PORT OF TOWNSVILLE
SEAGRASS MONITORING PROGRAM 2020

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Report No. 21/14

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A Report for the Port of Townsville Limited

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KEY FINDINGS

Seagrass Condition 2020

Good

LTSMP meadows

Good

CUSP meadows

In 2019, the Long-term Seagrass Monitoring Program (LTSMP), established in 2007, expanded to incorporate the Channel Upgrade Seagrass Program (CUSP), a targeted program for the Townsville Channel Upgrade Project (CU Project).

This report presents the results of the 14th year of the LTSMP and the 2nd year of the CUSP.

The overall condition of seagrasses in Townsville was good with recovery from declines related to the February 2019 flooding.

Baseline conditions for each seagrass health indicator (biomass, area and species composition) have now been established for the CUSP monitoring meadows to assess seagrass change through the life of the CU Project.

An extensive footprint of seagrass was present in the greater port region, and the area and biomass of the majority of monitoring meadows were at or above long-term averages.

Dugongs and their feeding trails were observed throughout all areas of the Port in 2020 and indicate a relatively high use of the area by dugongs.

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

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. The LTSMP provides a regular assessment of seagrass condition in the area to inform port management and other stakeholders. Information from the LTSMP provides key input into the condition and trend of habitats for the Dry Tropics Partnership for Healthy Water reporting (https://drytropicshealthywaters.org/).

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 14th year of the LTSMP and the 2nd year of the CUSP.

We have implemented a baseline scoring system for all CUSP monitoring meadows based on their historical condition with a ten year baseline history informing most meadows. For the two meadows newly added as part of the CUSP program, the baseline history is currently four to five years. We have set interim baselines for these in this report, noting that these will continue to be modified as more data is added to the program in future monitoring events.

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 when seagrasses are generally at the peak of distribution and abundance; between September and November. During this dry season survey, all seagrasses within the broader port limits are surveyed, not just the LTSMP and CUSP monitoring meadows.

In 2020 two seagrass habitat surveys were conducted in the Port of Townsville:

- April 2020 post-wet season survey focusing on the coastal CUSP meadows only and,
- September-October 2020 dry season whole-of-port survey that encompassed the CUSP and LTSMP monitoring meadows, as well as all seagrass within the broader port area.

In 2020 the overall condition of LTSMP and CUSP meadows was good. An increase in condition for the majority of meadows from 2019. 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 14,511± 1,895 ha in 2020 of which the LTSMP meadows covered 6,938 ± 592 ha, the CUSP meadows covered 4,075 ± 403 ha and the deep-water *Halophila* meadow (Meadow 19) covered 2,664 ± 561 ha. For the LTSMP, this is highest total area of seagrass since 2007 (Figure 2).

For coastal inshore seagrass, the total area increased by 13% from October 2019. The deep-water meadow however, declined between years from 8,023 ± 1343 ha to 2,666 ± 561 ha. This was not an unusual outcome because the species that make up deep-water meadows (*Halophila* species) are ephemeral, are generally present for part of the year, and can have distinct year to year variability in their presence and location (Chartrand et al. 2017; York et al 2015).

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). In Townsville, coastal CUSP meadow area increased by 19% from low season to growing season in 2020, but seasonal change in above-ground biomass was mixed. Data from the LTSMP and CUSP indicate that these seagrasses may not have a strong seasonal signal in above-ground biomass, particularly if environmental conditions over the wet season are mild, as they were in the 2019/20 (Figure 3). For deep-water seagrasses, seasonal patterns are typically stronger with seagrasses absent during the low season due to their life history strategy; germinating and flourishing for a brief period during the growing season (Chartrand et al. 2017; York et al. 2015).

Dugong were observed while conducting field work, and dugong feeding trails were recorded throughout the coastal survey area, indicating wide use of available seagrass habitat as a food source for megafauna.

The healthy condition of Townsville seagrasses in 2020 was likely associated with recovery leading in to the 2020 wet season, followed by below average wet season conditions (rainfall/river flow), and generally favourable light conditions for seagrass growth. Other environmental conditions that can effect seagrass growth such as levels of air exposure and temperature were generally favourable throughout 2020, and likely contributed to the good condition of seagrass (Figure 3).

The LTSMP and now CUSP has shown that historically the Townsville monitoring meadows and the species that make up these meadows can behave differently to each other in response to environmental pressures. Capturing the range of species and meadow types ensures that the range of potential responses by seagrasses to environmental pressures, as well as the CU Project are adequately captured. The established baseline conditions, long history of data collection and extensive network of CUSP meadows provides a strong foundation to assess potential impacts from dredging activities versus climate or non-project related drivers of seagrass change.

The Townsville long-term monitoring program 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. Monitoring at other sites in the network has shown a range of results during 2020. Coastal areas to the north and south of Townsville had seagrass in good condition (e.g. Gladstone – Smith et al. 2021a; Cairns Harbour - Reason et al. 2021; and Abbot Point – McKenna et al. 2021). In contrast the estuarine habitat in Trinity inlet was in poor condition (Reason et al. 2021), and coastal meadows around Hay Point were in satisfactory condition while their offshore counterparts were in poor condition (York et al. 2021).

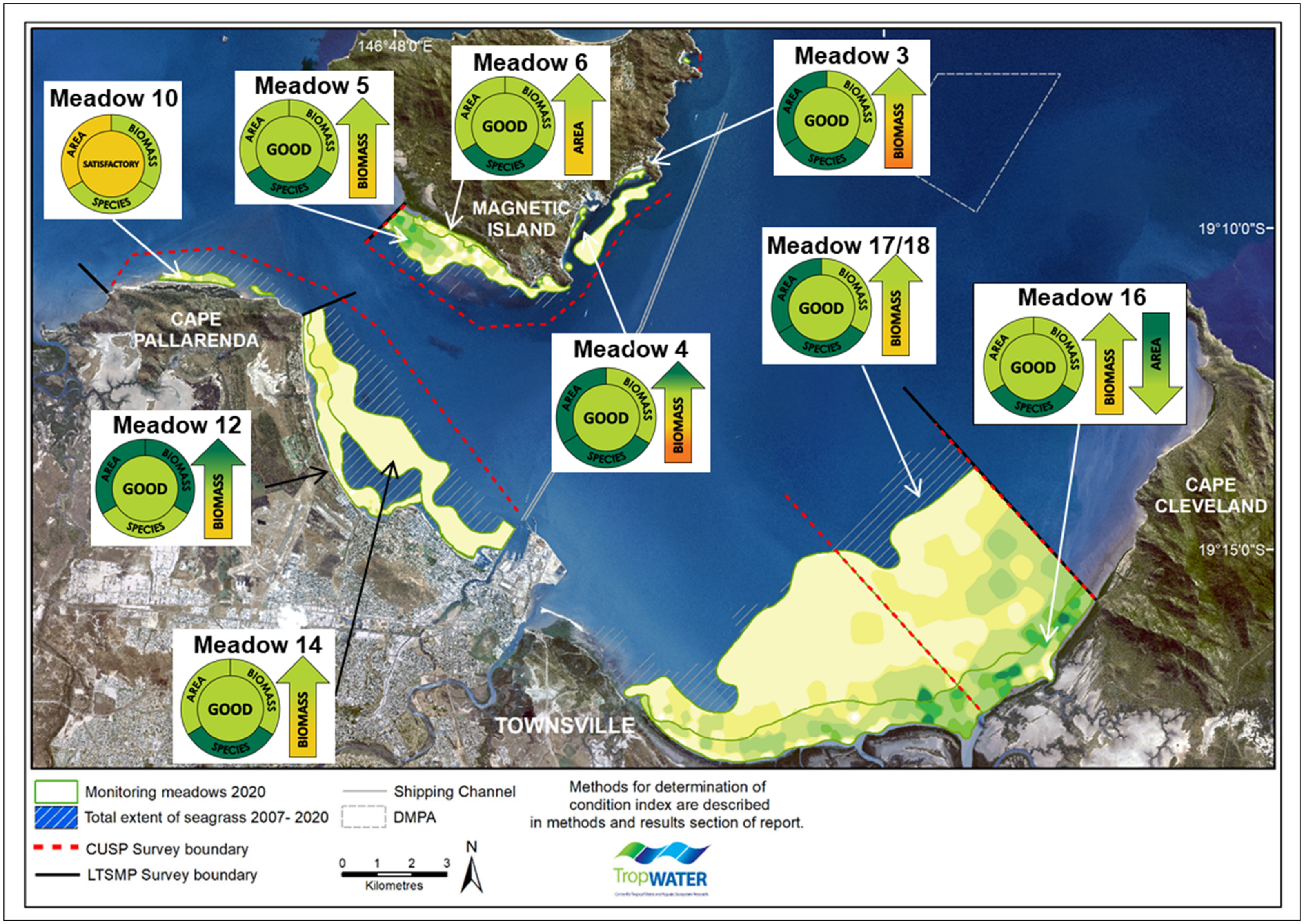

Figure 1. Seagrass condition for meadows monitored as part of the LTSMP. For CUSP meadow condition see results section 3.2.

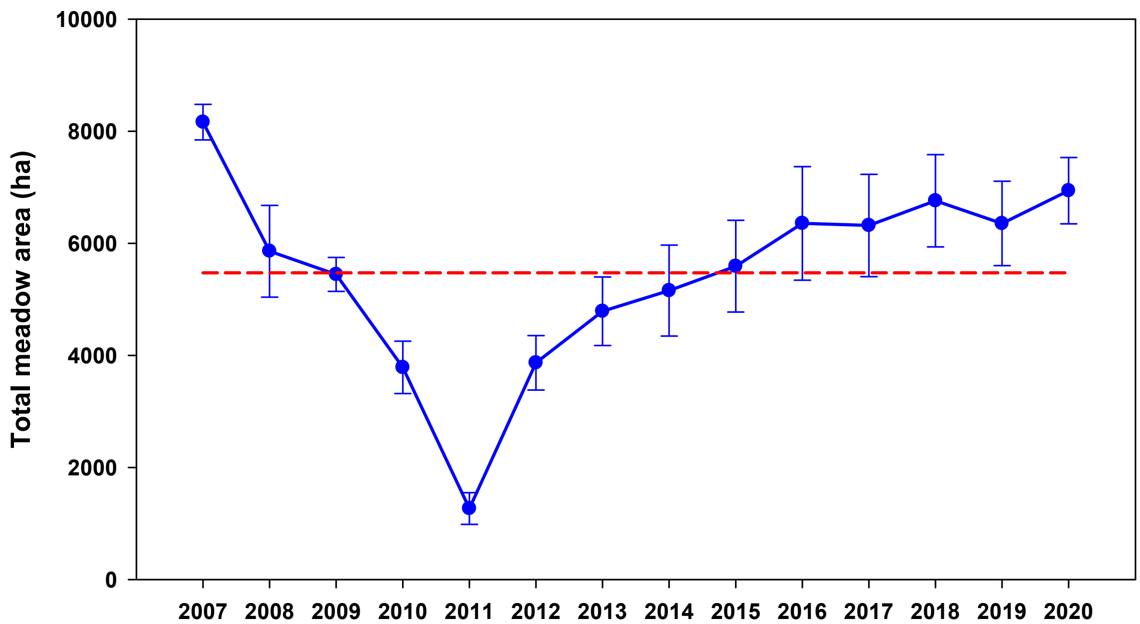

Figure 2. Total area of the Long-term seagrass monitoring program meadows (LTSMP); 2007-2020 (error bars = "R" reliability estimate), (red dashed line = long-term average).

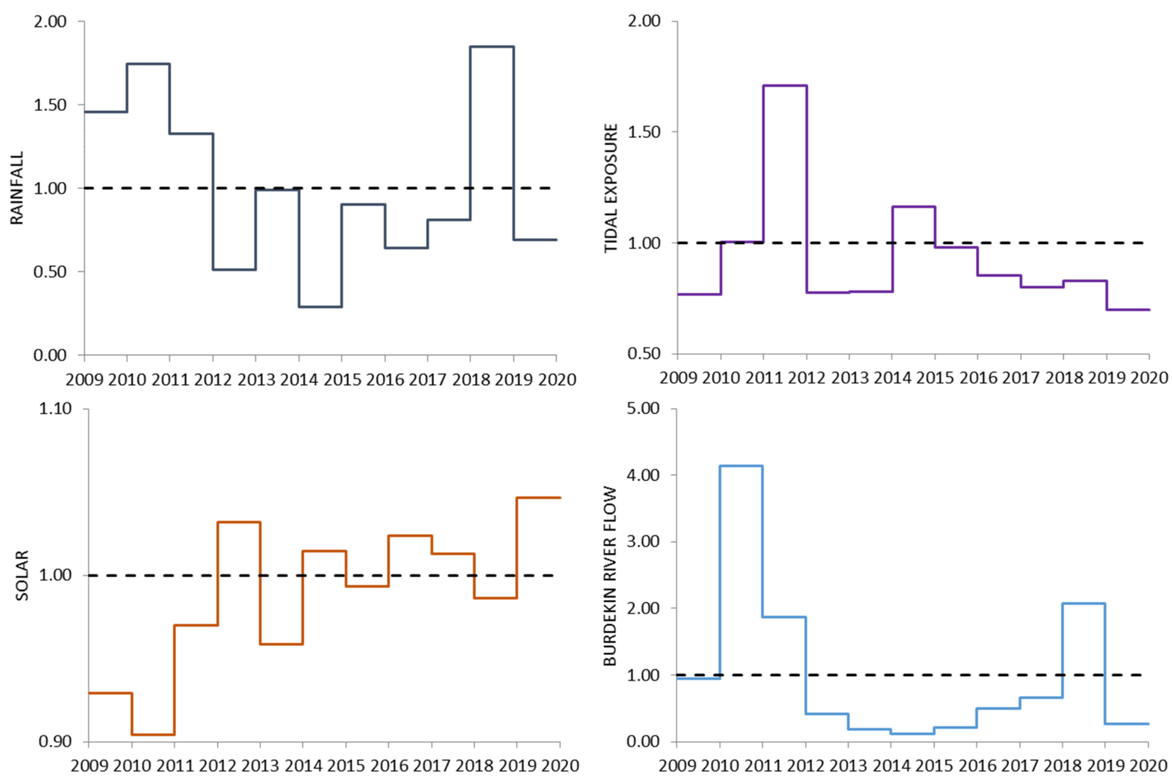

Figure 3. Change in climate variables as a proportion of the long-term average in Townsville. See Section 3.5 for detailed climate data for the Townsville region.

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1 INTRODUCTION

Seagrasses are one of the most productive marine habitats on earth and provide a variety of important ecosystem services worth 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 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 the Seagrass Ecology Group at 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 https://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 Seagrass Ecology Group 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) were selected for annual monitoring, with broader whole-of-port mapping occurring every other year (2007, 2008, 2013, 2016, 2019, 2020). 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 (Figure 1 & 5). 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 4). Information from the program also provides key input into the condition and trend of habitats for the Dry Tropics Partnership for Healthy Water reporting (https://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. Works for the project began in 2019 and will continue for two to three years.

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 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;
- Delineating changes to seagrass habitat due to project works, climate/weather events or natural background changes.

This report presents the results of the 14th year of the LTSMP, and the 2nd year of the CUSP. Results and discussions include:

- Maps of seagrass distribution, abundance and species composition at the whole-of-port scale that encompass both the CUSP and the LTSMP meadows;

- Maps of seagrass distribution, abundance and species composition at the CUSP and LTSMP meadow scale;
- Establish the pre-works base conditions for each of the CUSP monitoring meadows;
- Assessments of seagrass condition and change within the context of historical seagrass conditions;
- Discussion of the implications of monitoring results in relation to the overall health of the marine environment in Cleveland Bay and provide advice for management;
- Discussion of the observed changes in a regional and state-wide context;

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, 5). The majority of these meadows or meadow sections also form the CUSP (Table 1, Figure 5). 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 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 will form control and impact regions for the CU Project (Figure 5).

See Table 1 and Figure 5 below for the monitoring locations and the seagrass meadows that are monitored in each program, with some meadows common to each program.

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)
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)
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)

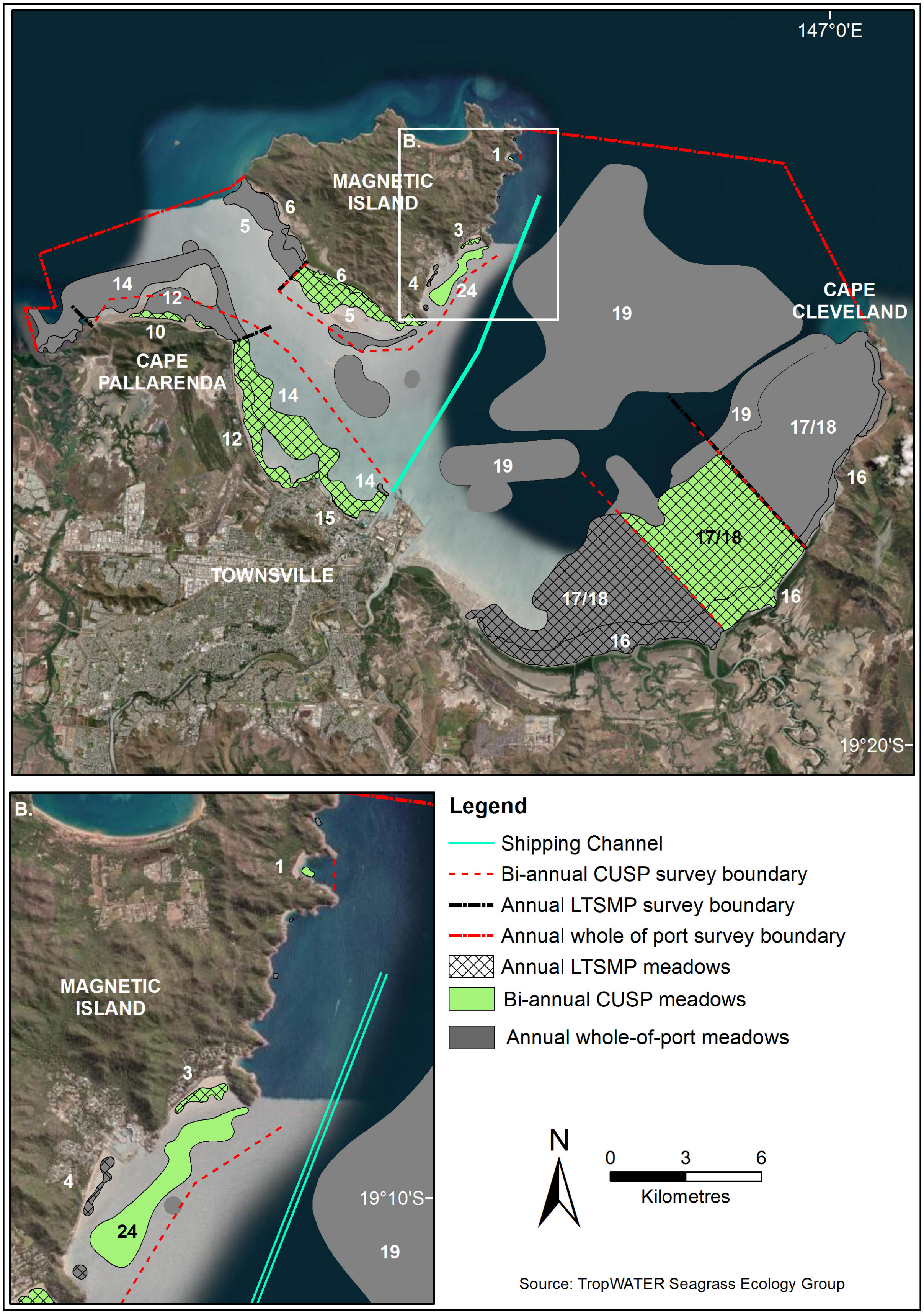


Figure 5. Location and survey extent of meadows assessed in annually surveyed LTSMP meadows, at the whole-of-port of port scale and the biannually surveyed CUSP.

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 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*: boat-based free diving or digital camera drop surveys – sites are sampled perpendicular to the shoreline approximately every 50-500 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.

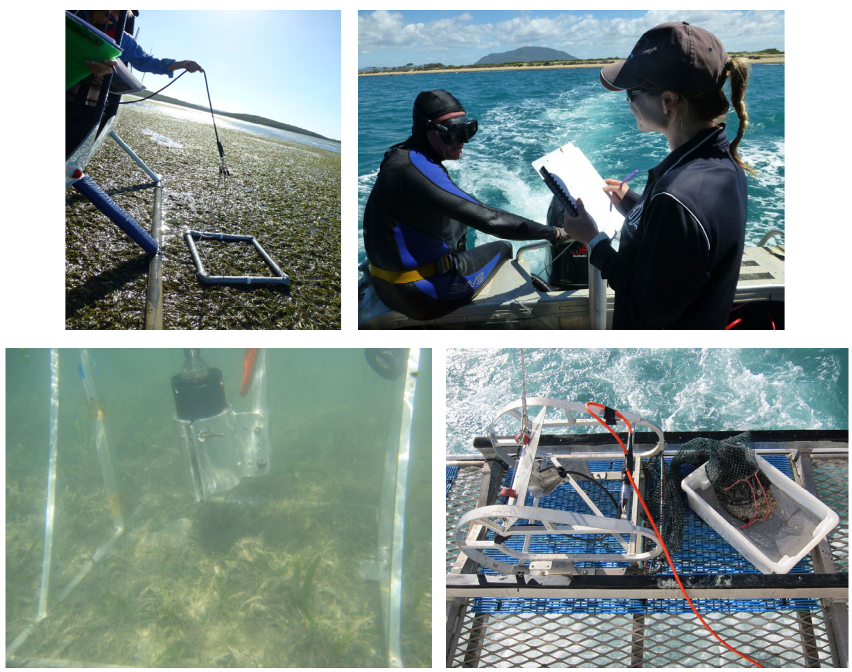


Figure 6. The different seagrass monitoring techniques: helicopter aerial surveillance, boat based free divers and digital, live feed camera systems.

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 (gDW 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 7).
    - 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

<u>*Isolated seagrass patches*</u>
The majority of area within the meadow consists of unvegetated sediment interspersed with isolated patches of seagrass.

<u>*Aggregated seagrass patches*</u>
The meadow consists of numerous seagrass patches but still features substantial gaps of unvegetated sediment within the boundary.

<u>*Continuous seagrass cover*</u>
The majority of meadow area consists of continuous seagrass cover with a few gaps of unvegetated sediment.

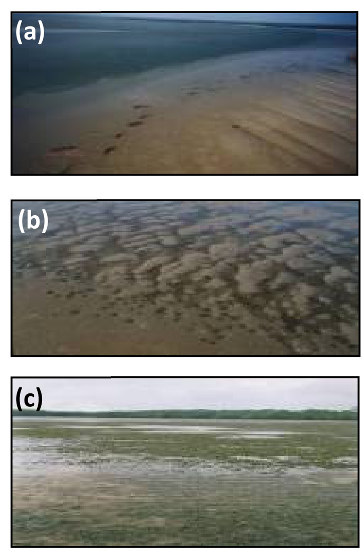


Figure 7. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover

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, 2020.

Mapping precision	Mapping methodology
3-20 m	• Intertidal meadows completely exposed or visible at low tide; • 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.
20-40 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 8). 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 (five years for Meadow 1 and four 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 8. 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 has not begun, 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 2020 two monitoring surveys were conducted in the Port of Townsville as part of both the LTSMP and CUSP:

- <u>April 2020</u>; post-wet season survey focusing on the coastal CUSP meadows only (Figure 5, 21A):
    - A total of 639 sites were assessed for seagrass condition with seagrass present at 61% of sites;
    - The CUSP seagrass meadow footprint covered 3,420 ± 415;
    - Deep-water meadows (e.g. meadow 19) are not surveyed in the post-wet season survey.

- <u>September-October 2020</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 5, 21B, 24):
    - A total of 1,351 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 14,511 ± 1,895 ha of which the:
        - LTSMP meadows covered 6,938 ± 592 ha
        - CUSP meadows covered 4,075 ± 403 ha.
        - The deep-water *Halophila* meadow (Meadow 19) covered 2,664 ± 561 ha.

Ten seagrass species have historically been identified within the Townsville region. With the exception of *Syringodium isoetifolium*, which was last found in the port in 2015, all species (nine) were present in the 2020 surveys (Figure 9).

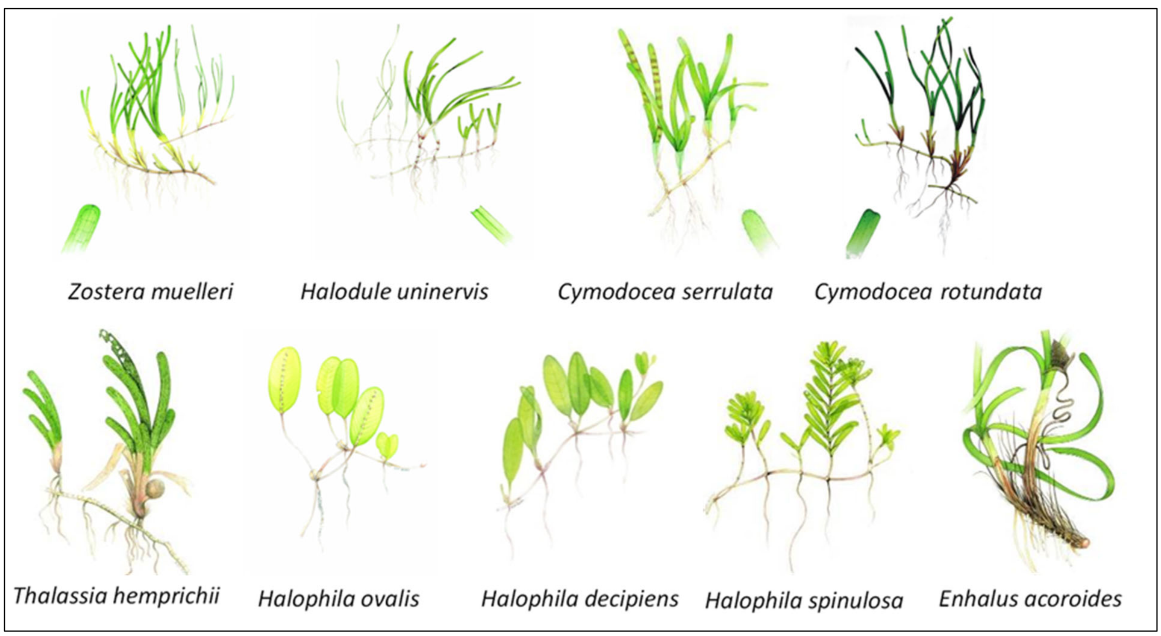


Figure 9. Seagrass species present within the Townsville area in 2020.

3.2 Seagrass condition in the LTSMP and CUSP monitoring meadows

3.2.1 Seagrass distribution, abundance and composition

In 2020 the overall condition of LTSMP and CUSP meadows was good (Table 5). An increase in condition for the majority of meadows from 2019. All three condition indicators (seagrass biomass, area and species composition) were graded as satisfactory or better for all monitoring meadows in both programs (Table 5).

Overall, seagrass area in both LTSMP and CUSP monitoring meadows were of satisfactory or better condition (Table 5). Total meadow area expanded by 9% across LTSMP meadows (Figure 10) and 6% in CUSP meadows from peak season 2019 to peak season 2020. Individual area of monitoring meadows ranged from 1.74 ha in the subtidal *H. uninervis* Florence Bay meadow (Meadow 1; Figure 11) to 4,368 ha, for the subtidal Cleveland Bay meadow (Meadow 17/18; Figure 23).

The biggest spatial increases between 2019 and 2020 included:

- The subtidal *H. spinulosa* meadow east of Nelly Bay (CUSP meadow 24) increased to its largest recorded area so far; 120ha (Figure 16);
- The intertidal *Z. muelleri* at Cockle Bay (Meadow 6) increased by 100% between years (Figure 15);
- LTSMP Meadow 4 at Nelly Bay, and Meadow 17/18 in Cleveland Bay were at their largest extent since 2009 and 2007 respectively (Figures 13 and 23).

Some meadows did decline between years, but these declines were not large enough for meadows to be classed as less than satisfactory (Table 5).

Seagrass biomass in all monitoring meadows was in satisfactory or better condition in 2020 (Table 5). Seagrass meadow biomass increased in all monitoring meadows between 2019 and 2020. For most meadows, the biomass more than doubled. Above-ground biomass in monitoring meadows ranged from 1.4 ± 0.20 g DW m^{-2} in the intertidal/shallow subtidal *H. uninervis* meadow along the Strand (Meadow 15) to 28.11 ± 2.61 g DW m^{-2} in the intertidal *Z. muelleri* meadow in Cleveland Bay (CUSP section of Meadow 16).

The species composition of all monitoring meadows was in good or very good condition (Table 5). Species composition ranged from monospecific patches of seagrass to multispecific (up to six species) meadows. Seagrass meadows mostly consisted of aggregated patches or continuous cover of seagrass, with a light to moderate cover of seagrass.

The deep-water meadow (Meadow 19) that is surveyed annually as part of the whole-of-port surveys decreased in area between 2019 and 2020; 8,023 ± 1343 ha to 2,666 ± 561 ha, and became fragmented (Figures 27, 28). Such large shifts in deep-water seagrass is not unusual.

Dugong were observed while conducting field work, and dugong feeding trails were recorded at 49 survey sites throughout the coastal survey area. This suggests ongoing broad use of the available seagrass habitat as a food source for megafauna.

Table 5. Condition scores for seagrass indicators (biomass, area and species composition) for the LTSMP and CUSP meadows; September/October 2020 survey.

Meadow	Region	LTSMP/CUSP	Biomass	Area	Species Composition	LTSMP Overall Meadow Score	CUSP Overall Meadow Score
1	Magnetic Island	CUSP	0.85	0.91	1.00		0.85
3		LTSMP & CUSP	0.67	0.87	1.00	0.67	0.67
4		LTSMP	0.82	0.95	1.00	0.82	
5		LTSMP & CUSP	0.70	0.77	0.99	0.70	0.70
6		LTSMP & CUSP	0.70	0.75	0.91	0.70	0.70
24		CUSP	0.52	0.95	0.86		0.52
10	Cape Pallarenda - Strand	LTSMP & CUSP	0.84	0.50	0.78	0.50	0.50
12		LTSMP & CUSP	0.85	0.99	0.83	0.83	0.83
14		LTSMP & CUSP	0.68	0.71	0.93	0.68	0.68
15		LTSMP	0.74	0.67	0.92	0.67	
16	Cleveland Bay	LTSMP	0.78	0.80	0.93	0.78	
16 (CUSP meadow section)		CUSP	0.85	0.92	0.97		0.85
17/18		LTSMP	0.75	0.95	0.98	0.75	
17/18 (CUSP meadow section)		CUSP	0.79	0.89	0.98		0.79
LTSMP - Overall Score for the Port of Townsville 2020						**0.71**	
CUSP - Overall Score for the Port of Townsville 2020							**0.72**

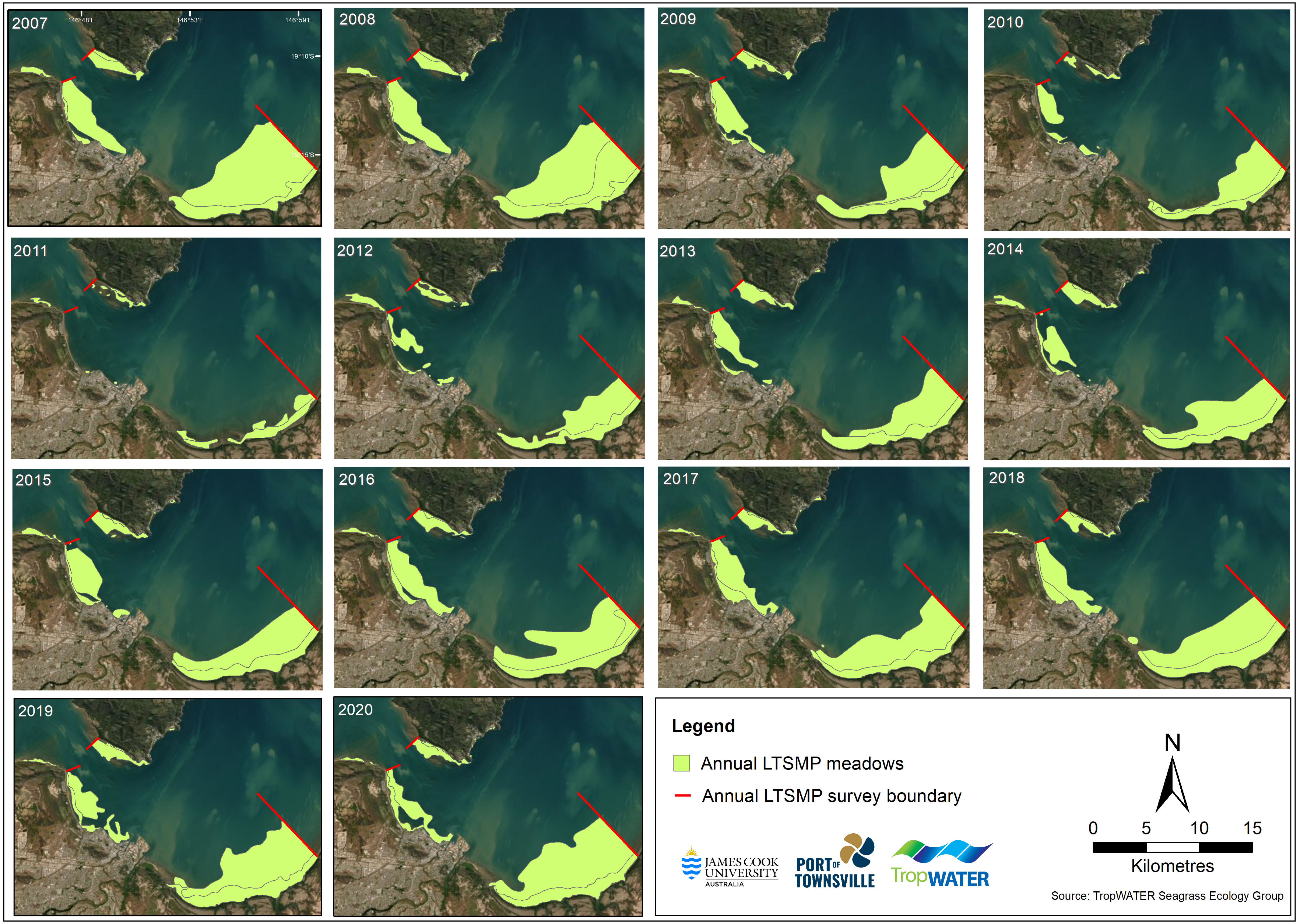


Figure 10. Long-term Seagrass monitoring meadow location and spatial extent from 2007 – 2020.

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 5, 11-16). These meadows range from intertidal to deep-water (>8m below MSL) meadows.

Above-ground biomass in all Magnetic Island meadows increased between 2019 and 2020. Individual meadow biomass ranged from 1.62 ± 0.24 g DW m^{-2} to 10.70 ± 1.4 g DW m^{-2} at the Island. The greatest change in condition was in the intertidal *H. uninervis* Meadow in Geoffrey Bay; Meadow 3. This meadow was in poor condition in 2019, due to a poor biomass score (Figure 12). Between 2019 and 2020 the meadow substantially increased in biomass, increasing to good condition (Figure 12).

The area of all monitoring meadows around Magnetic Island was rated as good or very good compared to their historical baselines (Table 5; Figures 11-16). The largest spatial increase was the expansion of the subtidal Geoffrey Bay *H. spinulosa* meadow (Meadow 24) to its largest recorded area since monitoring began in 2007 (Figure 16). In 2019, this meadow only occupied the Geoffrey Bay area. In 2020, the meadow expanded from Geoffrey Bay down to Nelly Bay (Figure 16).

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 4).

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 17-20). All meadows in this area were of satisfactory or better condition (Table 5).

Seagrass above-ground biomass increased in all four meadows between 2019 and 2020. Biomass increases were significant enough to change the condition score for meadows 12 and 14 (predominantly subtidal meadows) from satisfactory in 2019 to good or better condition in 2020 (Table 5; Figures 18 and 19). This condition change ended three consecutive years of biomass decline in the subtidal *H. spinulosa* meadow (14) (Figure 19).

The distribution of the intertidal *Z. muelleri* meadow (10) has remained relatively similar since 2017 and was rated as satisfactory condition (Table 5; Figure 17). This intertidal meadow underwent significant losses between 2014 and 2017, primarily at the outer edge and eastern end (Cape Pallarenda) of the meadow.

Species composition for all four meadows was in good or very good condition in 2020 (Table 5). Species composition has been relatively stable at the inshore *H. uninervis* meadow (12) (Figure 18). In contrast, species composition has varied in the subtidal *H. spinulosa* meadow (14). Since 2015, *H. uninervis* has contributed a higher proportion of the species mix in the meadow (Figure 18; Appendix 4). *Halodule uninervis* is considered a more persistent higher light requiring species to *H. spinulosa*, traditionally the dominant species in the meadow, and has been the dominant species in the meadow for the last two years.

For the intertidal *Z. muelleri* meadow (10) at Shelley Beach, species composition has been in good or very good condition since 2017. It is worth noting that there was a decrease in the presence of *Z. muelleri*, the dominant species in the meadow, in 2020, and an equivalent increase in less persistent species (Figure 17; Appendix 4). This is the first time species composition has not been in 'very good' condition since 2017, but is still within the historical range (Figure 17; Appendix 4).

3.2.4 Cleveland Bay seagrass meadows

There are two monitoring meadows in Cleveland Bay; an intertidal *Z. muelleri* meadow (16) and the shallow subtidal *H. uninervis* meadow (Figures 21-24). These meadows are the largest coastal meadows in Townsville (Figure 28). For the CUSP, only a section of these large meadows is monitored biannually. Both meadows were in good or better condition in 2020 (Table 5; Figures 21, 23).

At the intertidal *Z. muelleri* meadow (16), above-ground biomass declined in 2019 to below the long-term average to a satisfactory condition (Figure 21, 22). In 2020, biomass increased to above the long-term average to be in good/very good condition again, similar to previous years.

The area of this meadow has remained relatively constant since 2012 with a significant spatial footprint near to or above the long-term average (Figure 21, 22). Species composition has been in very good condition since 2014 (Figure 21, 22; Appendix 4).

At the adjacent subtidal Cleveland Bay meadow (meadow 17/18), above-ground biomass rebounded to be in good condition in 2020 (Table 5, Figure 23, 24). The area of this meadow has also been increasing over the last couple of years to recording one of the highest areas in the program in 2020 since 2007 (Figure 23, 24). Much of this increase has come from the meadow expanding at the deeper margins. In 2018 the deepest seagrass was found in this meadow was 4.26m (below MSL); 2019 it was 4.69m, and in 2020 seagrass was found to 4.98m (below MSL). The relative proportion of *H. uninervis* and *C. serrulata* has remained relatively stable in this meadow since 2016 (Figure 23, 24; Appendix 4). *Halodule uninervis* accounts for around 50% of the meadow biomass.

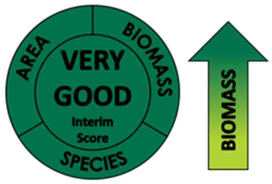
3.2.5 Deep water seagrass meadows

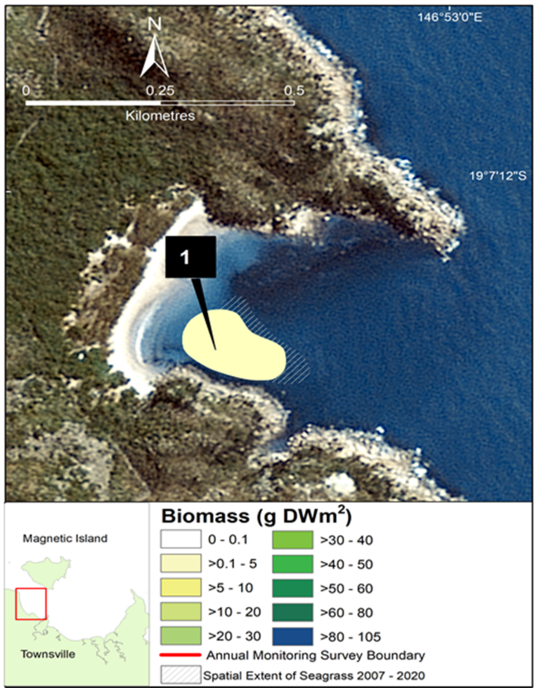
Whole-of-port surveys that target deep-water seagrasses in Townsville have been conducted in 2007, 2008, 2013, 2016, May and October 2019 and October 2020 (Figure 27, 28). In 2019, the extent of this highly variable ephemeral deep-water seagrass meadow was the largest recorded since 2008 (Figure 28). In 2020, this area decreased by nearly 67%, receding from 8,023 ± 1343 ha to 2,666 ± 561 ha, and became fragmented (Figures 27, 28). In 2019 seagrass was recorded to 14.4m (below MSL), whereas in 2020 seagrass was only recorded to 12.7m (below MSL).

Three species of seagrass was found in the 2020 deep-water meadow: *H. decipiens*, *H. spinulosa* and *H. uninervis*.

Meadow 1 – **CUSP** monitoring meadow
Shallow subtidal meadow
Halodule uninervis

*Baseline means will continue to be adjusted as more years of data are collected

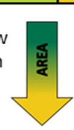




Condition index

	A Very Good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above 40% below	40-70% below	70-90% below	>90% below
Area (stable)	>10% above	10% above 10% below	10-30% below	30-50% below	>50% below
Species (stable single)	> 0% above	0-20% below	20-50% below	50-80% below	>80% below

Decrease below threshold from the previous year



Increase above threshold from the previous year

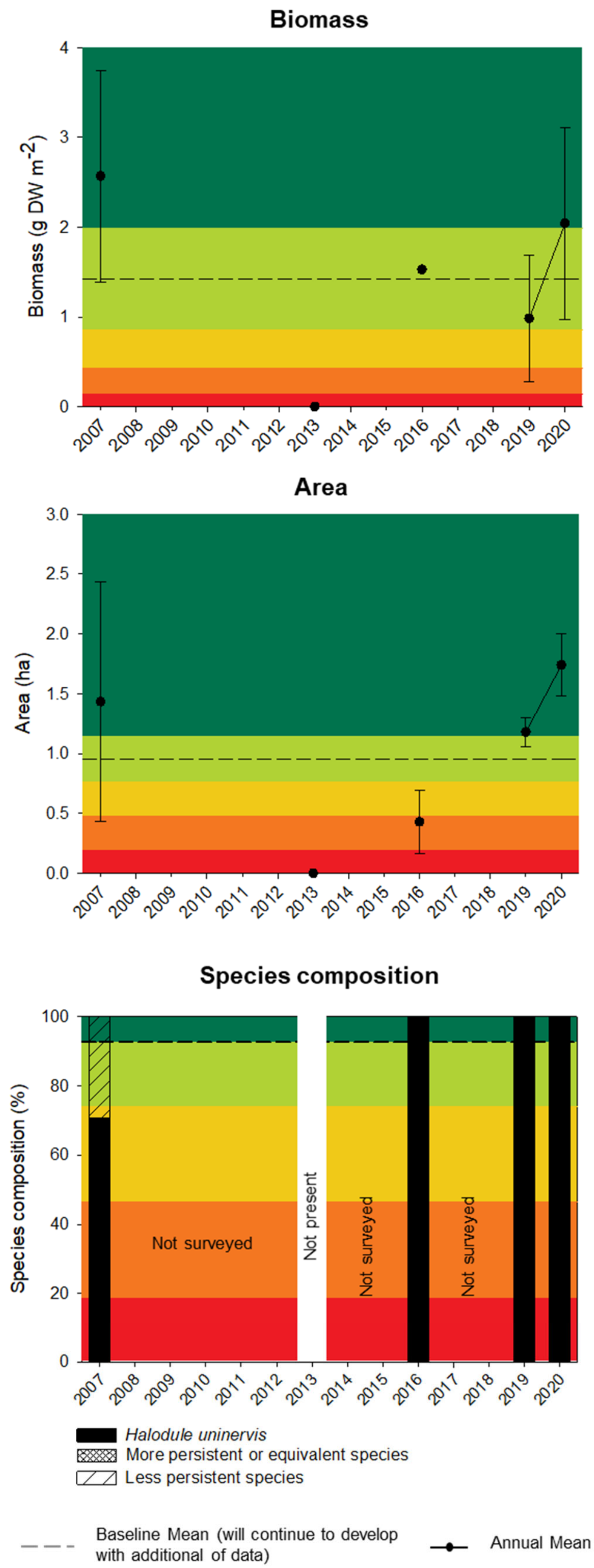


Figure 11. Changes in meadow area, biomass and species composition for seagrass Meadow 1 at Magnetic Island, 2007 – 2020. (biomass error bars = SE; area error bars = "R" reliability estimate).

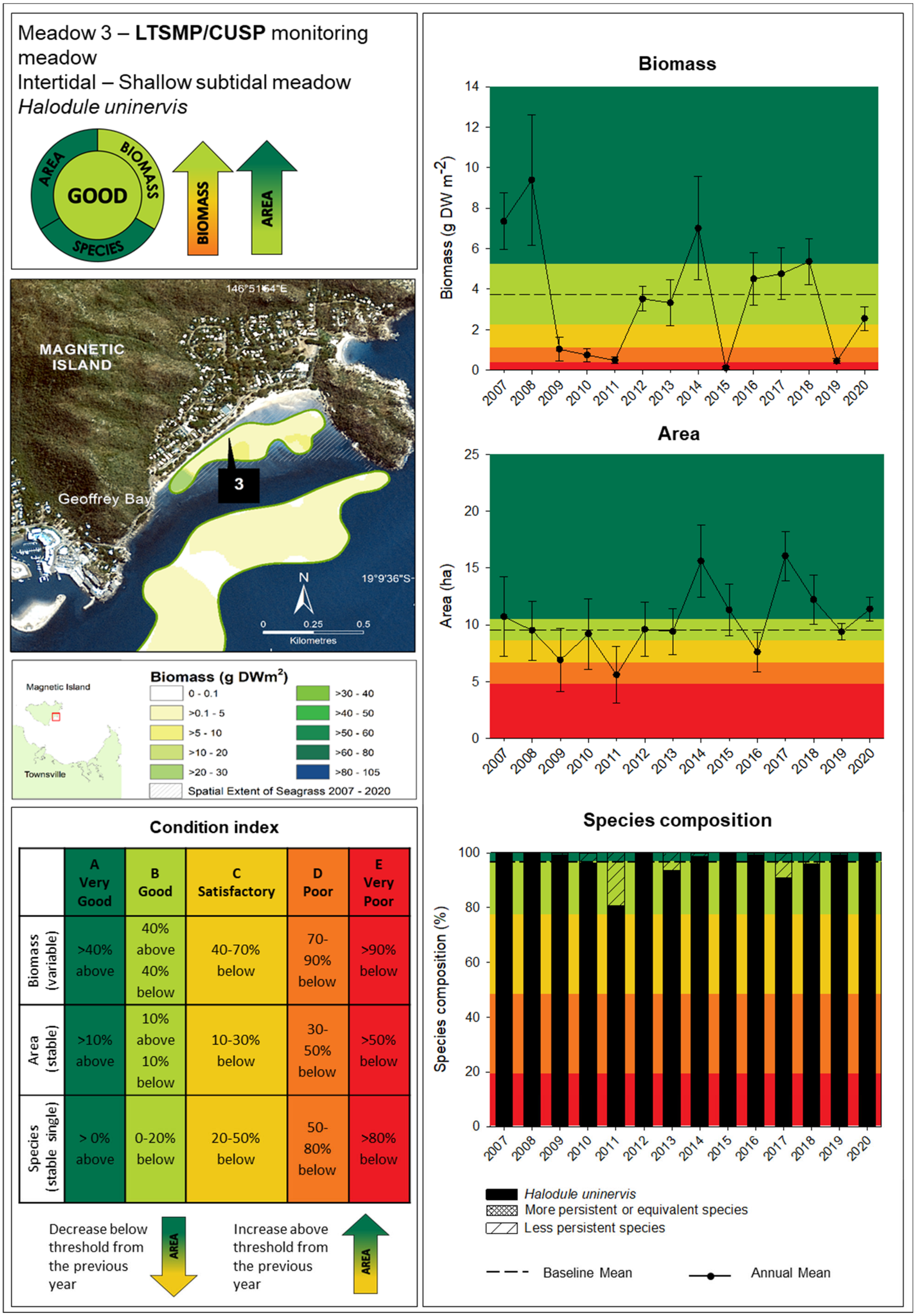
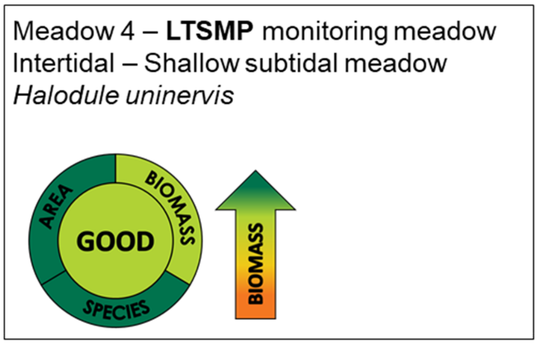
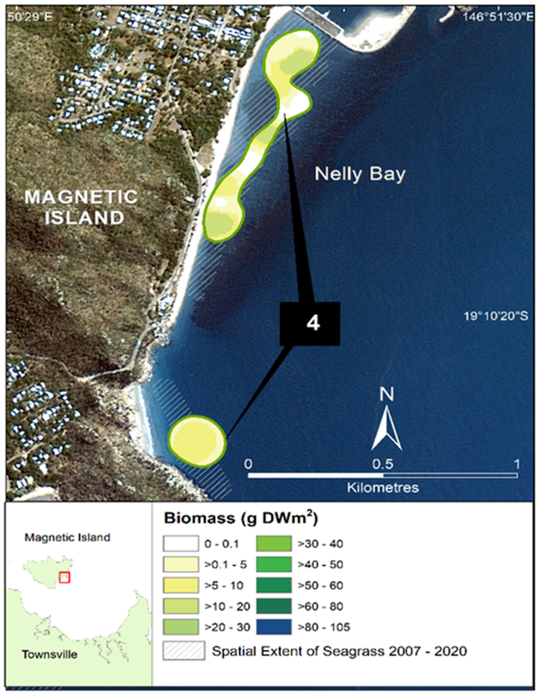


Figure 12. Changes in meadow area, biomass and species composition for seagrass Meadow 3 at Magnetic Island, 2007 – 2020. (biomass error bars = SE; area error bars = "R" reliability estimate).





Condition index

	A Very Good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above 40% below	40-70% below	70-90% below	>90% below
Area (stable)	>10% above	10% above 10% below	10-30% below	30-50% below	>50% below
Species (stable single)	> 0% above	0-20% below	20-50% below	50-80% below	>80% below

Decrease below threshold from the previous year (AREA)

Increase above threshold from the previous year (AREA)

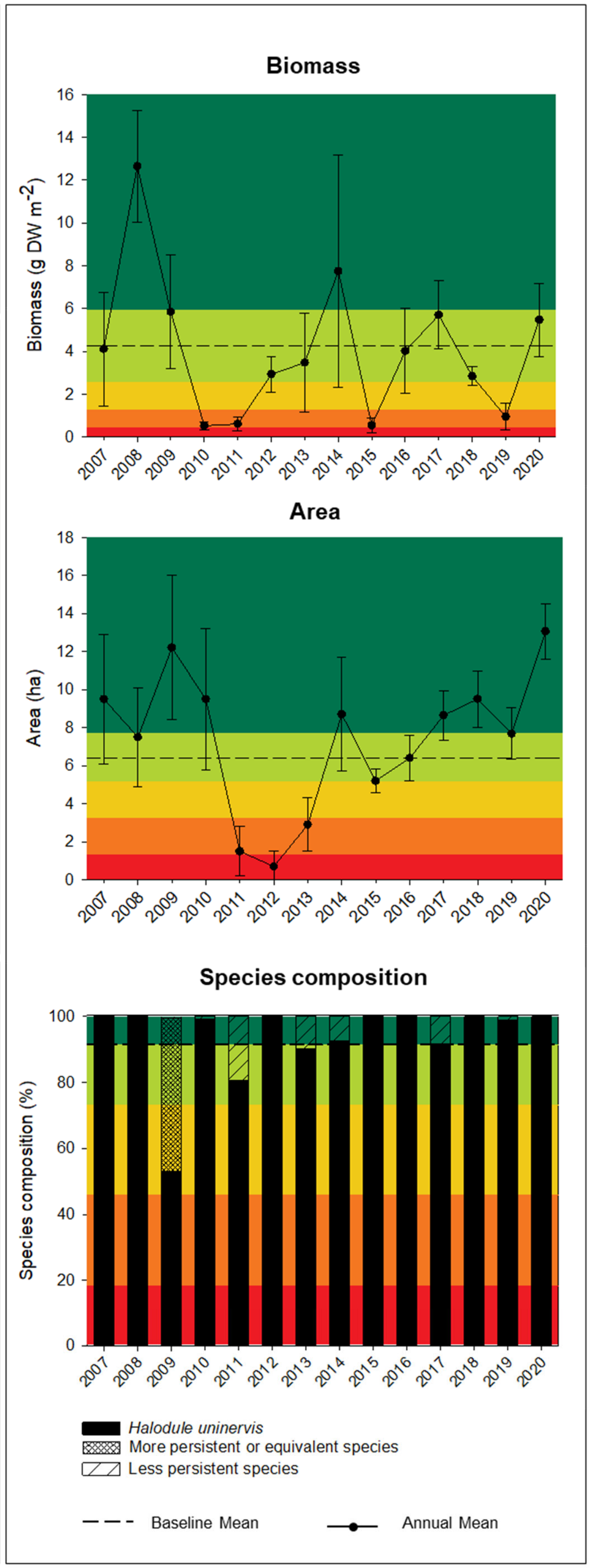
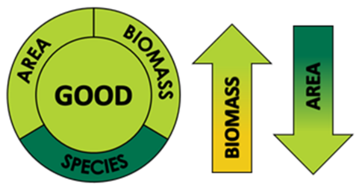
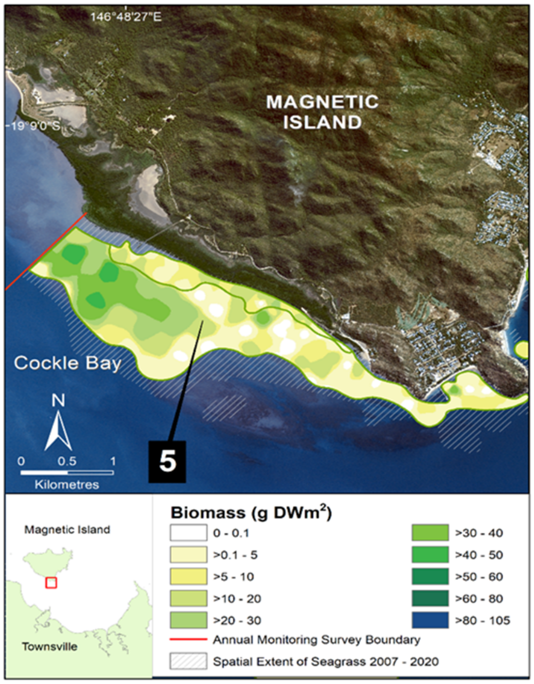


Figure 13. Changes in meadow area, biomass and species composition for LTSMP seagrass Meadow 4 at the Strand, 2007 – 2020. (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadow 5 – **LTSMP/CUSP** monitoring meadow
Intertidal – Shallow subtidal meadow
Halodule uninervis





Condition index

	A Very Good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above 40% below	40-70% below	70-90% below	>90% below
Area (stable)	>10% above	10% above 10% below	10-30% below	30-50% below	>50% below
Species (stable single)	> 0% above	0-20% below	20-50% below	50-80% below	>80% below

Decrease below threshold from the previous year (AREA)

Increase above threshold from the previous year (AREA)

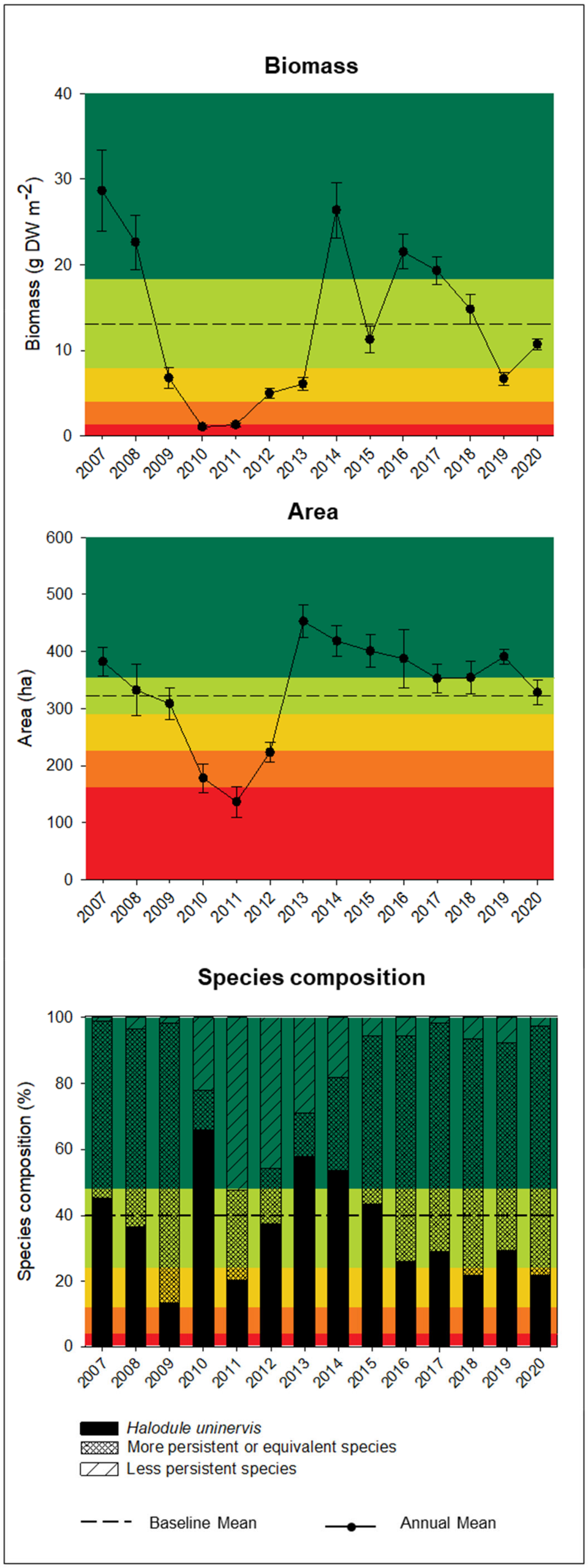
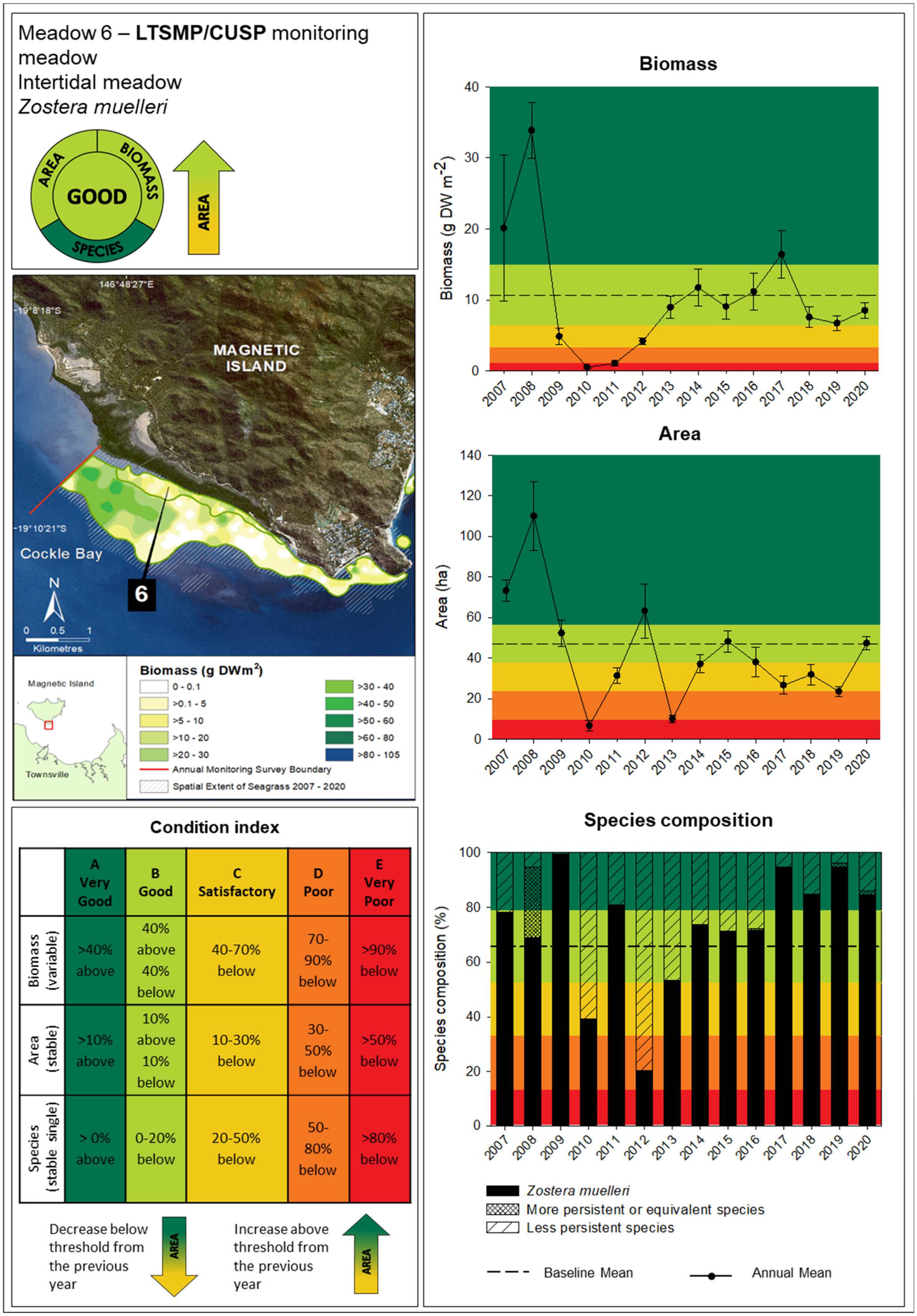
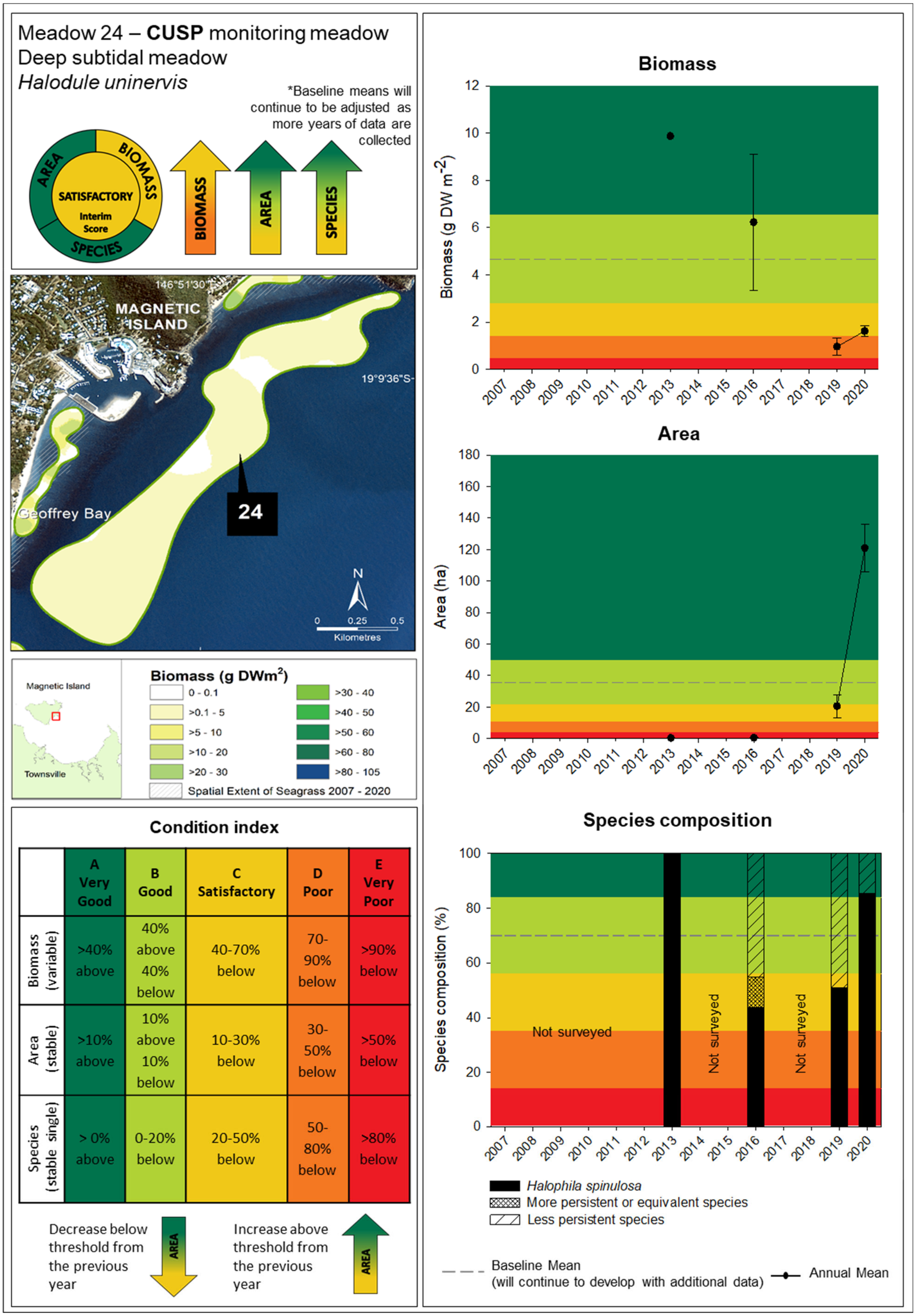


Figure 14. Changes in meadow area, biomass and species composition for seagrass Meadow 5 at Magnetic Island, 2007- 2020. (biomass error bars = SE; area error bars = “R” reliability estimate).



	A Very Good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above 40% below	40-70% below	70-90% below	>90% below
Area (stable)	>10% above	10% above 10% below	10-30% below	30-50% below	>50% below
Species (stable single)	> 0% above	0-20% below	20-50% below	50-80% below	>80% below

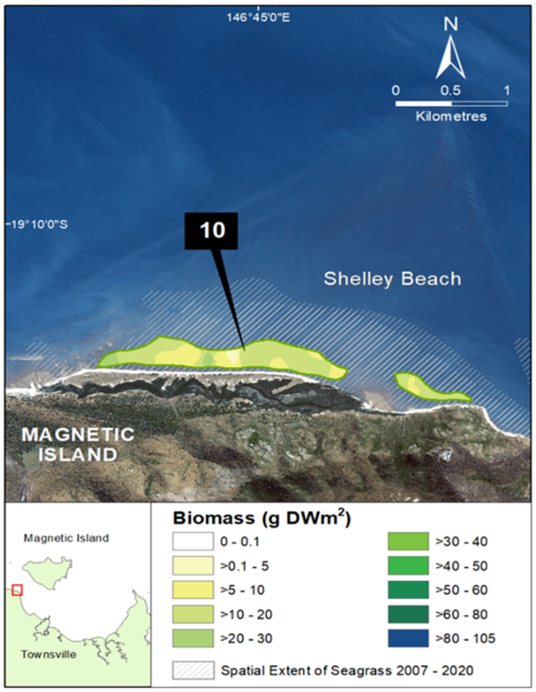
Figure 15. Changes in meadow area, biomass and species composition for seagrass Meadow 6 at Magnetic Island, 2007 – 2020. (biomass error bars = SE; area error bars = "R" reliability estimate).



	A Very Good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above 40% below	40-70% below	70-90% below	>90% below
Area (stable)	>10% above	10% above 10% below	10-30% below	30-50% below	>50% below
Species (stable single)	> 0% above	0-20% below	20-50% below	50-80% below	>80% below

Figure 16. Changes in meadow area, biomass and species composition for seagrass Meadow 24 in Geoffrey Bay, 2007 – 2020. (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadow 10 – **LTSMP/CUSP** monitoring meadow
Intertidal meadow
Zostera muelleri



Condition index

	A Very Good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above 40% below	40-70% below	70-90% below	>90% below
Area (stable)	>10% above	10% above 10% below	10-30% below	30-50% below	>50% below
Species (stable single)	> 0% above	0-20% below	20-50% below	50-80% below	>80% below

Decrease below threshold from the previous year — AREA

Increase above threshold from the previous year — AREA

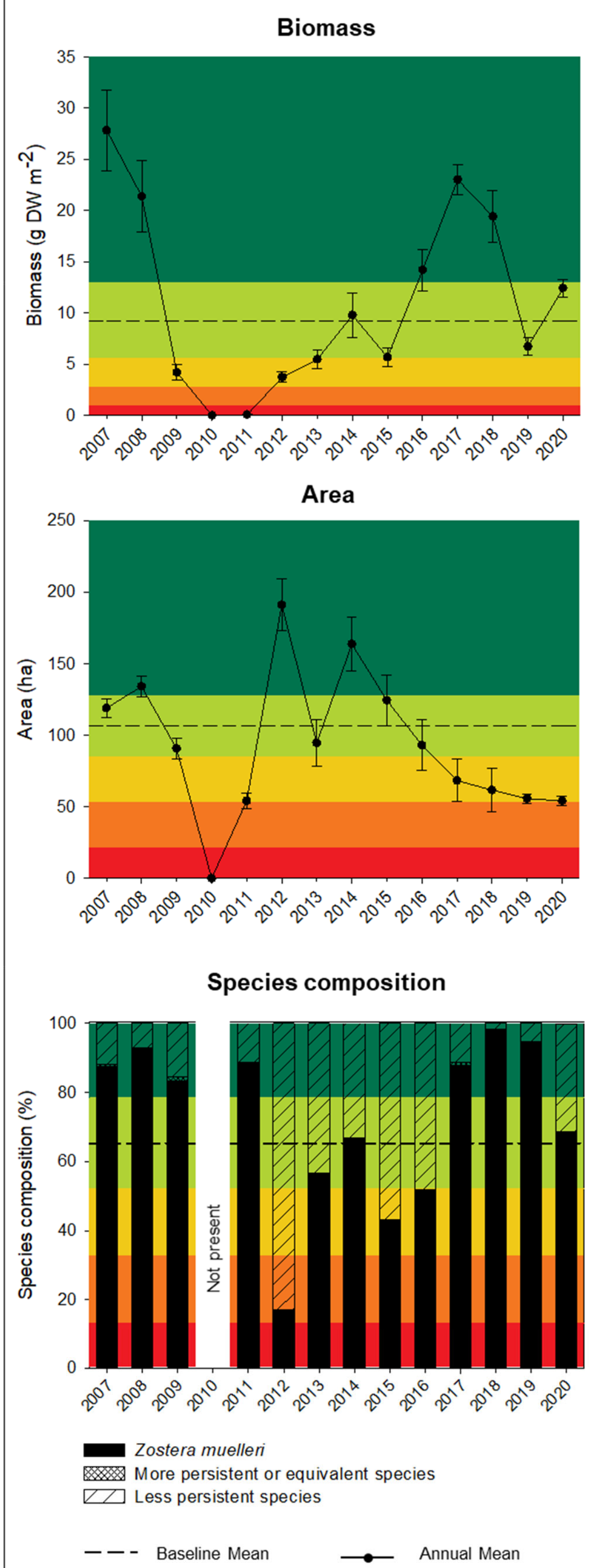


Figure 17. Changes in meadow area, biomass and species composition for seagrass Meadow 10 in Shelley Beach, 2007 – 2020. (biomass error bars = SE; area error bars = "R" reliability estimate).

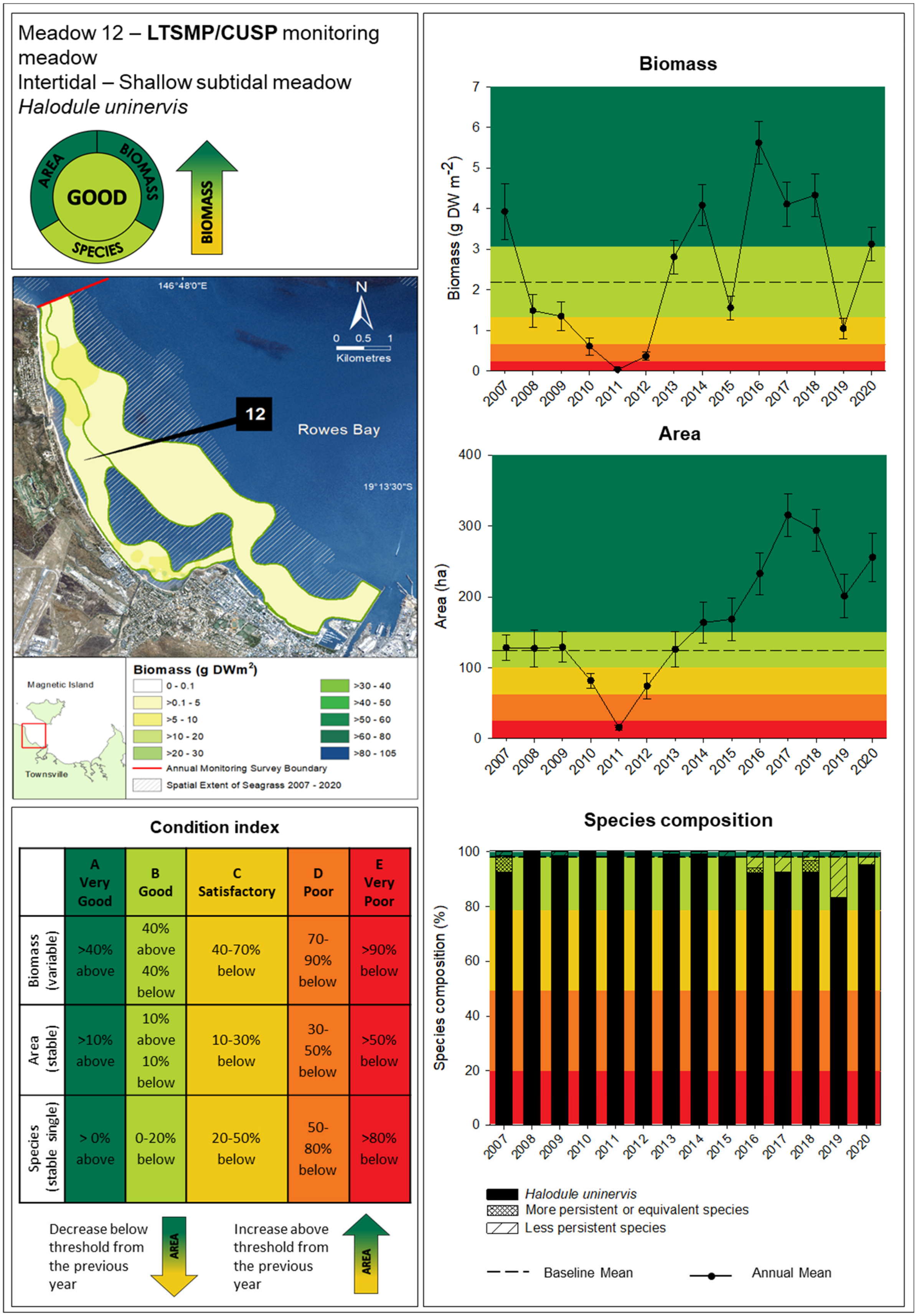


Figure 18. Changes in meadow area, biomass and species composition for seagrass Meadow 12, in Rowes Bay, 2007 – 2020. (biomass error bars = SE; area error bars = "R" reliability estimate).

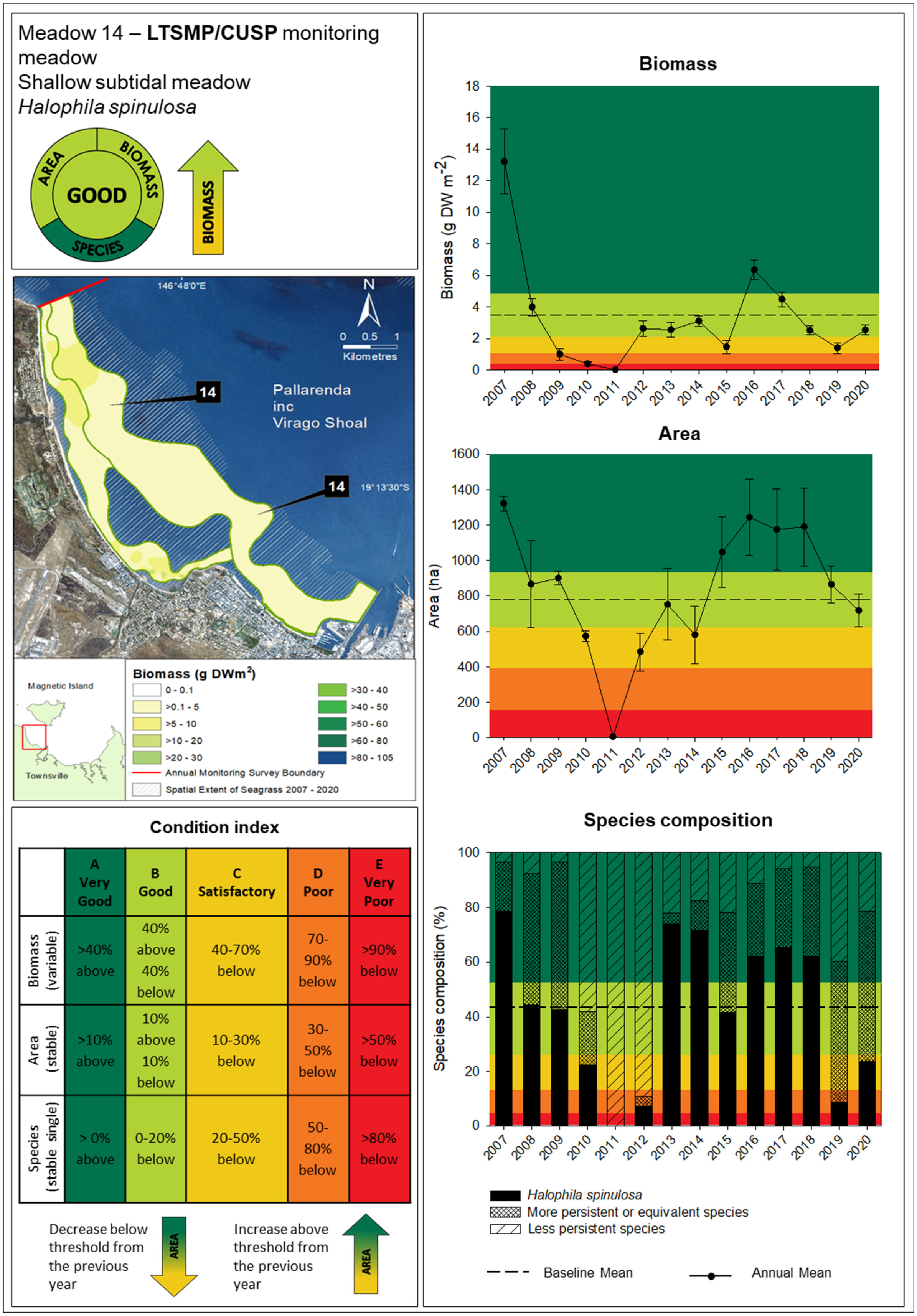


Figure 19. Changes in meadow area, biomass and species composition for seagrass Meadow 14 at Pallarenda, Virago Shoal and the Strand, 2007 – 2020. (biomass error bars = SE; area error bars = “R” reliability estimate).

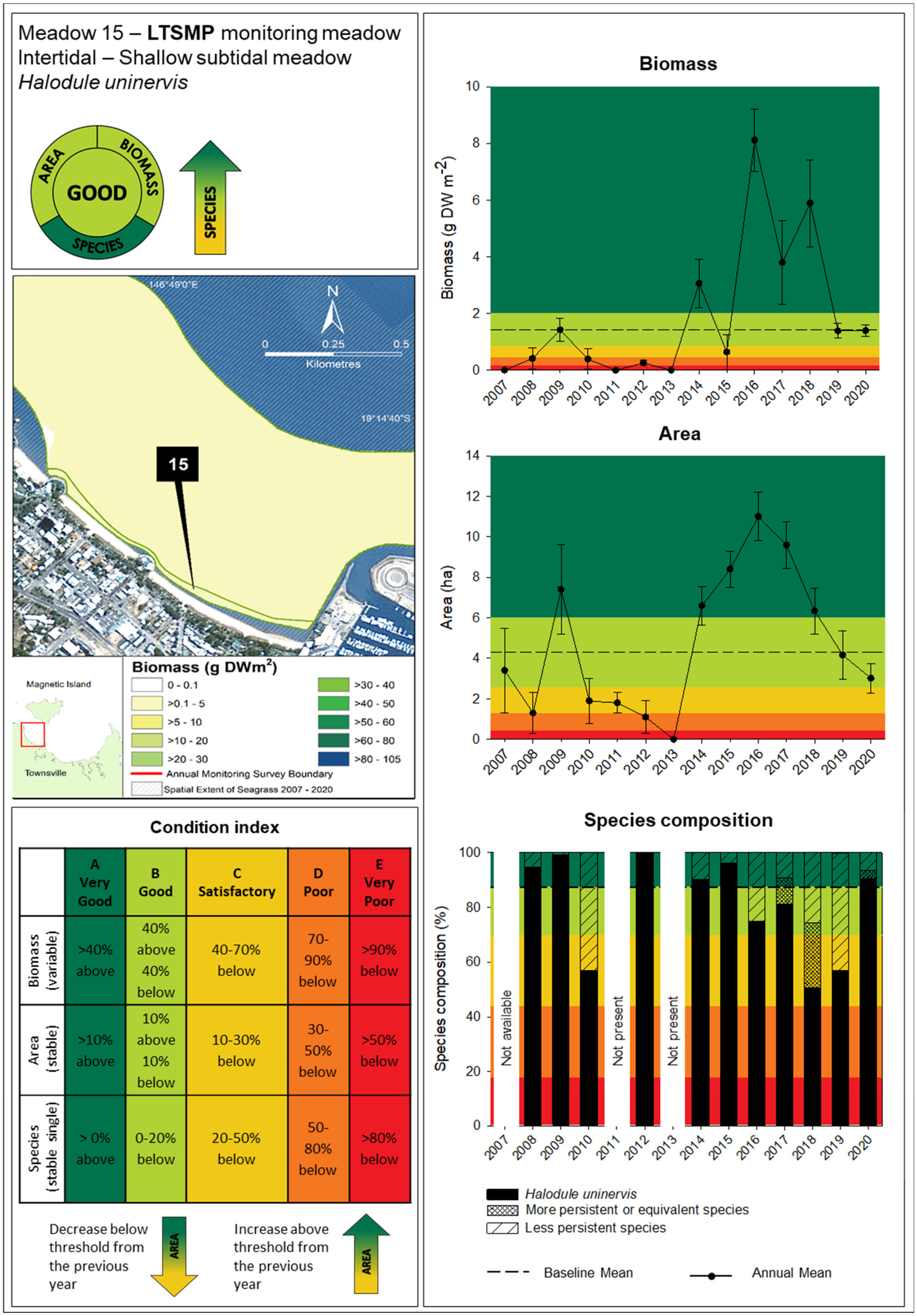


Figure 20. Changes in meadow area, biomass and species composition for LTSMP seagrass Meadow 15 at the Strand, 2007 – 2020. (biomass error bars = SE; area error bars = "R" reliability estimate

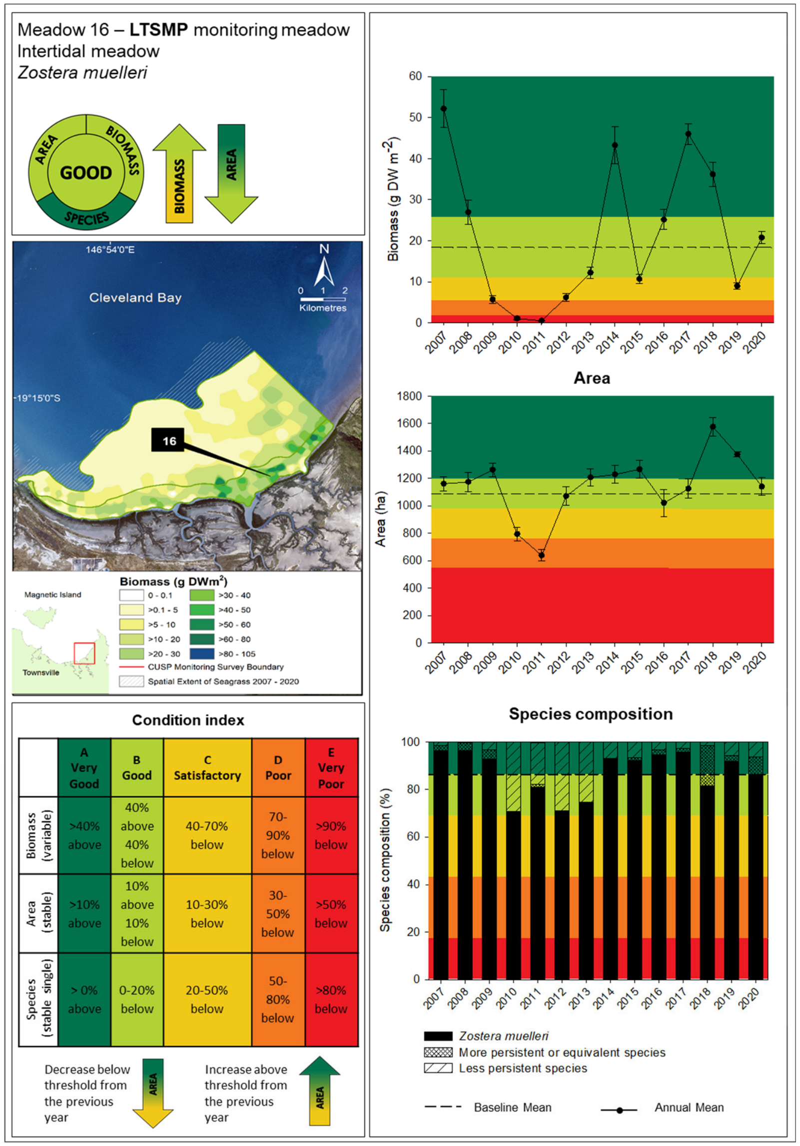


Figure 21. Changes in meadow area, biomass and species composition for LTSMP seagrass Meadow 16 in Cleveland Bay, 2007 – 2020. (biomass error bars = SE; area error bars = "R" reliability estimate).

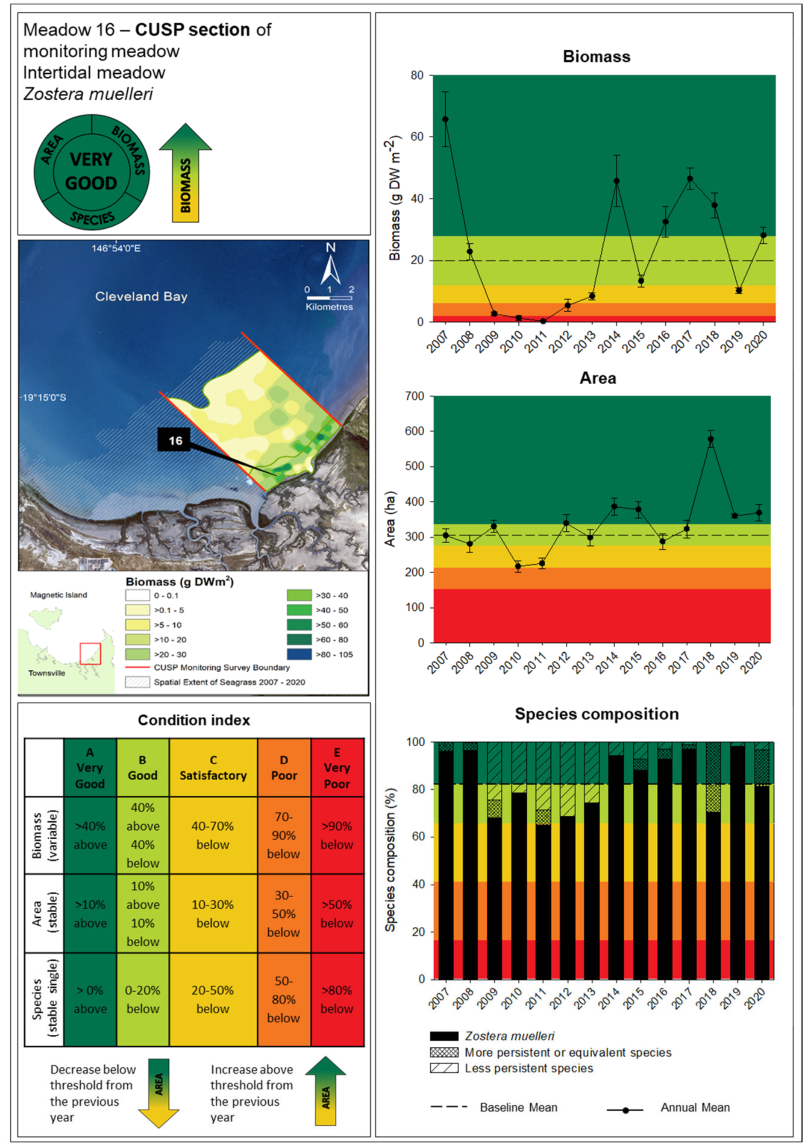


Figure 22. Changes in meadow area, biomass and species composition for CUSP seagrass Meadow 16 in Cleveland Bay, 2007 – 2020. (biomass error bars = SE; area error bars = "R" reliability estimate).

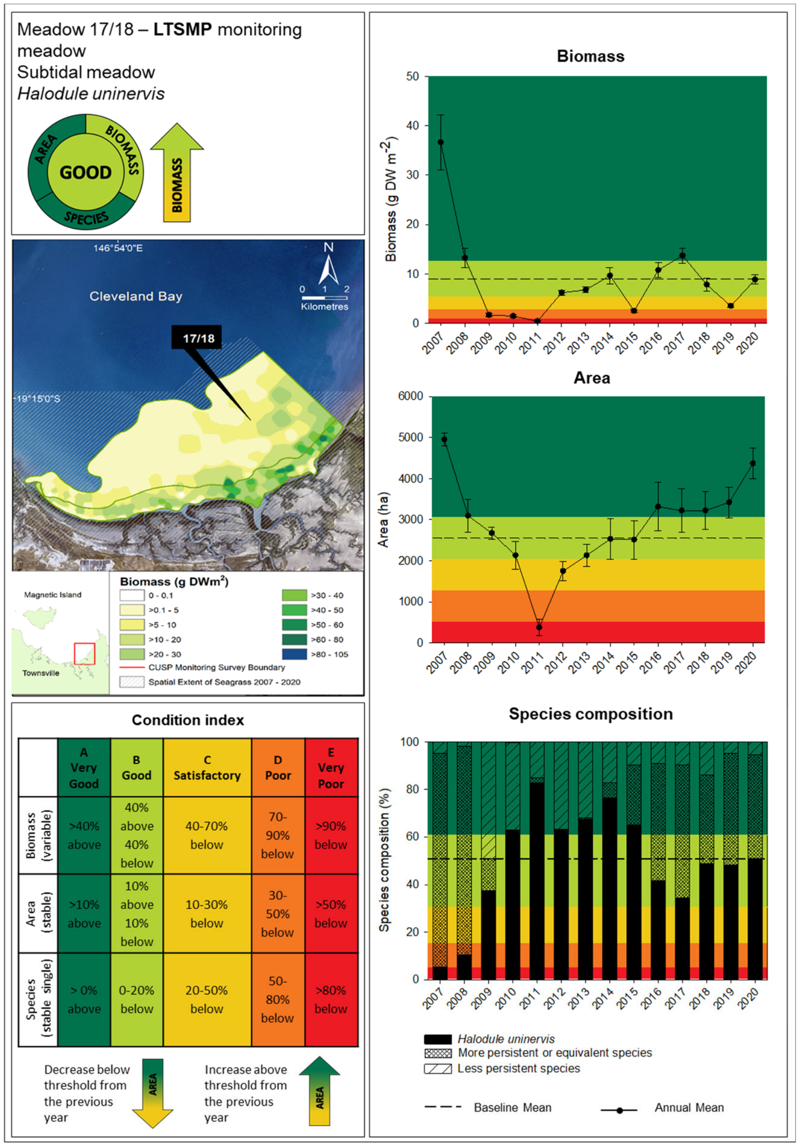


Figure 23. Changes in meadow area, biomass and species composition for LTSMP seagrass Meadow 17/18 in Cleveland Bay, 2007 – 2020. (biomass error bars = SE; area error bars = "R" reliability estimate).

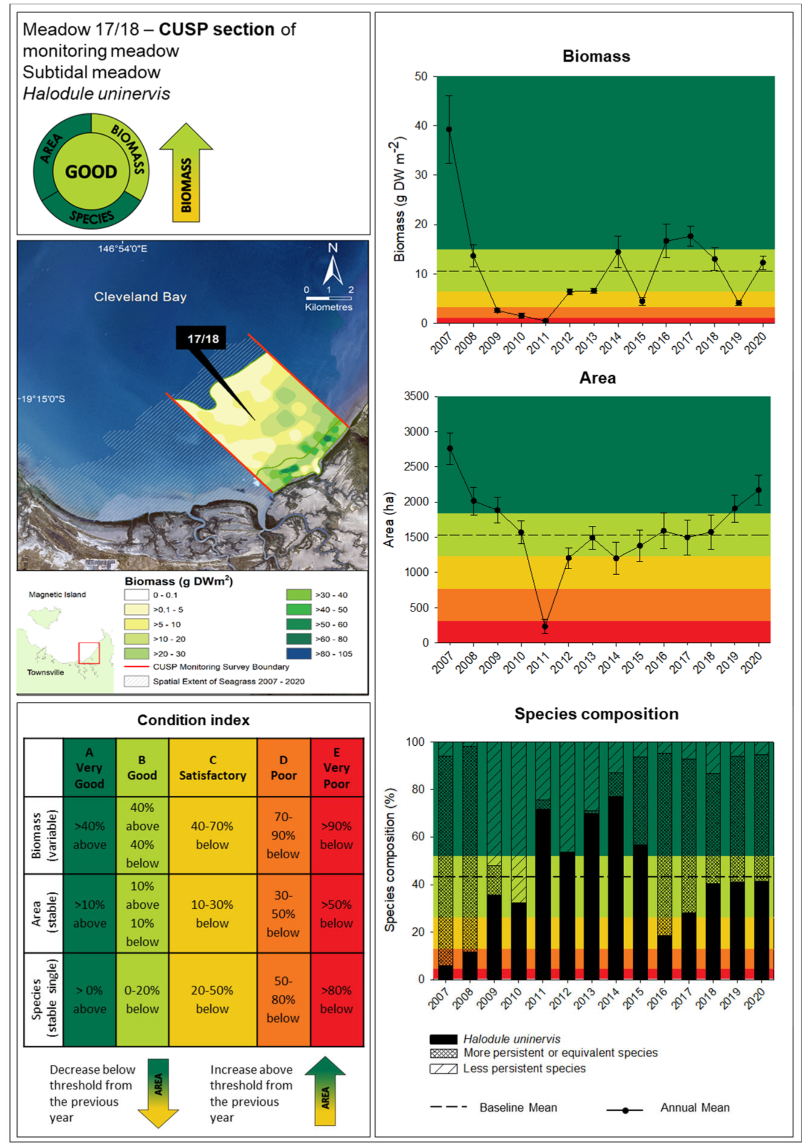


Figure 24. Changes in meadow area, biomass and species composition for CUSP seagrass Meadow 17/18 in Cleveland Bay, 2007 – 2020. (biomass error bars = SE; area error bars = "R" reliability estimate).

3.3 Seasonal comparisons of Townville seagrass

Seagrass meadows that form the CUSP are surveyed biannually (Table 1). Biannual surveys help determine if there is seasonality in seagrass meadows. Seagrass biomass and area typically increase from May, when tropical Queensland seagrasses typically show diminished growth (their “low season”), to a peak in late spring (i.e. growing season). The seasonal differences tend to be more pronounced in deep-water seagrass meadows and their species. Queensland deep-water seagrass meadows, predominantly comprised of *Halophila* species, can be completely absent during the low season due to their life history strategy; germinating and flourishing for a brief period during the growing season (Chartrand et al. 2017; York et al. 2015).

In Townsville, meadow area increased by 19% from April to October in 2020 (Figure 25, 26). The biggest changes in area occurred in subtidal meadows that contained the seasonal and ephemeral *Halophila* species (Figure 25, 26). The seasonal presence of these species and their expansion joined fragmented subtidal meadows to form more continuous seagrass meadows in the growing season (i.e. meadows 14 and 24; Figure 26).

Seasonal change in above-ground biomass in individual meadows were mixed, similar to 2019 (Figures 25, 26). At Magnetic Island, only the intertidal *Z. muelleri* meadow in Cockle Bay (meadow 6) and the subtidal *H. spinulosa* meadow (24) significantly increased in biomass between seasons (Figure 25, 26). Similarly, in the Cape Pallarenda-Strand region only the *Z. muelleri* meadow (meadow 10) significantly increased in biomass between seasons (Figure 25), with the other two meadows remaining similar between seasons. In contrast the intertidal *Z. muelleri* meadow in the Cleveland Bay region (meadow 16) decreased from 40.66 ± 3.89 g DW m^2 in the low season to 28.11 ± 2.61 g DW m^2 in the peak season (Figure 25, 26). The subtidal *H. uninervis* meadow in the Cleveland Bay region also decreased from 17.45 ± 2.47 g DW m^2 in the low season to 12.26 ± 1.40 g DW m^2 in the peak season (Figure 25). The biomass declines occurred across all of the species present in these meadows (Appendix 4). As a comparison, in 2019, the biomass of six meadows declined or remained unchanged from May to October 2019, while the rest of the meadows increased in biomass (McKenna et al. 2020).

Dugong feeding trails in monitoring meadows were only observed at one site in the low season, compared to ten sites in the peak season. The animals themselves were only observed once in the low season during the surveys, compared to the peak season where they were frequently observed.

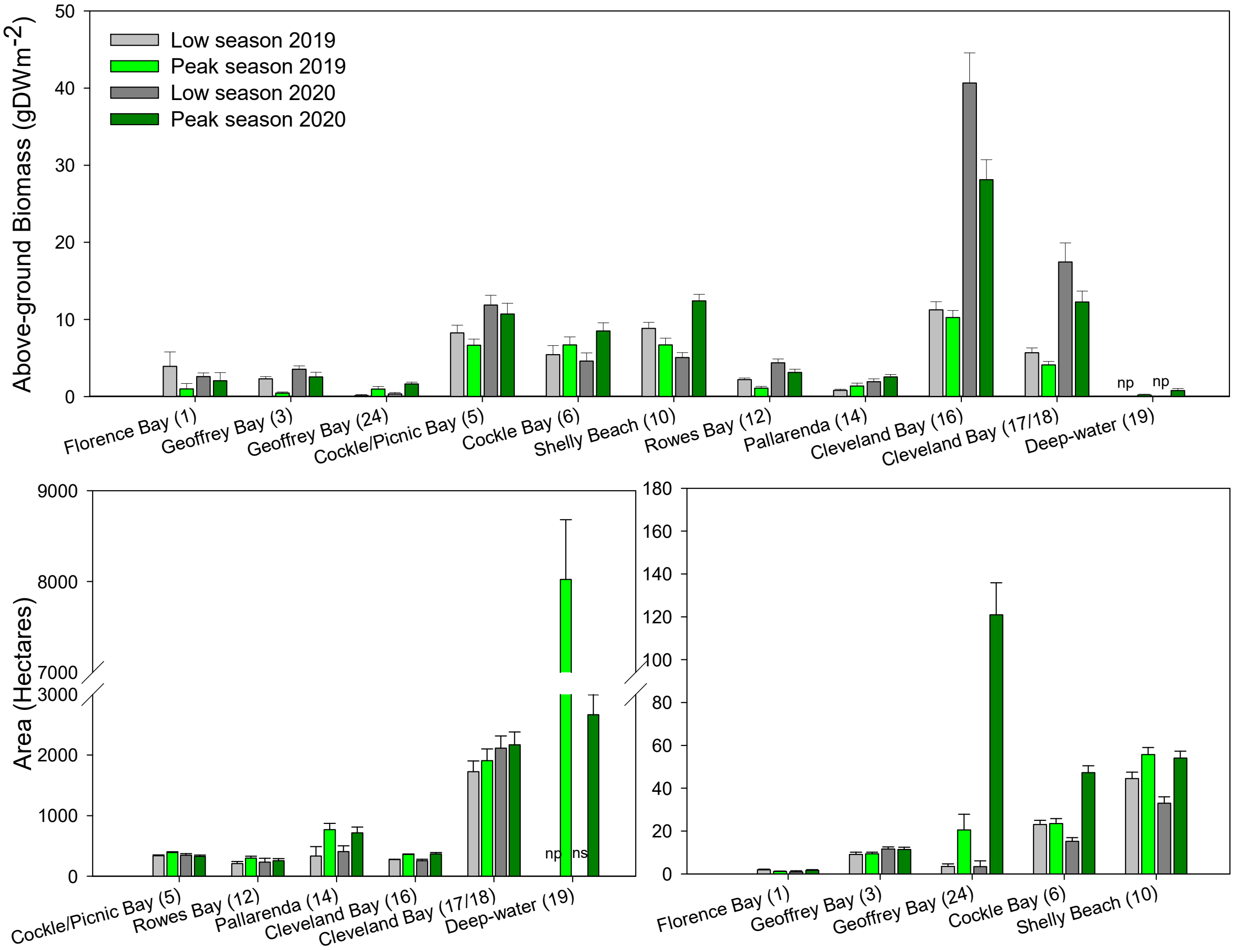


Figure 25. Seasonal meadow biomass and area in low season and peak season surveys 2019 - 2020.

A)

B)

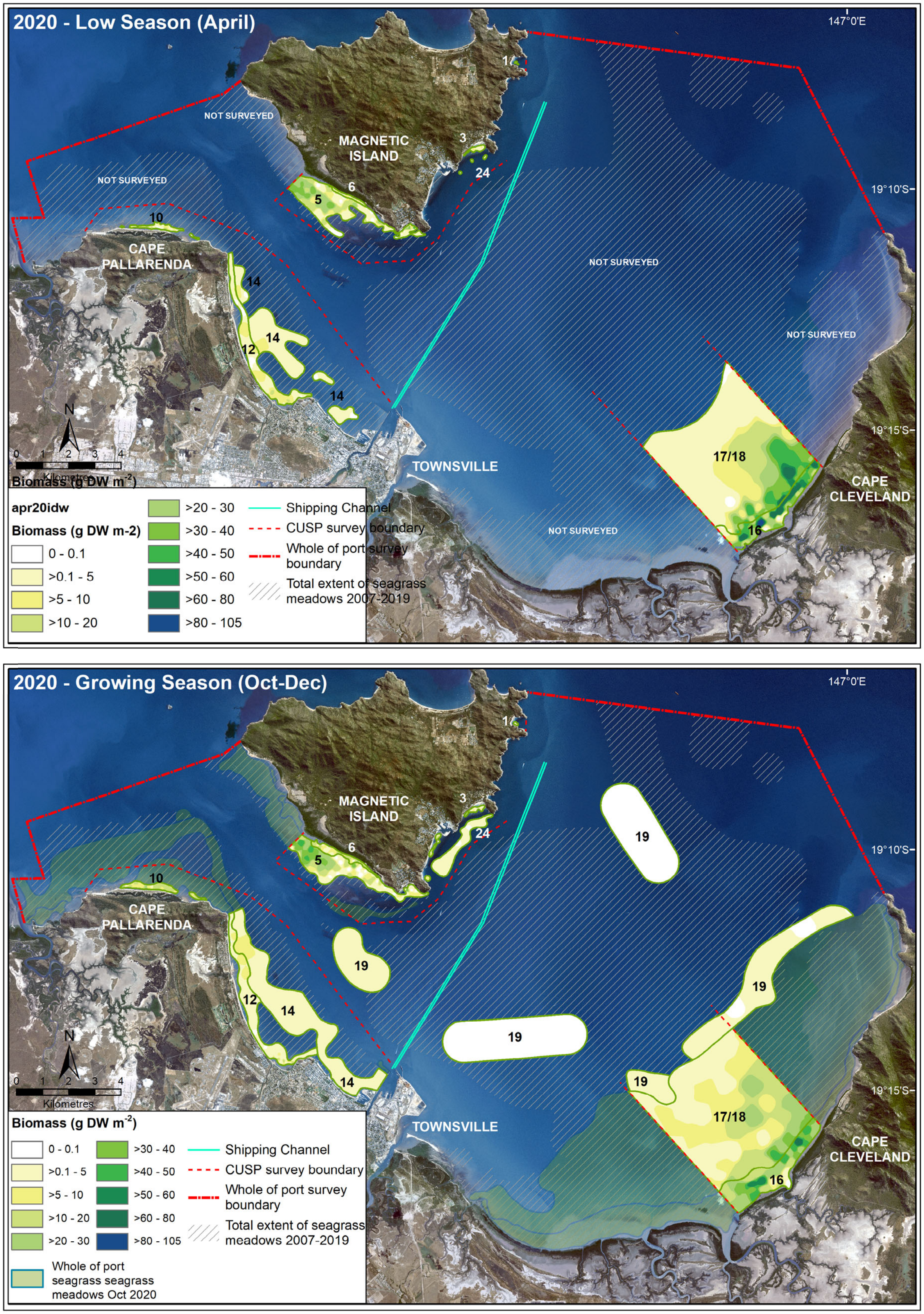


Figure 26. Seagrass density and distribution in the 2020 A) senescent and B) growing season surveys.

3.4 Whole-of-port comparisons of Townsville seagrass

A total of 1,351 sites were assessed for seagrass condition as part of the October 2020 whole-of-port seagrass surveys with seagrass present at 61% of sites. The whole-of-port seagrass footprint covered 14,511± 1,895 ha in 2020 (Figures 27, 28). For coastal seagrass, the total area increased by 13% from October 2019, recovering from the declines related to the February 2019 flood (Figure 27, 28). The highly variable deep-water meadow however, declined between years from 8,023 ± 1343 ha in 2019 to 2,666 ± 561 ha in 2020 (Figure 27, 28).

Dry season whole-of-port surveys have previously been conducted four times since the LTSMP program was established in 2007; 2007, 2013, 2016 and 2019 (Figure 27, 28). 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 couple of surveys 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 deep-water meadow has been much more variable, a typical attribute of deep-water *Halophila* meadows in tropical Queensland (Figure 23).

Seagrass above-ground biomass has been more 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 had increased again in 2020. The greatest increase occurred in both of the Cleveland Bay meadows.

During field surveys, dugongs were regularly observed. Dugong feeding trails were recorded at 49 intertidal survey sites indicating wide use of available seagrass habitat as a food source for megafauna.

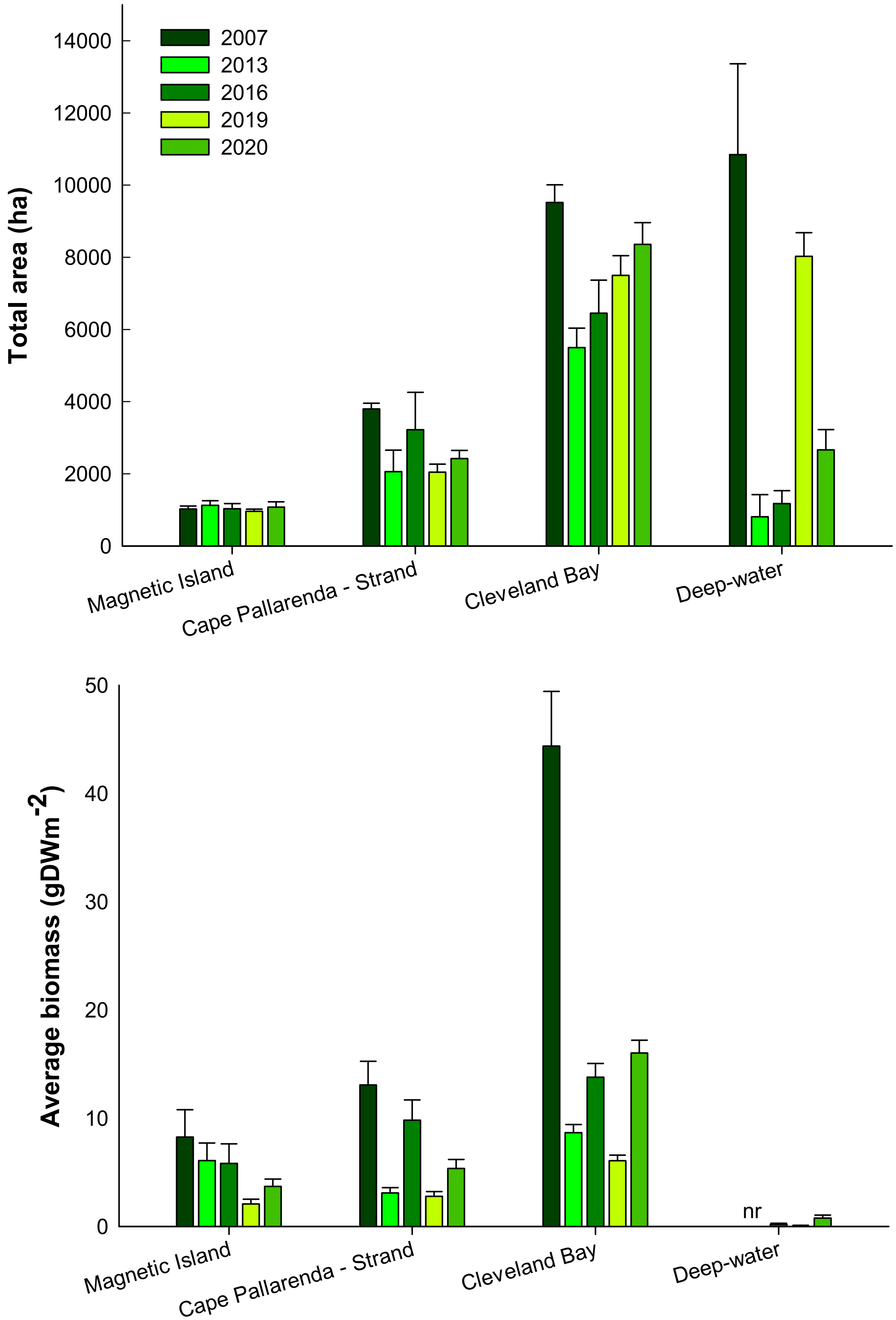


Figure 27. Comparison of whole-of-port meadow area and biomass in the four regions around Townsville in the peak season surveys in 2007, 2013, 2016, 2019 and 2020. (biomass error bars = SE; area error bars = "R" reliability estimate, nr = not recorded as part of survey).

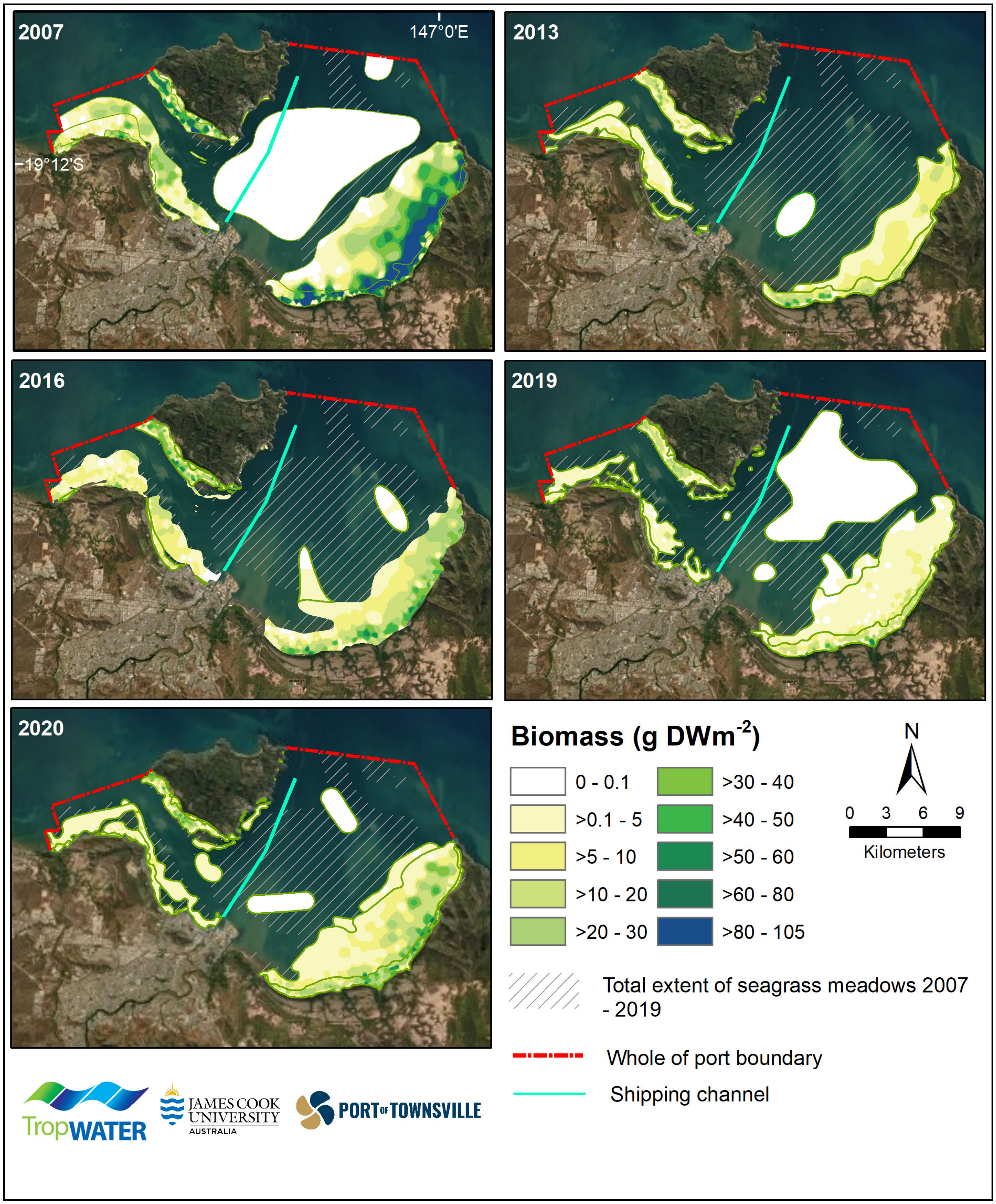


Figure 28. Comparison of whole-of-port peak season seagrass biomass (g DWm^{-2}) and meadow extent; 2007, 2013, 2016, 2019, 2020.

3.5 Townsville Climate Patterns

3.5.1 Rainfall and River flow

Rainfall in Townsville is highly seasonal with the majority of rainfall typically occurring from December to April (Figure 29A). Rainfall was generally below the monthly long-term average in 2020 (Figure 29A). May was the only month that had above-average rainfall, immediately after the April 2020 senescent season survey. Total annual rainfall in 2019/20 was well below the long-term average (Figure 29B).

River flow from all three of the rivers surrounding Townsville (the Black River, Alligator Creek and the Burdekin River) was well below the long-term averages in 2020 (Figure 30).

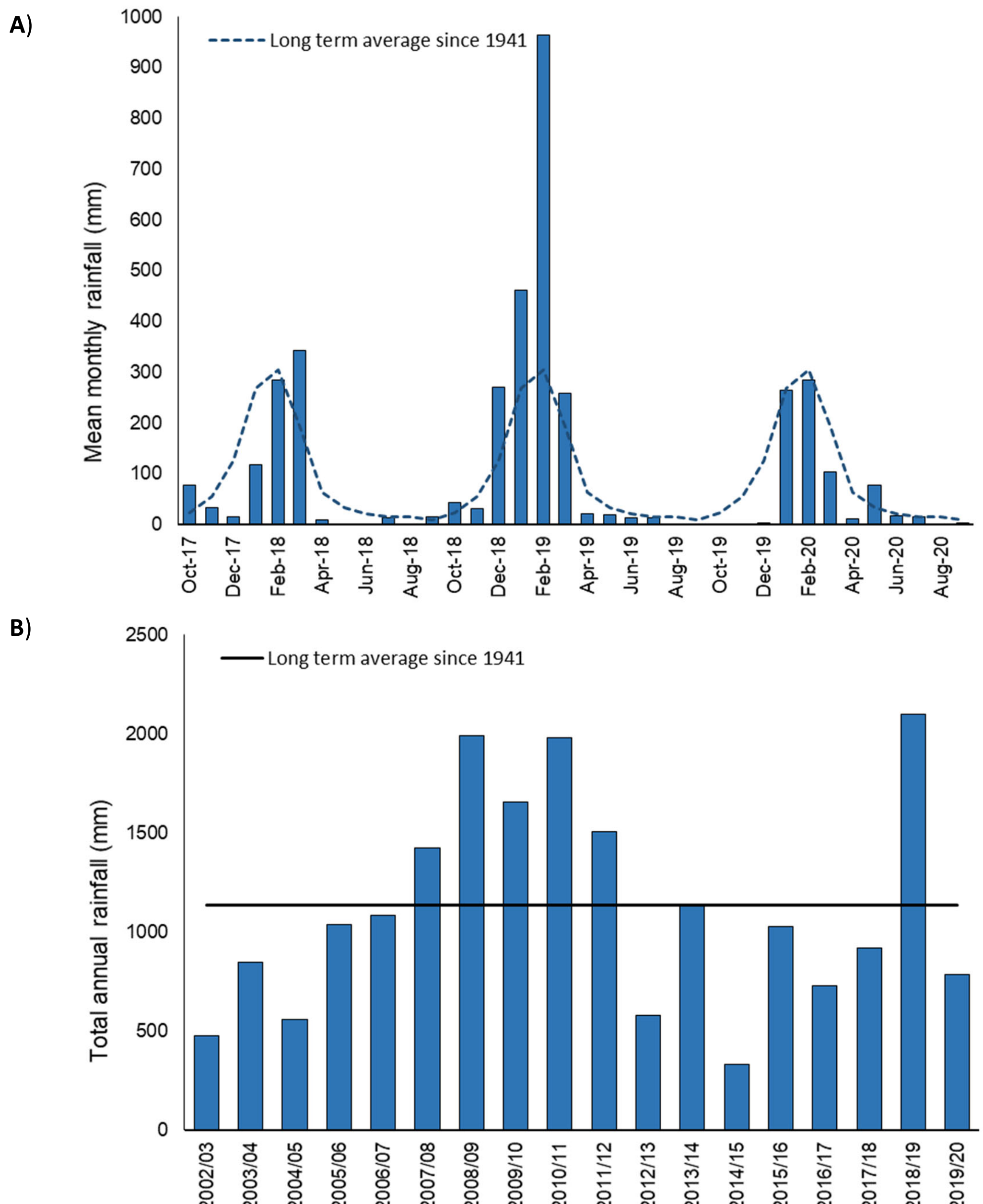


Figure 29. (A) Total monthly rainfall from October 2017 and (B) total annual rainfall from 2002/2003 to 2019/20 recorded at Townsville airport (Data from the Bureau of Meteorology, Station 032040 http://www.bom.gov.au).

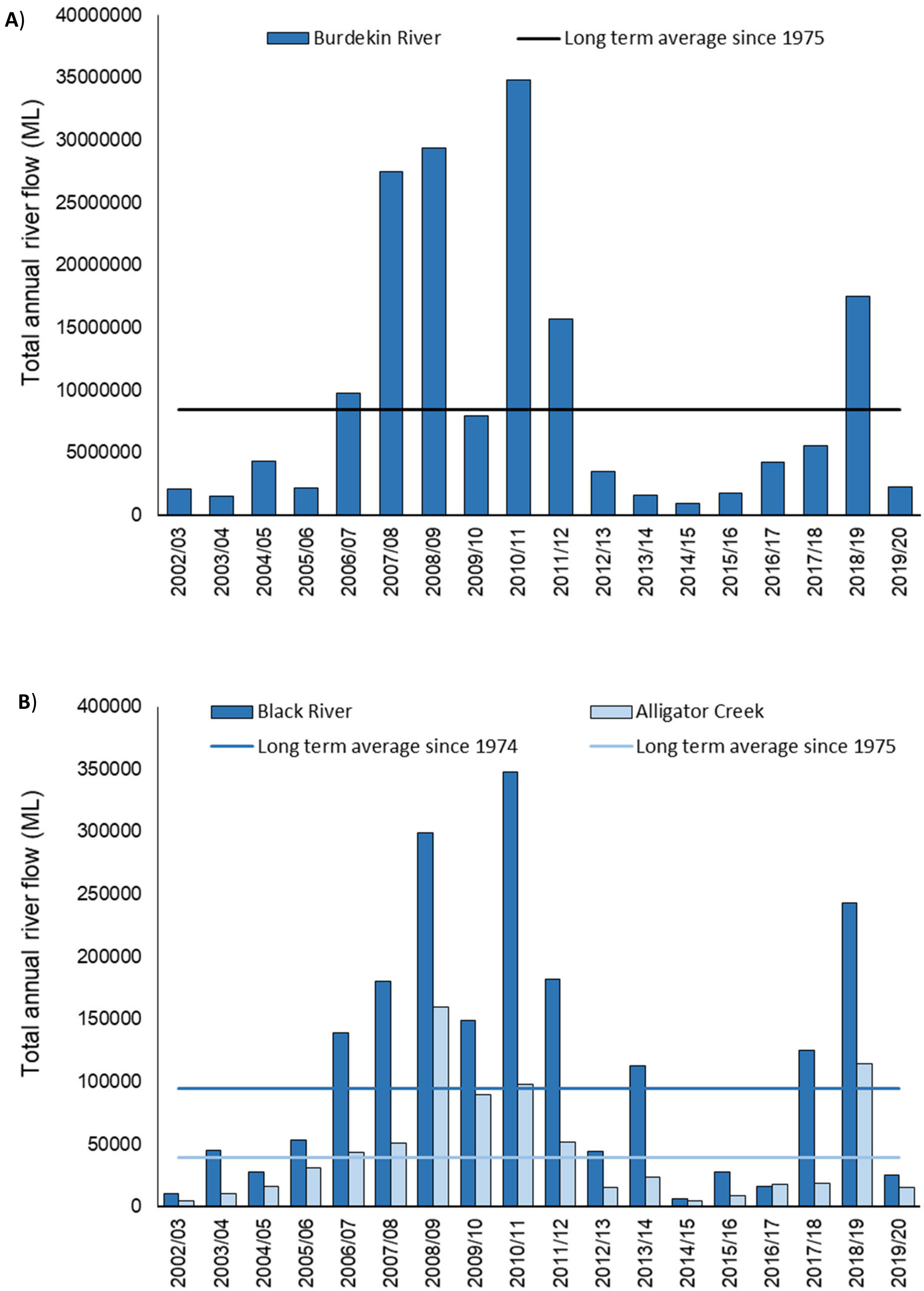


Figure 30. (A) Total annual flow of the Burdekin River from 2002/03 to 2019/20, and (B) total annual flow of the Black River and Alligator Creek from 2002/03 to 2019/20. (Department of Natural Resources, Mines and Energy, https://water-monitoring.information.qld.gov.au/).

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 2019/20 was above the long-term average and one of the highest recordings since 2004/05 (Figure 31).

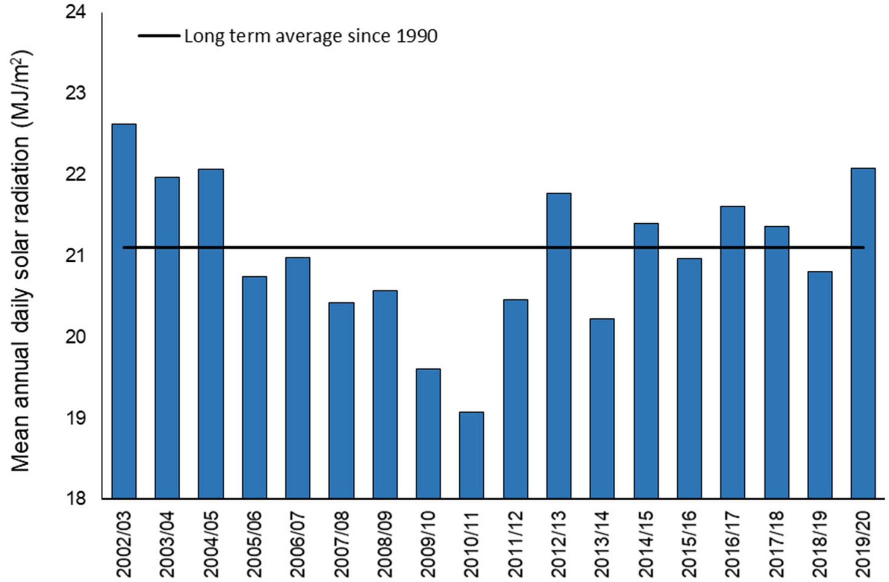


Figure 31. Mean annual daily solar radiation recorded at Townsville airport 2002/03 to 2019/20. (Data from the Bureau of Meteorology, Station 032040 http://www.bom.gov.au).

3.5.3 Air Temperature & Tidal Exposure of Seagrass Meadows

Mean annual daily maximum air temperature for 2019/20 was 29.9°C, slightly above the long-term average of 29°C (Figure 32).

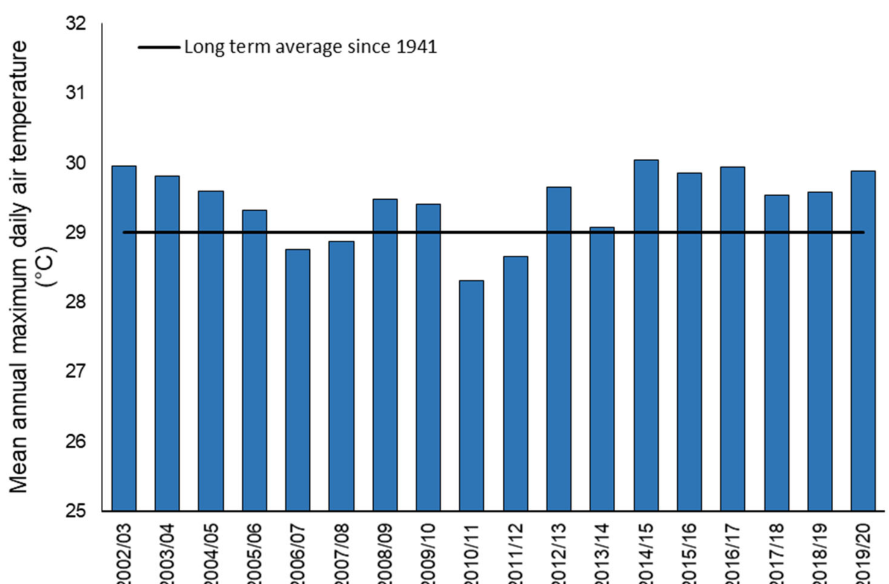


Figure 32. Mean annual maximum daily air temperature (°C) recorded at Townsville Airport, 2002/03 to 2019/20. (Data from the Bureau of Meteorology, Station 032040 http://www.bom.gov.au).

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 in the months preceding the 2020 surveys (April and September) was lower than the long-term average (Figure 33A).Total hours of tidal exposure in the one month period prior to the September growing season survey was 33 hours; slightly above the long-term average of 27 hours (Figure 33B). Total hours of tidal exposure in the three month period before the September survey was below the long-term average similar to previous years (Figure 33B).

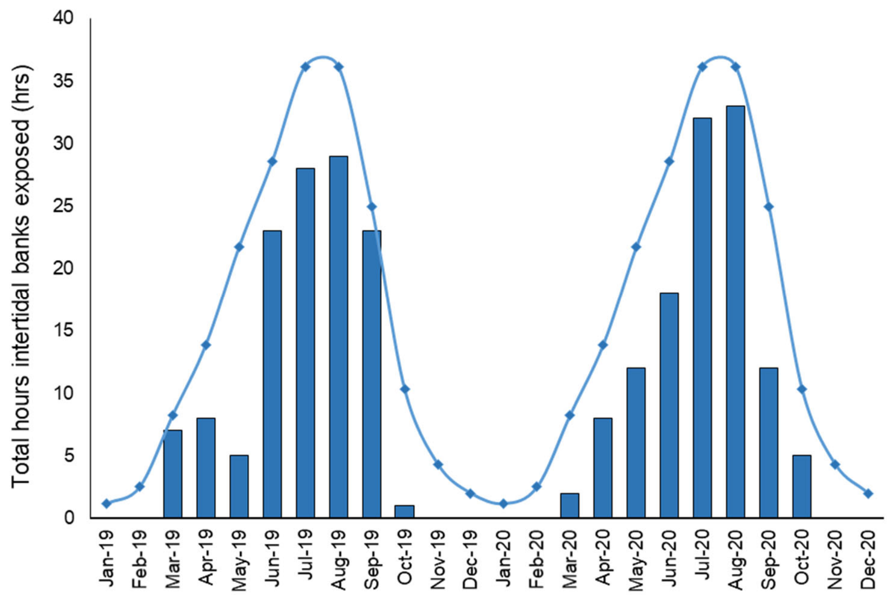


Figure 33A. Total monthly daytime intertidal exposure (<0.8m tidal height) Jan 2019 – December 2020 (Maritime Safety Queensland, www.msq.qld.gov.au).

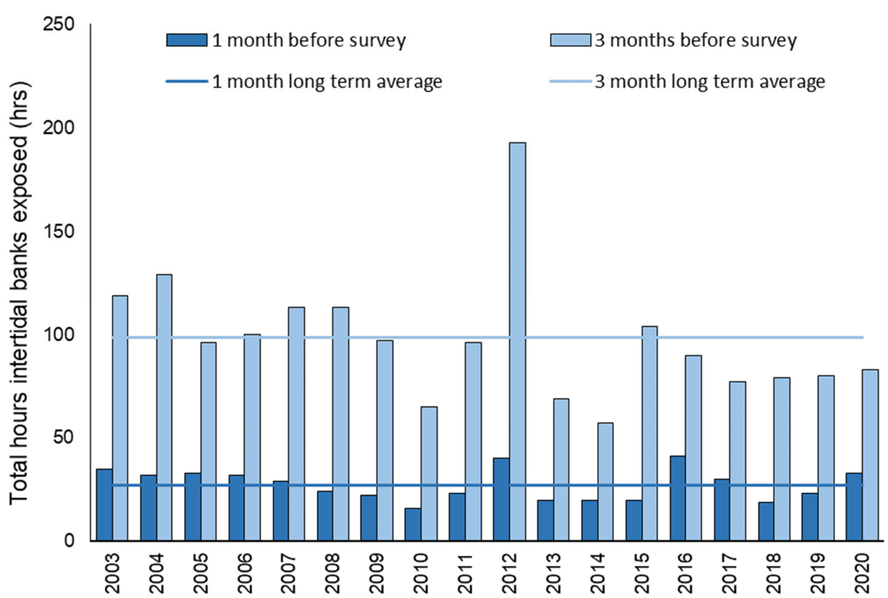


Figure 33B. Total daytime intertidal exposure (<0.8m tidal height) one month and three months prior to the growing season monitoring in Townsville (September 2020) (Maritime Safety Queensland, www.msq.qld.gov.au).

4 DISCUSSION

Seagrasses in Townsville were in a good condition in 2020. 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. In 2020 seagrass in the port had recovered from the declines related to the February 2019 flooding. The presence of turtles and dugongs and their feeding trails in meadows throughout the survey area indicated megafauna were making extensive use of the available seagrass habitat. The healthy condition of Townsville's seagrasses mean they were entering 2021 with some level of resilience to natural or anthropogenic disturbances.

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 tropical 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 we only have two "low-season" surveys so it is difficult to make any strong conclusions on the degree of seasonality in Townsville seagrass meadows, especially as one of those surveys was influenced by floods in 2019, and the other followed a particularly mild wet-season. These early results however, 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 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 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 was similar to the two whole-of-port surveys prior to that (2016 and 2013). These deep 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).

Monitoring at other locations in the Queensland wide seagrass monitoring network indicated that the declines in Townsville in 2019 were localised with smaller impacts to the south at Abbot Point and no impacts recorded in Hay Point or Cairns seagrass meadows. Similar to Townsville in 2020, results for Abbot Point indicate there has also been some recovery (McKenna et al. 2021). Hay Point seagrasses were in a satisfactory condition in 2020 (York et al. 2021).

The continued recovery and overall good condition of seagrasses in Townsville in 2020 indicates they should have some resilience to natural or anthropogenic disturbances in 2021.

In summary the 2020 seagrass monitoring found:

- The overall condition of seagrasses in Townsville was good with recovery from declines related to the February 2019 flooding.
- 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.
- Seasonal signals and patterns are still being established, but at this stage results indicate that Townsville's coastal seagrasses may not have a strong seasonal signal compared with deeper meadows.
- Dugongs and their feeding trails were observed widely across seagrass meadows within the Port of Townsville in 2020 indicating a broad use of the area by dugongs.
- The baseline conditions for the new Channel Upgrade Seagrass Program meadows not previously monitored has been established with plans to continue to improve those baselines as data becomes available.
- The healthy condition of Townsville's seagrasses indicates they have some level of resilience to any potential natural or anthropogenic disturbances in 2021.

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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

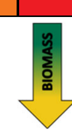
Seagrass condition for each indicator was assigned one of five grades (very good (A), good (B), satisfactory (C), poor (D), very poor (E)). Threshold levels for each grade were set relative to the baseline and based on meadow class. This approach accounted for historical variability within the monitoring 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
Biomass	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
Area	Stable	>10% above	10% above - 10% below	10-30% below	30-50% below	>50% below
Area	Variable	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
Area	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
Species composition	Stable; Mixed species	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
Species composition	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	≥0.85	1.00
B	Good	≥0.65	<0.85
C	Satisfactory	≥0.50	<0.65
D	Poor	≥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).

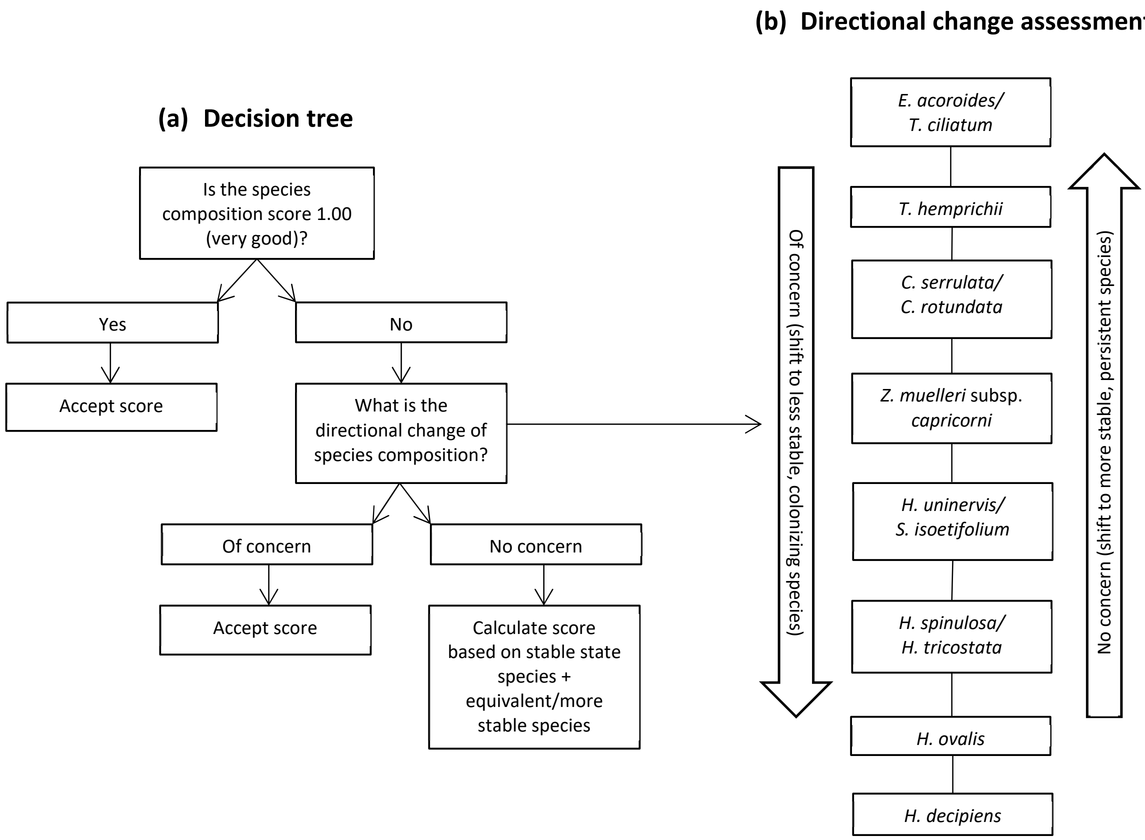


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in Townsville.

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

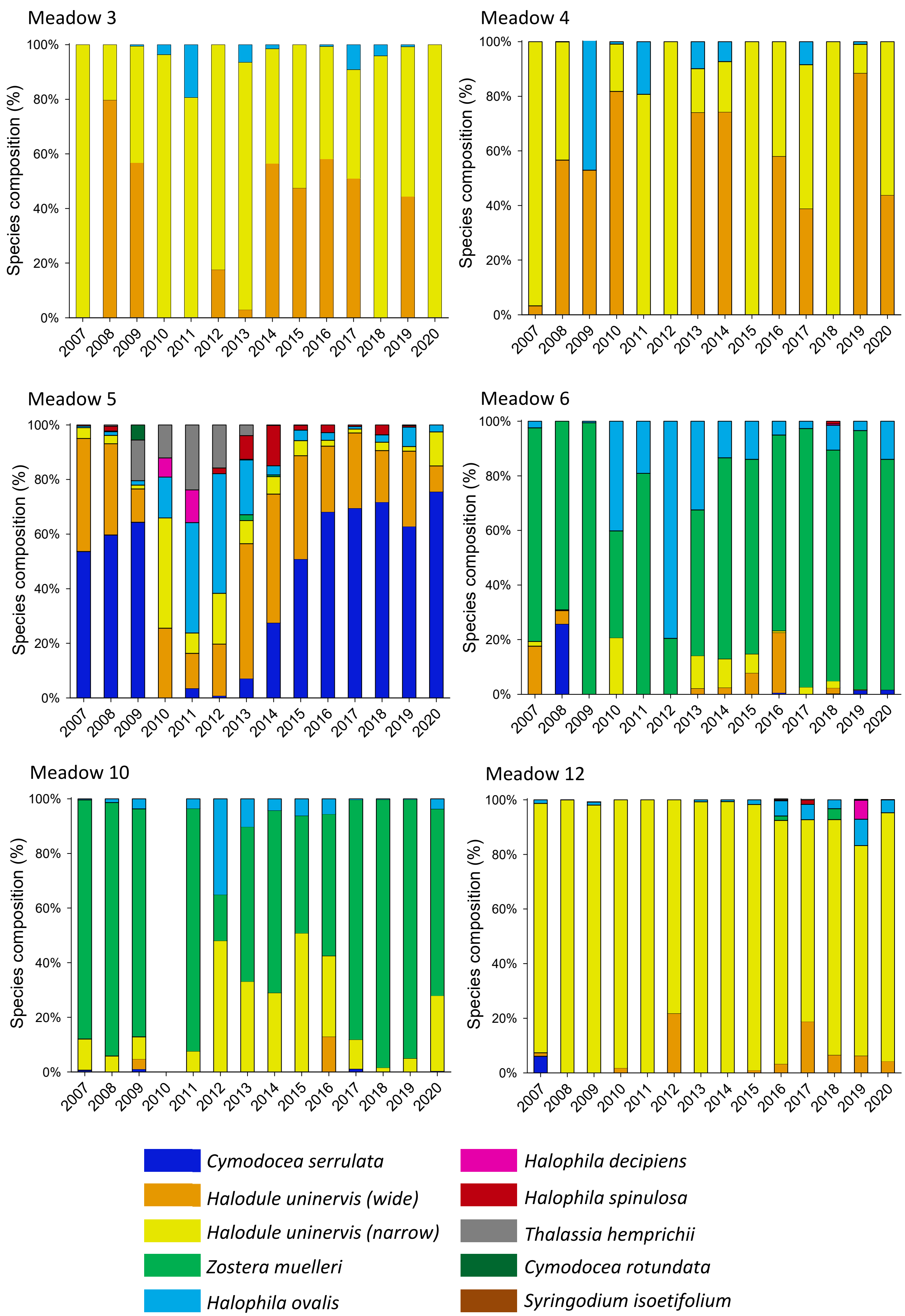
Appendix 3. Detailed meadow above-ground biomass and area

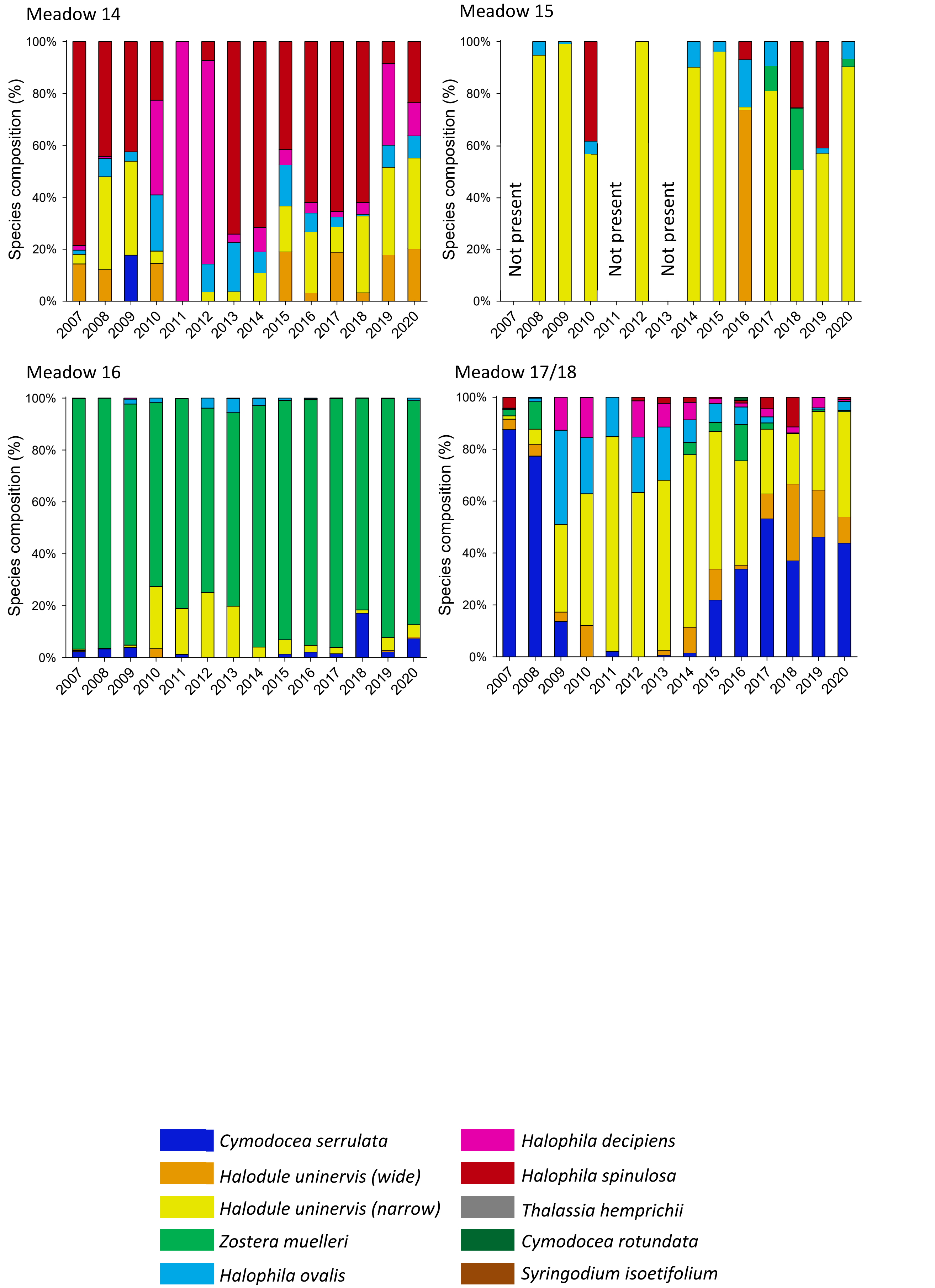
Mean above-ground biomass and meadow area within LTSMP meadows in the Port of Townsville, 2007-2020. (SE= Standard error, n= number of sampling sites, R= reliability estimate)

	Monitoring Meadow (ID number)	Meadow Cover	Mean Biomass ± SE in g DW m^2 no. of sites													
			2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Magnetic Island	Geoffrey Bay (3) Intertidal/subtidal *Halodule* dominated	Aggregated patches	7.3 ± 1.4 6	9.4 ± 3.2 13	1.0 ± 0.6 6	0.7 ± 0.3 14	0.5 ± 0.2 9	3.5 ± 0.6 12	3.3 ± 1.1 9	7.0 ± 2.6 14	0.10 ± 0.1 10	4.5 ± 1.3 11	4.8 ± 1.3 17	5.4 ± 1.1 14	0. 5 ± 0.1 24	2.6±0.6 20
	Nelly Bay (4) Intertidal/subtidal *Halodule* dominated	Aggregated patches	4.1 ± 2.6 5	12.6 ± 2.6 9	5.8 ± 2.6 9	0.5 ± 0.2 13	0.6 ± 0.3 3	2.9±0.82 2	3.5 ± 2.3 4	7.7 ± 5.4 6	0.5 ± 0.3 5	4.0 ± 2.0 8	5.7 ± 1.6 13	2.8 ± 0.4 12	0.9 ± 0.6 18	6.0 ± 1.5 12
	Cockle Bay Reef (5) Intertidal *Halodule* dominated	Continuous cover	28.7 ± 4.8 34	22.6 ± 3.2 47	6.8 ± 1.2 85	1.1 ± 0.3 51	1.3 ± 0.2 50	5.0 ± 0.6 50	6.1 ± 0.7 111	26.4 ± 3.2 82	11.3 ± 1.1 79	21.5 ± 2.0 87	19.3 ± 1.6 87	15.0 ± 1.7 87	6.7 ± 0.8 112	10.7 ± 1.4 84
	Cockle Bay Reef (6) Intertidal *Zostera* dominated	Aggregated patches	20.1 ± 10.2 6	35.3 ± 3.8 23	4.8 ± 1.1 42	0.5 ± 0.2 9	1.1 ± 0.4 23	4.2 ± 0.5 23	9.0 ± 1.6 7	11.7 ± 2.6 10	9.0 ± 1.7 15	11.2 ± 2.6 24	16.4 ± 3.3 15	7.5 ± 1.4 31	6.7±1.0 28	8.7±1.0 33
Cape Pallarenda	Shelly Beach (10) Intertidal *Zostera* dominated	Aggregated patches	27.8 ± 4.0 15	21.4 ± 3.5 17	4.2 ± 0.8 22	Not present	0.1 ± 0.0 25	3.7 ± 0.5 43	5.5 ± 0.9 29	9.8 ± 2.2 28	5.7 ± 0.9 32	14.2 ± 2.0 34	23.0 ± 1.4 48	19. 4 ± 2.5 38	6.7 ± 0.9 39	12.4±0.8 33
	Rowes Bay (12) Intertidal/Subtidal *Halodule* dominated	Aggregated patches	3.9 ± 0.7 33	1.5 ± 0.4 19	1.3 ± 0.4 49	0.6 ± 0.2 14	0.0 ± 0.0 16	0.4 ± 0.1 923	2.8 ± 0.4 43	4.1 ± 0.5 36	1.6 ± 0.3 36	5.6 ± 0.5 63	4.1 ± 0.5 49	4.3 ± 0.5 49	1.0 ± 0.2 47	4.2±0.4 56
	Pallarenda (14) Subtidal *Halophila* dominated	Aggregated patches	13.2 ± 2.1 40	4.0 ± 0.5 36	1.0 ± 0.4 40	0.4 ± 0.1 21	NA	2.6 ± 0.5 35	2.5 ± 0.5 25	3.1 ± 0.3 23	1.5 ± 0.4 41	6.4 ± 0.6 46	4.5 ± 0.5 72	2.5 ± 0.3 67	1.4 ± 0.3 46	2.5±0.3 39
	Strand (15) Intertidal/Subtidal *Halodule* dominated	Continuous cover	NA	4.0± 0.4 2	1.4 ± 0.4 11	0.4 ± 0.4 2	NA	0.3±0.1 2	NA	3.1 ± 0.8 6	0.6 ± 0.6 5	8.1 ± 1.1 13	3.8 ± 1.5 11	5.9 ± 1.5 9	1.4 ± 0.3 29	1.4±0.2 18
Cleveland Bay	Cleveland (16) Intertidal *Zostera* dominated	Continuous cover	52.1 ± 4.6 94	27.0 ± 3.0 60	5.7 ± 1.0 99	1.1 ± 0.3 37	0.5 ± 0.1 51	6.2 ± 1.0 67	12.2 ± 1.4 73	43.3 ± 4.6 72	10.5 ± 1.1 73	25.2 ± 2.4 56	46.0 ± 2.5 56	36.2 ± 2.9 68	9.0 ± 0.8 147	20.8±1.4 104
	Cleveland (17&18) Subtidal *Halodule* dominated	Continuous cover	37.3 ± 5.6 51	13.2 ± 1.9 50	1.8 ± 0.4 44	1.5 ± 0.3 35	0.4 ± 0.2 15	6.2 ± 0.6 42	6.8 ± 0.6 27	9.6 ± 1.6 43	2.5 ± 0.4 57	10.8 ± 1.5 62	13.7 ± 1.5 81	7.8 ± 1.3 50	3.5 ± 0.3 114	8.9±0.9 110

	Monitoring Meadow (ID number)	**Meadow Cover**	**Total Meadow Area ± R in hectares**													
			2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Magnetic Island	Geoffrey Bay (3) Intertidal/subtidal *Halodule* dominated	Aggregated patches	10.7 ± 3.5	9.5 ± 2.6	6.9 ± 2.8	9.2 ± 3.1	5.6 ± 2.5	9.6 ± 2.4	9.4 ± 2.0	15.6 ± 3.2	11.3 ± 2.3	7.6 ± 1.8	16.1 ± 2.2	12.2 ± 2.2	9.4 ± 0.7	11.4± 1.0
	Nelly Bay (4) Intertidal/subtidal *Halodule* dominated	Aggregated patches	9.5 ± 3.4	7.5 ± 2.6	12.2 ± 3.8	9.5 ± 3.7	1.5 ± 1.3	0.7 ± 0.7	2.9 ± 1.4	8.7 ± 3.0	5.2 ± 0.6	6.4 ± 1.2	8.7 ± 1.3	9.5 ± 1.5	7.7 ± 1.4	13.1± 1.5
	Cockle Bay Reef (5) Intertidal *Halodule* dominated	Continuous cover	382.4 ± 25.5	332.3 ± 45.4	308.8 ± 27.2	178.3 ± 24.9	136.7 ± 26.8	223.3 ± 17.8	452.9 ± 28.7	418.4 ± 27.15	401.1 ± 29.2	387.5 ± 51.0	352.7 ± 25.9	354.4 ± 27.8	390.9 ± 13.5	328.4± 21.0
	Cockle Bay Reef (6) Intertidal *Zostera* dominated	Aggregated patches	73.2 ± 5.3	110.0 ± 17.1	52.3 ± 6.4	6.6 ± 2.7	31.3 ± 3.9	63.2 ± 13.3	10 ± 1.9	37.1 ± 4.5	48.2 ± 5.3	38.0 ± 7.2	26.6 ± 4.4	31.9 ± 5.0	23.5 ± 2.3	47.3± 3.2
Cape Pallarenda	Shelly Beach (10) Intertidal *Zostera* dominated	Aggregated patches	118.9 ± 6.7	134.0 ± 7.6	90.6 ± 6.9	Not present	54.1 ± 5.1	191.0 ± 17.8	94.5 ± 16.0	163.6 ± 18.8	124.4 ± 17.6	93.0 ± 17.8	68.3 ± 14.9	61.6 ± 15.1	55.7 ± 3.3	54.1± 3.2
	Rowes Bay (12) Intertidal/Subtidal *Halodule* dominated	Aggregated patches	128.3 ± 18.2	127.4 ± 26.3	129.1 ± 21.5	81.1 ± 10.6	15.8 ± 3.3	74.2 ± 17.7	126.0± 24.7	163.6 ± 28.8	168.5 ± 29.9	232.7 ± 29.7	315.4 ± 30.4	293.6 ± 29.2	201 ± 30.7	255.8± 34.2
	Pallarenda (14) Subtidal *Halophila* dominated	Aggregated patches	1321.3 ± 40.3	866.1 ± 244.8	900.9 ± 38.6	572.5 ± 31.7	6.6 ± 5.4	484.5 ± 106.4	751.4± 201.5	579.8± 162.8	1047.2± 198.4	1243.4± 214.6	1174.2± 230.1	1190.5± 220.3	864.8 ± 103.5	717.5± 92.3
	Strand (15) Intertidal/Subtidal *Halodule* dominated	Continuous cover	3.4 ± 2.1	1.3 ± 1.0	7.4 ± 2.2	1.9 ± 1.1	1.8 ± 0.5	1.1 ± 0.8	Not present	6.6 ± 1.0	8.4 ± 0.9	11 ± 1.2	9.6 ± 1.2	6.3 ± 1.1	4.2 ± 1.2	3.0 ± 0.7
Cleveland Bay	Cleveland (16) Intertidal *Zostera* dominated	Continuous cover	1160.1± 51.1	1173.1± 70.7	1262.0± 49.4	793.7 ± 47.8	638.1± 40.7	1069.8± 66.7	1206.5± 63.6	1228.6± 64.7	1265.5 ± 64.1	1020.5± 97.9	1124.3± 69.4	1575.1± 65.5	1373.9± 17.5	1139.6± 16.2
	Cleveland (17&18) Subtidal *Halodule* dominated	Continuous cover	4953± 161.2	3097 ± 400.7	2673.4± 144.2	2132.0± 341.1	376.2± 193	1749.2± 242.2	2133.3± 271.8	2533.3± 497.9	2511.5± 470.2	3315.0± 590.4	3221.8± 533.8	3223.3± 456.2	3422.8± 372.5	4367.8± 369.9

Appendix 4. Detailed meadow species composition; 2007-2020




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
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 have only been surveyed as part of whole-of-port surveys; 2007, 2013, 2016, 2019, 2020