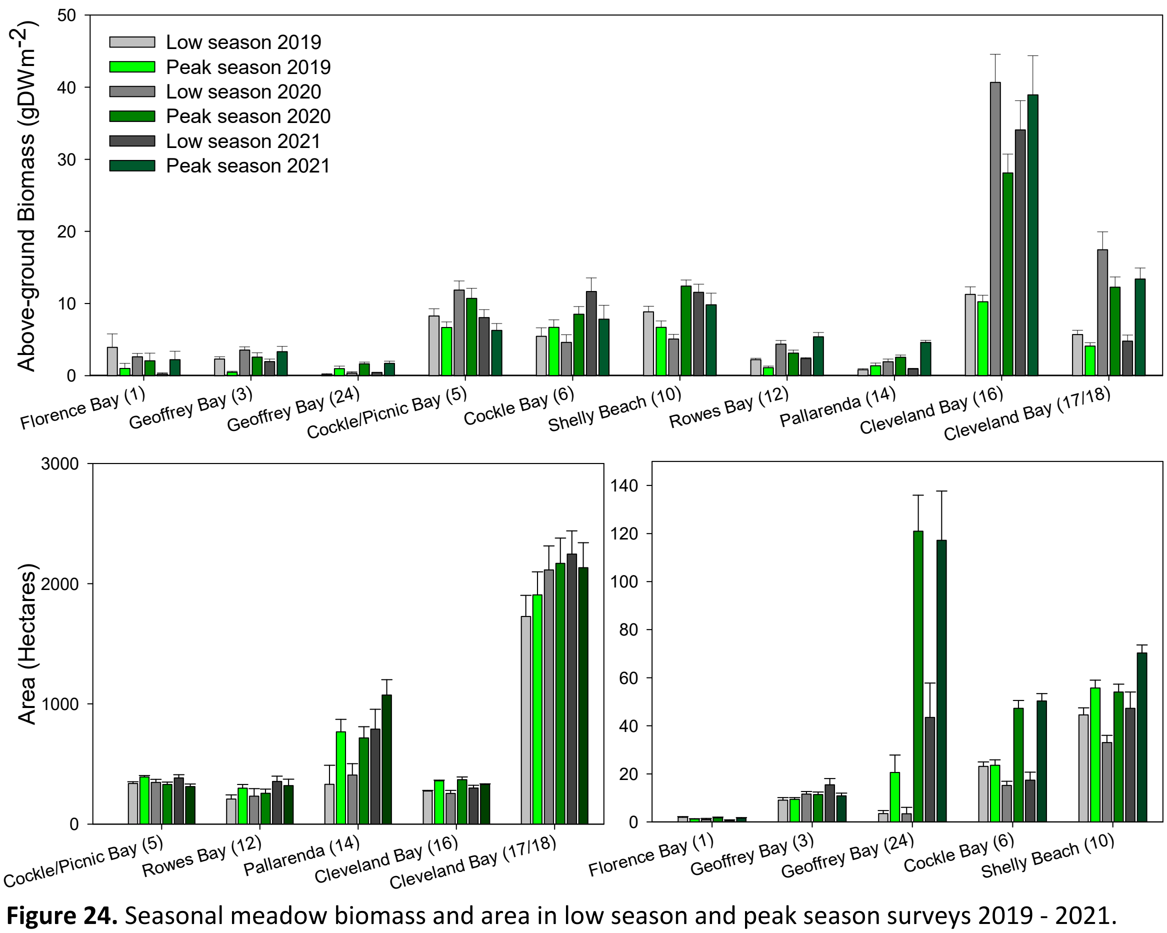
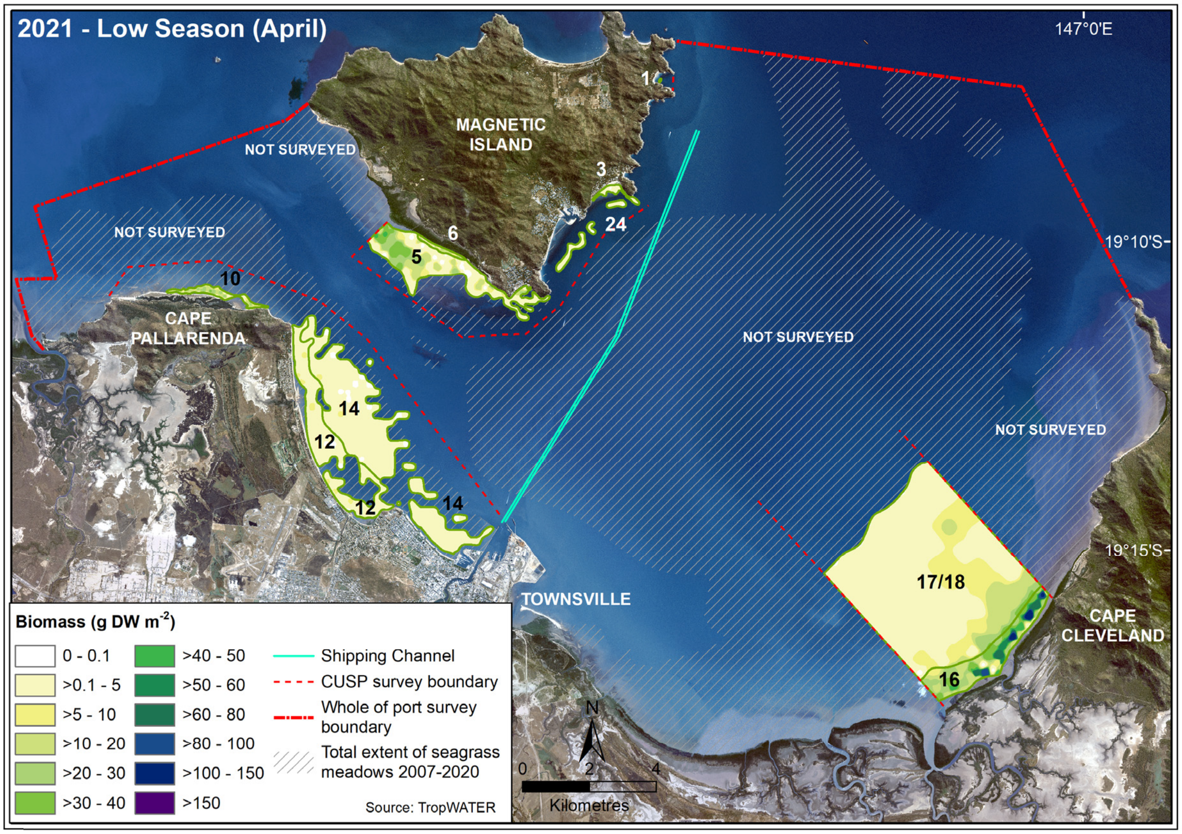


Figure 24. Seasonal meadow biomass and area in low season and peak season surveys 2019 - 2021.

A)



B)

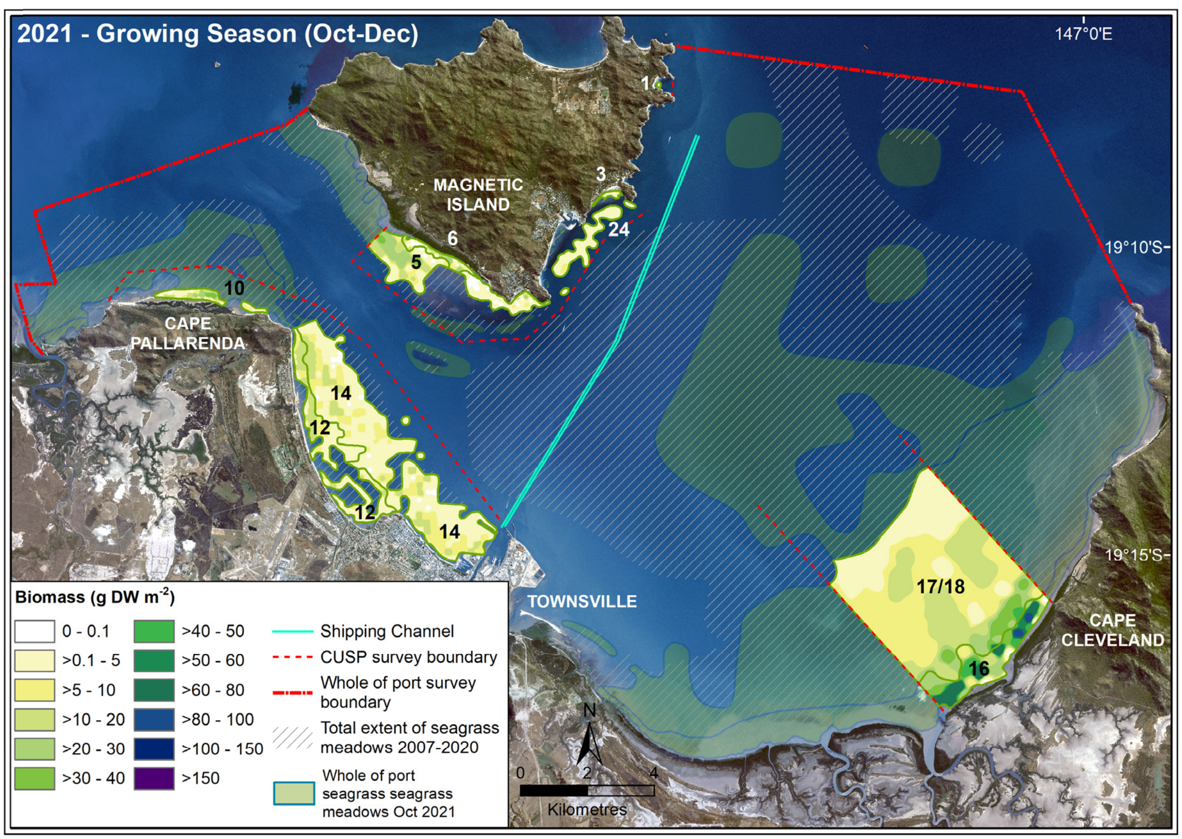


Figure 25. Seagrass density and distribution in the 2021 A) low and B) growing season surveys.

3.4 Whole-of-port comparisons of Townsville seagrass

A total of 1,577 sites were assessed for seagrass condition as part of the October 2021 whole-of-port seagrass surveys, with seagrass present at 61% of sites, similar to 2020. The whole-of-port seagrass footprint covered 17,146 ± 1,721 ha in 2021, an 18% increase from 2020 (Figures 26, 27).

Dry season whole-of-port surveys have now been conducted six times since the LTSMP program was established in 2007: 2007, 2013, 2016, 2019, 2020 and 2021. Seagrass meadow location and extent has been similar around the port for coastal meadows in each of these surveys, particularly around Magnetic Island and Cape Pallarenda - Strand. The Cleveland Bay meadows have expanded their footprint over the last few years following initial declines between 2007 and 2013. Most of the expansion of seagrass extent has been in the subtidal Cleveland Bay *H. uninervis* meadow (17/18). The spatial footprint of the Cleveland Bay deep-water meadow (Meadow 19) has been much more variable, a typical attribute of deep-water *Halophila* meadows in tropical Queensland (Figures 26, 27).

Mean seagrass above-ground biomass has varied between each of the whole-of-port surveys (Figures 26, 27). In 2019, above-ground biomass was the lowest for the program across all regions, but biomass has increased or remained stable since 2020 (Figure 26). Seagrass meadow density ‘hotspots’ have returned to the region, particularly in the Cleveland Bay *Z. muelleri* intertidal meadow where areas of over 60 g DW m^{-2} were regularly recorded throughout the meadow (Figure 27).

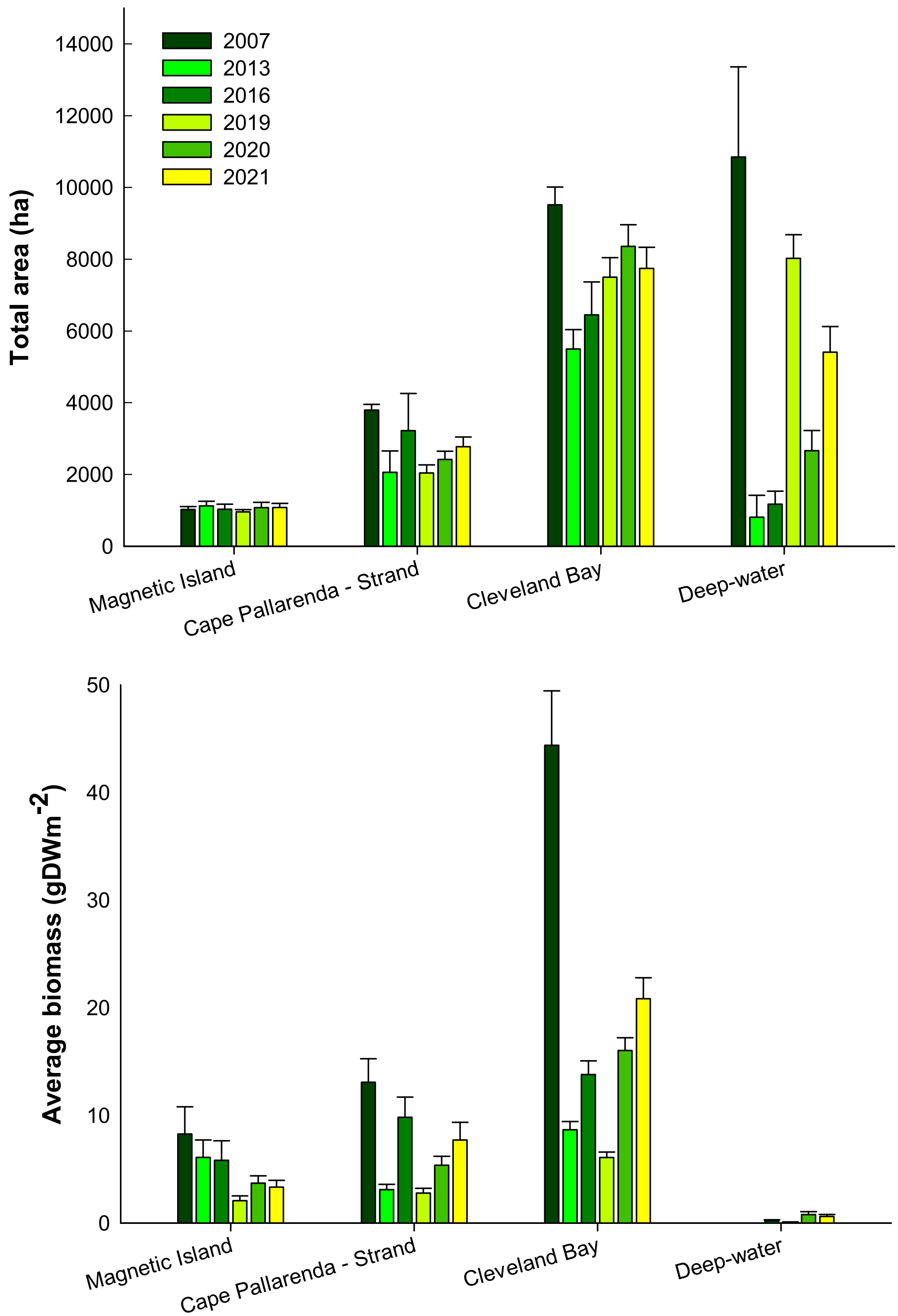


Figure 26. Comparison of whole-of-port meadow area and biomass in the four regions around Townsville in 2007, 2013, 2016, 2019, 2020 and 2021. (biomass error bars = SE; area error bars = "R" reliability estimate, nr = not recorded as part of survey).

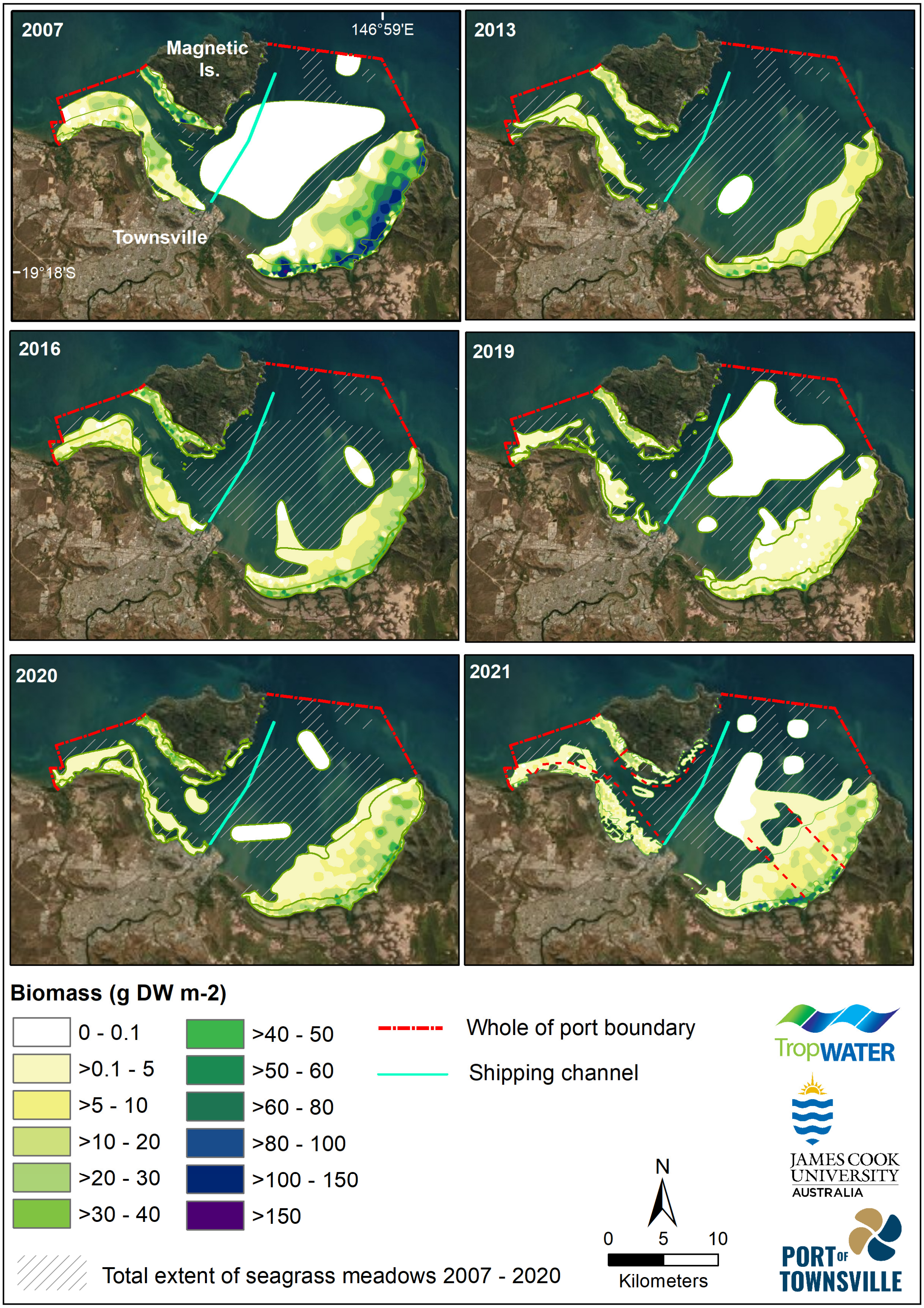


Figure 27. Comparison of whole-of-port peak season seagrass biomass (g DWm^{-2}) and meadow extent; 2007, 2013, 2016, 2019, 2020 and 2021.

3.5 Townsville Climate Patterns

3.5.1 Rainfall and River flow

Rainfall in Townsville is seasonal with the majority of rainfall typically occurring from December to April (Figure 28A). Rainfall was below the monthly long-term average for all months in 2021, except for April and August (Figure 28A). Total annual rainfall has been below the long-term average for the last two years (Figure 28B). River flow from all three of the 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 two years (Figure 29).

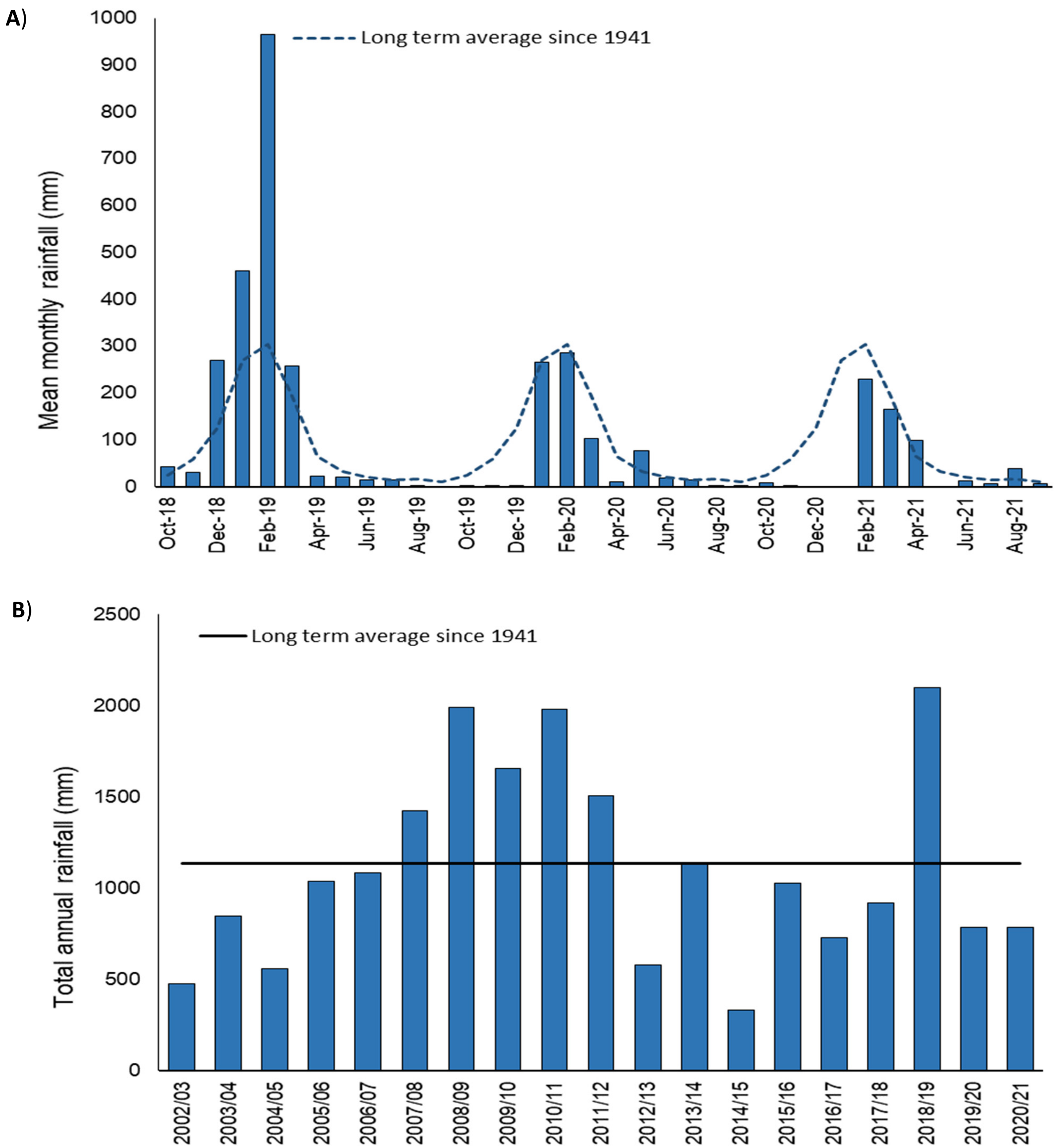
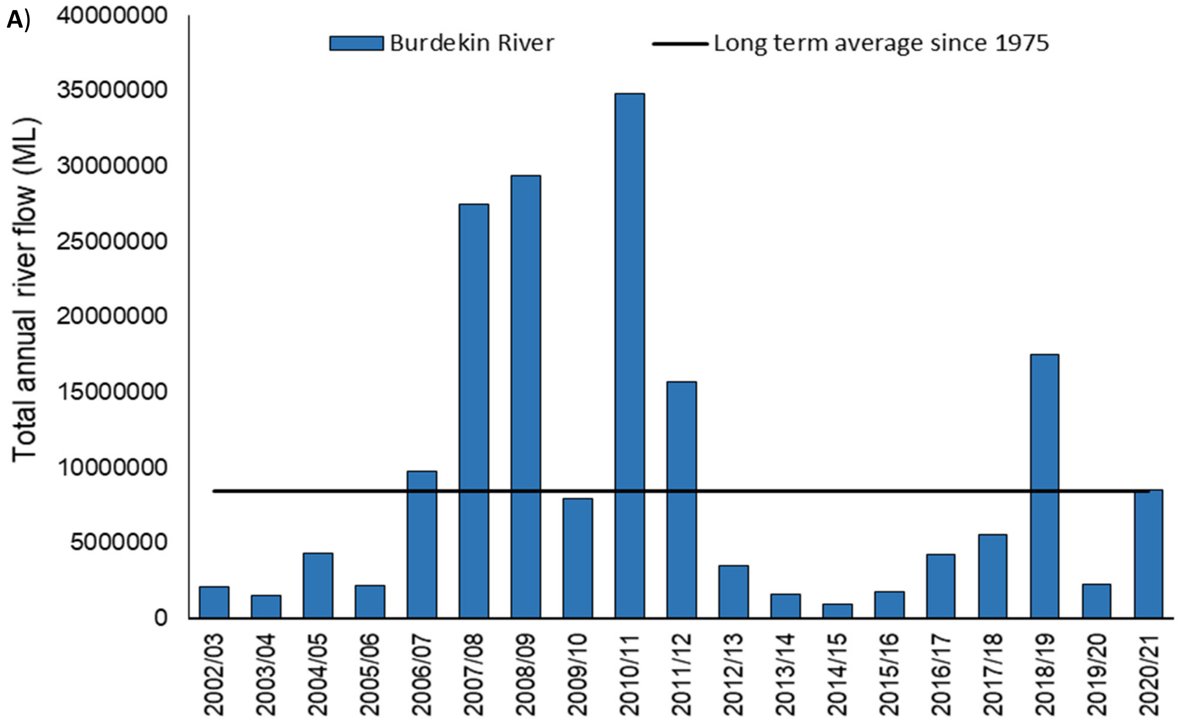


Figure 28. (A) Total monthly rainfall from October 2018 – September 2021 and (B) total annual rainfall from 2002/2003 to 2020/21 recorded at Townsville airport (Data from the Bureau of Meteorology, Station 032040 http://www.bom.gov.au).



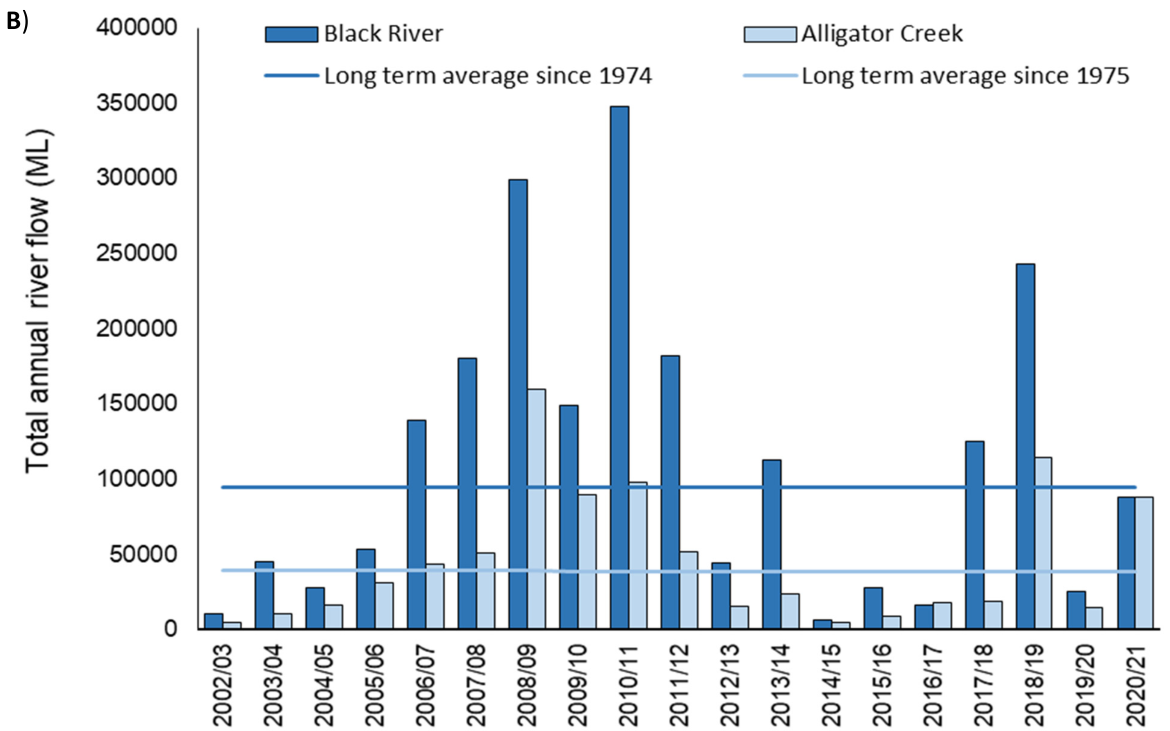


Figure 29. (A) Total annual flow of the Burdekin River from 2002/03 to 2020/21, and (B) total annual flow of the Black River and Alligator Creek from 2002/03 to 2020/21. (Department of Natural Resources, Mines and Energy, https://water-monitoring.information.qld.gov.au/).

3.5.2 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 2020/21 was below the long-term average (Figure 30).

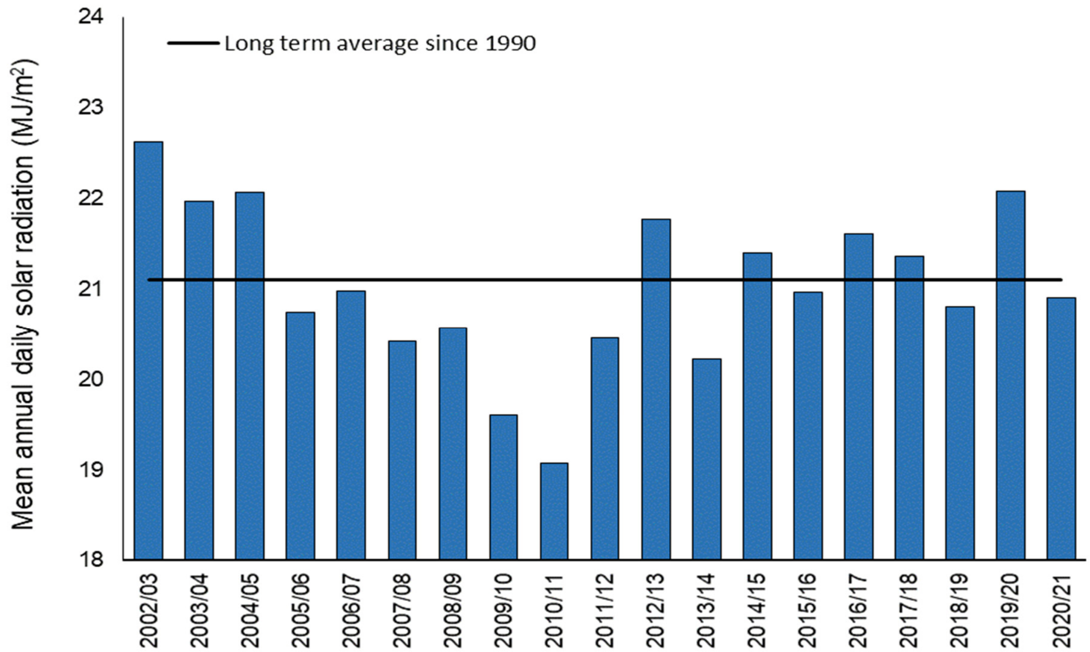


Figure 30. Mean annual daily solar radiation recorded at Townsville airport 2002/03 to 2020/21. (Data from the Bureau of Meteorology, Station 032040 http://www.bom.gov.au).

3.5.3 Air Temperature & Tidal Exposure of Seagrass Meadows

Mean annual daily maximum air temperature for 2020/21 was 29.4°C and has been above the long-term average of 29°C for the last nine years (Figure 31).

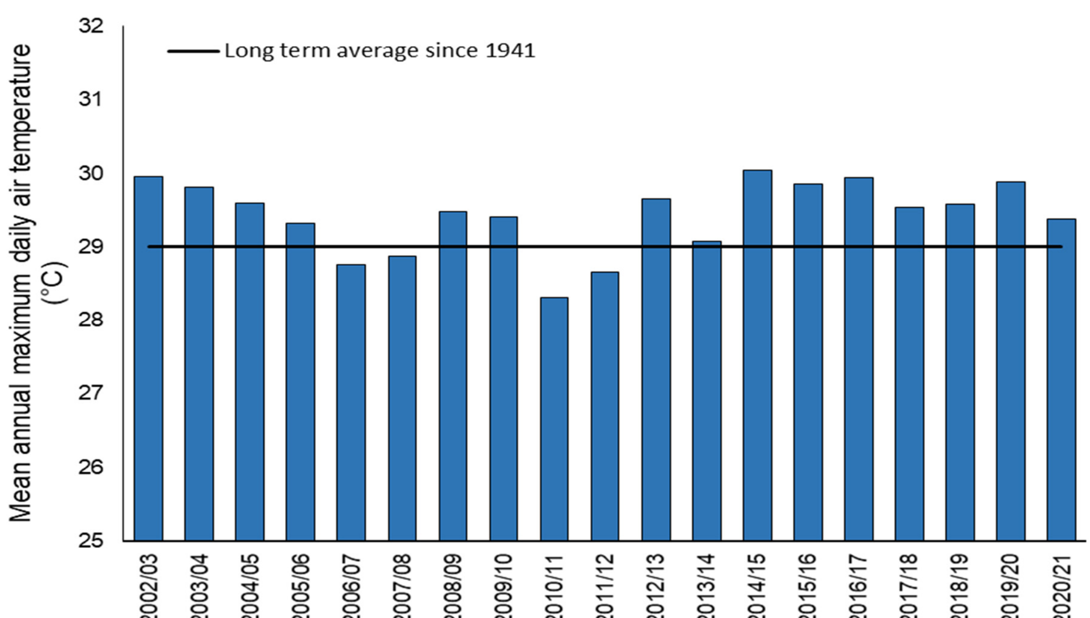


Figure 31. Mean annual maximum daily air temperature (°C) recorded at Townsville Airport, 2002/03 to 2020/21. (Data from the Bureau of Meteorology, Station 032040 http://www.bom.gov.au).

Total daytime exposure to air of intertidal seagrasses in Townsville is generally higher during the winter months and lower over summer/wet season (Figure 32A). The total time seagrass meadows were exposed to air in the months preceding the 2021 surveys (April and September) was lower than the long-term averages (Figure 32A). Total hours of tidal exposure in the one month period prior to the two 2021 surveys was 4 hours for the post-wet survey, and 29 hours for the dry season survey; both below the long-term average averages (Figure 32A & B). The total hours of tidal exposure in the three month period before dry season surveys has been below the long-term average for the six years (Figure 32B).

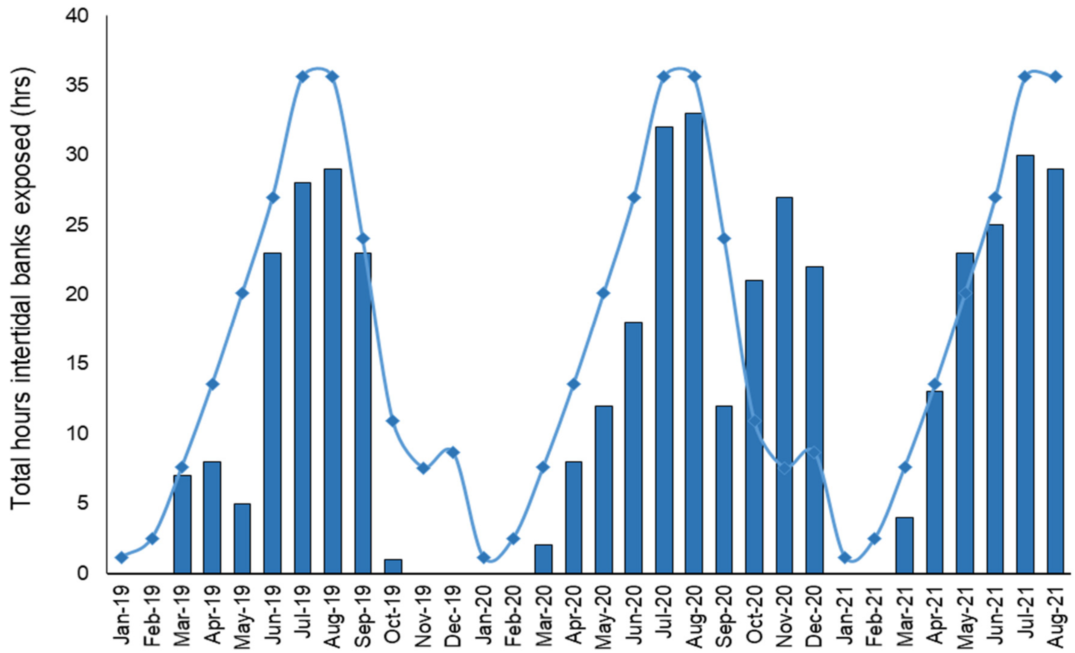


Figure 32A. Total monthly daytime intertidal exposure (<0.8m tidal height) Jan 2019 – December 2020 (Maritime Safety Queensland, www.msq.qld.gov.au).

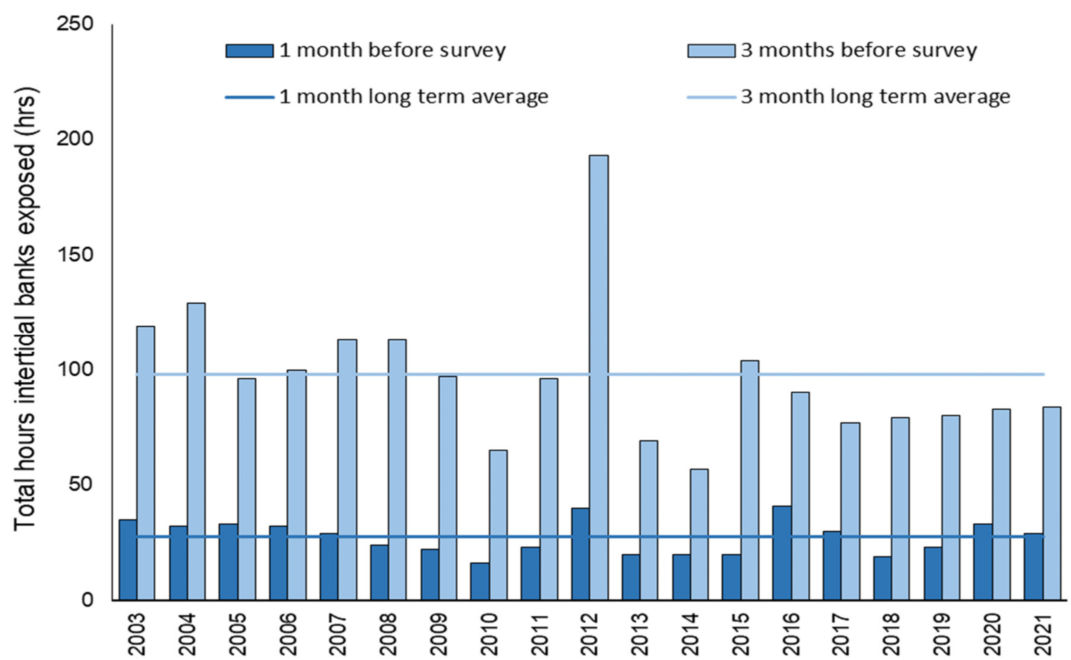


Figure 32B. Total daytime intertidal exposure (<0.8m tidal height) one month and three months prior to the growing season monitoring in Townsville (September 2021) (Maritime Safety Queensland, www.msq.qld.gov.au).

4 DISCUSSION

Seagrasses in Townsville were in a good condition in 2021. An extensive footprint of seagrass was found in the greater port region, and the area, biomass and species composition of all meadows was in satisfactory or better 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. The healthy condition of Townsville's seagrasses mean they were entering 2022 with good levels of resilience.

The Townsville seagrass monitoring programs have shown that historically the monitoring meadows and the species that make up these meadows can behave differently to each other in response to environmental pressures. Incorporating the range of species and meadow types in the monitoring programs ensures that the range of potential responses by seagrasses to environmental pressures as well as anthropogenic pressure, like the Channel Upgrade Project are adequately captured. We have now been able to establish baseline conditions of Townsville seagrass meadows using an extensive long-term history of measuring change for each meadow, and for each seagrass condition indicator. In most cases, this is based on ten years or more of data. For the two meadows with less than ten years of baseline history (Florence and Geoffrey Bay meadows), we have provided interim baselines and score ranges.

The Channel Upgrade Seagrass Program includes seasonal assessments of seagrasses during the typical low season for seagrasses in Queensland, and the growing season. Tropical seagrasses generally follow a seasonal pattern where above-ground biomass and meadow extent (area) diminish in the wet/post-wet season ("low" season), reaching a peak in distribution and density in the late spring (i.e. growing season) (Chartrand et al. 2017; Erftemeijer and Herman 1994; McKenzie 1994; Rasheed 1999; 2004; Unsworth et al. 2010; York et al. 2015). This seasonal cycle is influenced by a range of stressors such as episodic coastal flooding and cyclones, wind, rainfall and river flow that effect light availability; one of the primary drivers of seagrass condition (Petus et al. 2014; Bainbridge et al. 2012; Chartrand et al. 2012; Collier et al. 2012; Lambrechts et al. 2010). For the CUSP monitoring, early results and the original baseline surveys in 2007/2008 (Rasheed and Taylor 2008) suggest 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. 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.

As expected, the deep-water *Halophila* meadows in Townsville continued to be highly variable from year to year. There was a substantial decline in the area of deep-water seagrass from 2019 to 2020, but meadow area then increased substantially in 2021. 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 2021 dry season survey.

Seagrasses in Townsville continue to be in healthy condition in 2021. The maintenance of healthy seagrass coincides with a period of stable climate conditions over the past two years that has likely facilitated seagrass growth and increased plant reserves. The prolonged period of good seagrass health provides Townsville seagrass with a good level of resilience leading in to 2022.

In summary the 2021 seagrass monitoring found:

- The overall condition of seagrasses in Townsville was good.
- An extensive footprint of seagrass was maintained in the greater port region, and the area, biomass and species composition of all monitoring meadows was in satisfactory or better condition.

- At this stage, seasonal assessments of monitoring meadows in Townsville indicate that seasonal signals and patterns in Townsville's coastal seagrasses may not have a strong seasonal signal compared with deeper meadows.
- Green sea turtles, dugongs and their feeding trails were observed widely across seagrass meadows within the Port of Townsville in 2021 indicating a broad use of the area by herbivorous marine megafauna.
- The healthy condition of Townsville's seagrass indicates they were in a resilient state leading into 2022.

5 REFERENCES

Abal, E. and Dennison, W. 1996. Seagrass depth range and water quality in southern Moreton Bay, Queensland, Australia. Marine and Freshwater Research, 47: 763-771.

Bainbridge, Z. T., Wolanski, E., Álvarez-Romero, J. G., Lewis, S. E. and Brodie, J. E. 2012. Fine sediment and nutrient dynamics related to particle size and floc formation in a Burdekin River flood plume, Australia. Marine Pollution Bulletin, 65: 236-248.

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch E. W., Stier, A. C. and Silliman, B. R. 2011. The value of estuarine and coastal ecosystem services. Ecological Monographs, 81: 169-193.

Bryant, C. V. and Rasheed, M. A. 2018. Port of Townsville annual seagrass monitoring: September 2017, Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) Publication 18/11, James Cook University, Cairns, p. 49.

Bryant, C., Jarvis, J. C., York, P. and Rasheed, M. 2014. Gladstone Healthy Harbour Partnership Pilot Report Card; ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 14/53, James Cook University, Cairns, 74 pp.

Bryant, C., Davies, J. and Rasheed, M. 2016. Gladstone Healthy Harbour Partnership 2016 Report Card, ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research Publication 16/23, James Cook University, Cairns, 62 pp.

Carter, A., Bryant, C., Davies, J. and Rasheed, M. 2016. Gladstone Healthy Harbour Partnership 2016 Report Card, ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research Publication 16/23,James Cook University, Cairns, 62 pp.

Carter, A. B., Jarvis, J. C., Bryant, C. V. and Rasheed, M. A. 2015. Development of seagrass indicators for the Gladstone Healthy Harbour Partnership Report Card, ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 15/29, James Cook University, Cairns, 71 pp.

Chartrand, K. M., Bryant, C. V., Sozou, S., Ralph, P. J. and Rasheed, M. A. 2017. Final Report: Deep-water seagrass dynamics - Light requirements, seasonal change and mechanisms of recruitment, Centre for Tropical Water & Aquatic Ecosystem Research Publication, James Cook University, Cairns.

Chartrand, K. M., Ralph, P. J., Petrou, K. and Rasheed, M. A. 2012. Development of a light-based seagrass management approach for the Gladstone Western Basin dredging program. DEEDI Publication, Fisheries Queensland, Northern Fisheries Centre, Cairns, 92 pp.

Collier, C. J., Chartrand, K., Honchin, C., Fletcher, A. and Rasheed, M. 2016. Light thresholds for seagrasses of the GBR: a synthesis and guiding document. Including knowledge gaps and future priorities. Report to the National Environmental Science Programme, Cairns, 41 pp.

Collier, C. J., Waycott, M. and Ospina, A. G. 2012. Responses of four Indo-West Pacific seagrass species to shading. Marine Pollution Bulletin, 65: 342-354.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S. and Turner, R. K. 2014. Changes in the global value of ecosystem services. Global Environmental Change 26:152-158.

Dennison, W. C., Orth, R. J., Moore, K. A., Stevenson, J. C., Carter, V., Kollar, S., Bergstrom, P. W. and Batiuk, R. A. 1993. Assessing water quality with submersed aquatic vegetation: Habitat requirements as barometers of Chesapeake Bay health. Bioscience, 43: 86-94.

Dunic, JC., Brown, CJ., Connolly, RM., Turschwell, MP. and Cote, IM. Accepted Article 2021. Long-term declines and recovery of meadow area across the world's seagrass bioregions. doi:10.1111/GCB.15684.

Erftemeijer, P. L. A. and Herman, P. M. J. 1994. Seasonal changes in environmental variables, biomass, production and nutrient contents in two contrasting tropical intertidal seagrass beds in South Sulawesi, Indonesia. Oecologia 99:45-59.

Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marba, N., Holmer, M., Mateo, M. A., Apostolaki, E. T., Kendrick, G. A., Krause- Jensen, D., McGlathery, K. J. and Serrano, O. 2012. Seagrass ecosystems as a globally significant carbon stock. Nature Geoscience 5: 505-509

Hammerstrom, K. K., Kenworthy, J. W., Fonseca, M. S. and Whitfield, P. E. 2006. Seed bank, biomass, and productivity of *Halophila decipiens*, a deep water seagrass on the west Florida continental shelf. Aquatic botany 84, 110-120.

Hammerstrom, K. K., and Kenworthy, J. W. 2003. A new method for estimation of Halophila decipiens Ostenfeld seed banks using density separation. Aquatic botany 76, 79-86.

Hemminga, M. A. and Duarte, C. M. 2000. Seagrass Ecology. Cambridge University Press, Cambridge, United Kingdom.

Kilminster, K., McMahon, K., Waycott, M., Kendrick, G. A., Scanes, P., McKenzie, L., O'Brien, K. R., Lyons, M., Ferguson, A., Maxwell, P., Glasby, T. and Udy, J. 2015. Unravelling complexity in seagrass systems for management: Australia as a microcosm. Science of The Total Environment, 534: 97-109.

Kirkman, H. 1978. Decline of seagrass in northern areas of Moreton Bay, Queensland. Aquatic Botany 5:63-76.

Lambrechts, J., Humphrey, C., McKinna, L., Gourge, O., Fabricius, K., Mehta, A., Lewis, S. and Wolanski, E. 2010. Importance of wave-induced bed liquefaction in the fine sediment budget of Cleveland Bay, Great Barrier Reef. Estuarine, Coastal and Shelf Science 89, 154-162.

McKenna S, Van De Wetering C, Wilkinson J and Rasheed M In prep. 'Port of Abbot Point Long-Term Seagrass Monitoring Program - 2019', JCU Publication 20/12, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns.

McKenna, S., Chartrand, K., Van De Wetering, C., Wells, J., Carter, A. B. and Rasheed, M. 2020. 'Port of Townsville Seagrass Monitoring Program: 2019,' James Cook University Publication, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), Cairns.

McKenzie, L. J. 1994. Seasonal changes in biomass and shoot characteristics of a Zostera capricorni Aschers. dominant meadow in Cairns Harbour, northern Queensland. Australian Journal of Marine and Freshwater Research 45:1337-1352.

McMillan, C. 1991. The longevity of seagrass seeds. Aquatic Botany 40, 195-198.

Mellors, J. E. 1991. An evaluation of a rapid visual technique for estimating seagrass biomass. Aquatic Botany 42:67-73.

Orth, R. J., Carruthers, T. J. B., Dennison, W. C., Duarte, C. M., Fourqurean, J. W., Heck, K. L., Hughes, A. R., Kendrick, G. A., Kenworthy, W. J., Olyarnik, S., Short, F. T., Waycott, M. and Williams, S. L. 2006. A global crisis for seagrass ecosystems. BioScience, 56: 987-996.

Petus, C., Collier, C., Devlin, M., Rasheed, M. and McKenna, S. 2014. Using MODIS data for understanding changes in seagrass meadow health: A case study in the Great Barrier Reef (Australia). Marine Environmental Research 98, 68-85.

Rasheed, M. A. 2004. Recovery and succession in a multi-species tropical seagrass meadow following experimental disturbance: the role of sexual and asexual reproduction. Journal of Experimental Marine Biology and Ecology, 310: 13-45.

Rasheed, M. A., McKenna, S. A., Carter, A. B. and Coles, R. G. 2014. Contrasting recovery of shallow and deep water seagrass communities following climate associated losses in tropical north Queensland, Australia. Marine Pollution Bulletin, 83: 491-499.

Rasheed, M. A. and Taylor, H. A. 2008. Port of Townsville seagrass baseline survey report. Department of Primary Industries Information Series PR08-4014, Northern Fisheries Centre, Cairns, Australia, 45 pp.

Scott, A. L., York, P. H., Duncan, C., Macreadie, P. I., Connolly, R. M., Ellis, M. T., Jarvis, J.C., Jinks, K.I., Marsh, H. and Rasheed, M. A. 2018. The role of herbivory in structuring tropical seagrass ecosystem service delivery. Frontiers in plant science, 9, 127.

Unsworth, R. K. F., McKenna, S. A. and Rasheed, M. A. 2010. Seasonal dynamics, productivity and resilience of seagrass at the Port of Abbot Point: 2008-2010. DEEDI Publication, Fisheries Queensland, Cairns, 68pp.

Wells, J. and Rasheed, M. 2017. Port of Townsville Annual Seagrass Monitoring and Baseline Survey: September - October 2016, James Cook University Publication, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), Cairns, p. 54.

York, P. H. and Rasheed, M. A. 2021. 'Annual Seagrass Monitoring in the Mackay-Hay Point Region – 2020', JCU Centre for Tropical Water & Aquatic Ecosystem Research Publication.

York, P. H., Carter, A. B., Chartrand, K., Sankey, T., Wells, J. and Rasheed, M. A. 2015. Dynamics of a deep-water seagrass population on the Great Barrier Reef: annual occurrence and response to a major dredging program, Scientific Reports. 5:13167.

6 APPENDICES

Appendix 1. Seagrass meadow condition index

Baseline Calculations

Baseline conditions for seagrass biomass, meadow area and species composition were established from annual means calculated over the first 10 years of monitoring (2007–2016) for the majority of meadows. Interim baseline conditions of four and five years were calculated for the two meadows new to the CUSP program where a more limited baseline history was available (see methods). The Townsville baselines were set using the methods developed for the Gladstone Healthy Harbour Partnership 2014 pilot and subsequent full report cards (Bryant et al. 2014). The 2007–2016 period incorporates a range of conditions present in Townsville, including El Niño and La Niña periods, and multiple extreme rainfall and river flow events. The 10 year long-term average will be reassessed each decade.

Baseline conditions for species composition were determined based on the annual percent contribution of each species to mean meadow biomass of the baseline years. The meadow was classified as either single species dominated (one species comprising ≥80% of baseline species), or mixed species (all species comprise <80% of baseline species composition). Where a meadow baseline contained an approximately equal split in two dominant species (i.e. both species accounted for 40–60% of the baseline), the baseline was set according to the percent composition of the more persistent/stable species of the two (see Grade and Score Calculations section and Table A1).

Meadow Classification

A meadow classification system was developed for the three condition indicators (biomass, area, species composition) in recognition that for some seagrass meadows these measures are historically stable, while in other meadows they are relatively variable. The coefficient of variation (CV) for each baseline for each meadow was used to determine historical variability. Meadow biomass and species composition were classified as either stable or variable (Table A1). Meadow area was classified as either highly stable, stable, variable, or highly variable (Table A1). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each condition indicator.

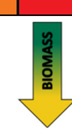
Table A1. Coefficient of variation (CV; %) thresholds used to classify historical stability or variability of meadow biomass, area and species composition.

Indicator	Class			
	Highly stable	**Stable**	**Variable**	**Highly variable**
Biomass	-	< 40%	≥ 40%	-
Area	< 10%	≥ 10, < 40%	≥ 40, <80%	≥ 80%
Species composition	-	< 40%	≥ 40%	-

Threshold Definition

Seagrass condition for each indicator was assigned one of five grades (very good (A), good (B), satisfactory (C), poor (D), very poor (E)). Threshold levels for each grade were set relative to the baseline and based on meadow class. This approach accounted for historical variability within the monitoring meadows and expert knowledge of the different meadow types and assemblages in the region (Table A2).

Table A2. Threshold levels for grading seagrass indicators for various meadow classes relative to the baseline. Upwards/ downwards arrows are included where a change in condition has occurred in any of the three condition indicators (biomass, area, species composition) from the previous year.

Seagrass condition indicators/ Meadow class		Seagrass grade				
		A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass	Stable	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
	Variable	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area	Highly stable	>5% above	5% above - 10% below	10-20% below	20-40% below	>40% below
	Stable	>10% above	10% above - 10% below	10-30% below	30-50% below	>50% below
	Variable	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
	Highly variable	> 40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Species composition	Stable and variable; Single species dominated	>0% above	0-20% below	20-50% below	50-80% below	>80% below
	Stable; Mixed species	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
	Variable; Mixed species	>20% above	20% above- 40% below	40-70% below	70-90% below	>90% below
	Increase above threshold from previous year			Decrease below threshold from previous year		

Grade and Score Calculations

A score system (0–1) and score range was applied to each grade to allow numerical comparisons of seagrass condition among Townsville meadows (Table A3; see Carter et al. 2016; Carter et al. 2015 for a detailed description).

Score calculations for each meadow's condition required calculating the biomass, area and species composition for that year (see Baseline Calculations section), allocating a grade for each indicator by comparing 2017 values against meadow-specific thresholds for each grade, then scaling biomass, area and species composition values against the prescribed score range for that grade.

Scaling was required because the score range in each grade was not equal (Table A3). Within each meadow, the upper limit for the very good grade (score = 1) for species composition was set as 100% (as a species could never account for >100% of species composition). For biomass and area the upper limit was set as the maximum mean plus standard error (SE; i.e. the top of the error bar) value for a given year, compared among years during the baseline period.

An example of calculating a meadow score for biomass in satisfactory condition is provided in Appendix 2.

Table A3. Score range and grading colours used in the Townsville report card.

Grade	Description	Score Range	
		Lower bound	Upper bound
A	Very good	$\geq$0.85	1.00
B	Good	$\geq$0.65	<0.85
C	Satisfactory	$\geq$0.50	<0.65
D	Poor	$\geq$0.25	<0.50
E	Very poor	0.00	<0.25

Where species composition was determined to be anything less than in "perfect" condition (i.e. a score <1), a decision tree was used to determine whether equivalent and/or more persistent species were driving this grade/score (Figure A1). If this was the case then the species composition score and grade for that year was recalculated including those species. Concern regarding any decline in the stable state species should be reserved for those meadows where the directional change from the stable state species is of concern (Figure A1). This would occur when the stable state species is replaced by species considered to be earlier colonisers. Such a shift indicates a decline in meadow stability (e.g. a shift from *Z. muelleri* subsp. *capricorni* to *H. ovalis*). An alternate scenario can occur where the stable state species is replaced by what is considered an equivalent species (e.g. shifts between *C. rotundata* and *C. serrulata*), or replaced by a species indicative of an improvement in meadow stability (e.g. a shift from *H. decipiens* to *H. uninervis* or any other species). The directional change assessment was based largely on dominant traits of colonising, opportunistic and persistent seagrass genera described by Kilminster et al. (2015). Adjustments to the Kilminster model included: (1) positioning *S. isoetifolium* further towards the colonising species end of the list, as successional studies following disturbance demonstrate this is an early coloniser in Queensland seagrass meadows (Rasheed 2004); and (2) separating and ordering the *Halophila* genera by species. Shifts between *Halophila* species are ecologically relevant; for example, a shift from *H. ovalis* to *H. decipiens*, the most marginal species found in Townsville, may indicate declines in water quality and available light for seagrass growth as *H decipiens* has a lower light requirement (Collier et al. 2016) (Figure A1).

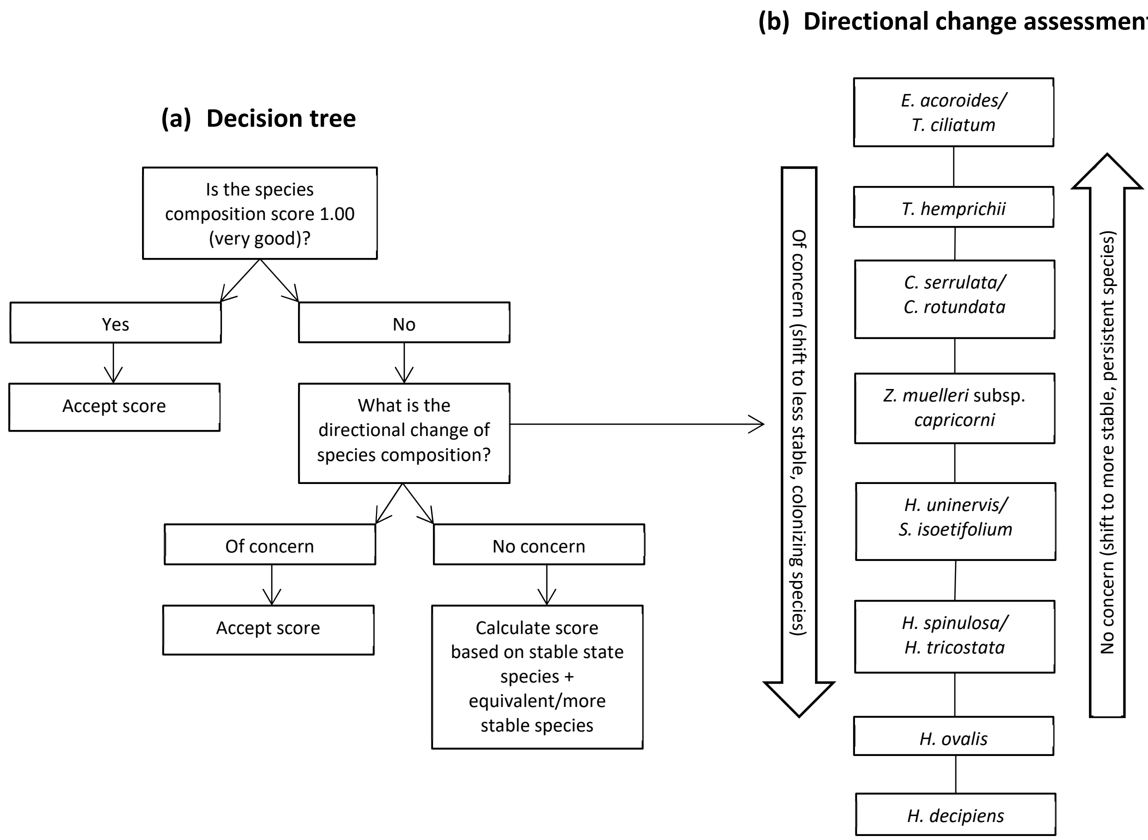


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in Townsville.

Score Aggregation

A review in 2017 of how meadow scores were aggregated led to a slight modification from previous years' report cards. This change was applied to correct an anomaly that resulted in some meadows receiving a zero score due to species composition, despite having substantial area and biomass. The change acknowledges that species composition is an important characteristic of a seagrass meadow in terms of defining meadow stability, resilience, and ecosystem services, but is not as fundamental as having some seagrass present, regardless of species, when defining overall condition. The overall meadow score was previously defined as the lowest of the three indicator scores (area, biomass or species composition). The new method still defines overall meadow condition as the lowest indicator score where this is driven by biomass or area as previously; however, where species composition was the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50%. The calculation of individual indicator scores remains unchanged.

Townsville grades/scores were determined by averaging the overall meadow scores for each monitoring meadow within the port, and assigning the corresponding grade to that score (Table A2). Where multiple meadows were present within the port, meadows were not subjected to a weighting system at this stage of the analysis. The meadow classification process applied smaller and therefore more sensitive thresholds for meadows considered stable, and less sensitive thresholds for variable meadows. The classification process served therefore as a proxy weighting system where any condition decline in the (often) larger, stable meadows was more likely to trigger a reduction in the meadow grade compared with the more variable, ephemeral meadows. Port grades are therefore more sensitive to changes in stable than variable meadows.

Appendix 2. Calculating meadow scores

Figure A2. An example of calculating a meadow score for biomass in satisfactory condition in 2018.

1. Determine the grade for the 2018 (current) biomass value (i.e. satisfactory).

2. Calculate the difference in biomass (B_{diff}) between the 2018biomass value (B_{2016}) and the area value of the lower threshold boundary for the satisfactory grade ($B_{satisfactory}$):

$$\mathrm{B_{diff}} = \mathrm{B_{2018}} - \mathrm{B_{satisfactory}}$$

Where $B_{satisfactory}$ or any other threshold boundary will differ for each condition indicator depending on the baseline value, meadow class (highly stable [area only], stable, variable, highly variable [area only]), and whether the meadow is dominated by a single species or mixed species.

3. Calculate the range for biomass values (B_{range}) in that grade:

$$\mathrm{B_{range}} = \mathrm{B_{good}} - \mathrm{B_{satisfactory}}$$

Where $B_{satisfactory}$ is the upper threshold boundary for the satisfactory grade.

Note: For species composition, the upper limit for the very good grade is set as 100%. For area and biomass, the upper limit for the very good grade is set as the maximum value of the mean plus the standard error (i.e. the top of the error bar) for a given year during the baseline period for that indicator and meadow.

4. Calculate the proportion of the satisfactory grade (B_{prop}) that B_{2016} takes up:

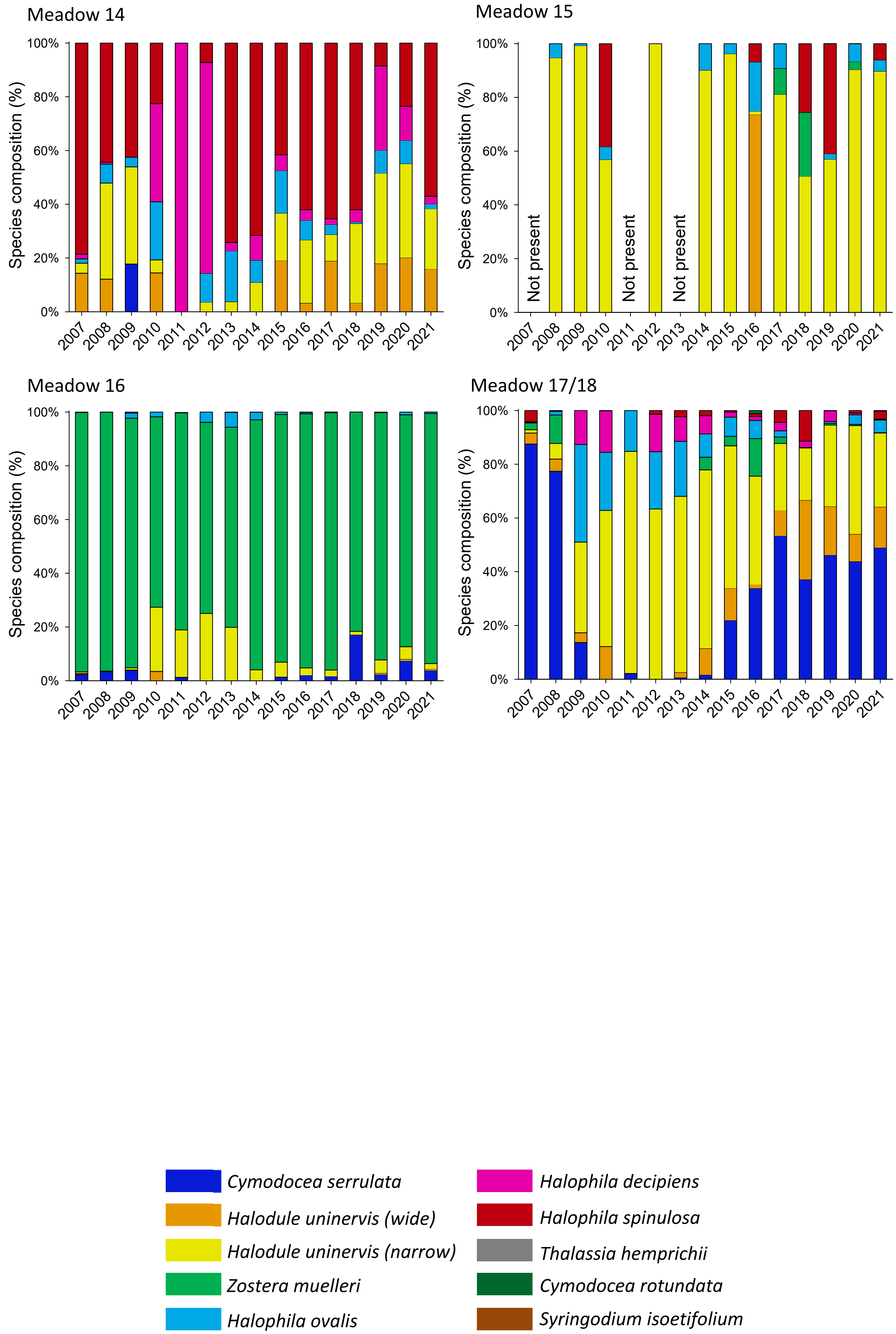
$$\mathrm{B_{prop}} = \frac{\mathrm{B_{diff}}}{\mathrm{B_{range}}}$$

5. Determine the biomass score for 2016 ($Score_{2016}$) by scaling B_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

$$\mathrm{Score_{2018}} = \mathrm{LB_{satisfactory}} + \left(\mathrm{B_{prop}} \times \mathrm{SR_{satisfactory}}\right)$$

Where $LB_{satisfactory}$ is the defined lower bound (LB) score threshold for the satisfactory grade, i.e. 0.50 units

Appendix 3. Detailed meadow species composition; 2007-2021


Meadow 14
Meadow 15
Meadow 16
Meadow 17/18
Species composition (%)
100%
80%
60%
40%
20%
0%
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
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 have only been surveyed as part of whole-of-port surveys; 2007, 2013, 2016, 2019, 2020