

**PORT OF TOWNSVILLE
SEAGRASS MONITORING
PROGRAM 2019**



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PORT OF TOWNSVILLE SEAGRASS MONITORING PROGRAM 2019

A Report for the Port of Townsville Limited

Report No. 20/16

February 2020

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KEY FINDINGS

- This report presents the results of the first year of the Channel Upgrade Seagrass Monitoring Program and builds on the Long-term Seagrass Monitoring Program established in 2007.
- The Townsville region was affected by heavy rainfall and flooding in February 2019 and concerns were raised about the impact these events had on seagrasses.
- The May 2019 whole-of-port senescent season survey indicated that these floods and the associated sediment plume did not have as great an impact on seagrass as was expected, with seagrass found throughout much of the Townsville port limits.
- The October 2019 whole-of-port peak season survey indicated that there may have been a ‘lag effect’ or legacy of the February floods, with seagrass density(biomass) at coastal meadows not returning to ‘typical’ peak season levels.
- The area of coastal seagrass meadows was similar to that previously recorded in peak season surveys, despite the overall density of coastal seagrass being lower than previous years.
- A significant deep-water seagrass meadow was recorded in the peak season survey with seagrass observed at 14.4m (below mean sea level). Such an extent of deep-water seagrass has not been recorded in Townsville since 2008.
- The overall condition of seagrass in the meadows monitored as part of the previously established Long-term Seagrass Monitoring Program was satisfactory in 2019.
- Dugongs and their feeding trails in seagrass meadows were observed during both 2019 field surveys.
- Continued persistence and growth of seagrass in Townsville will be contingent on environmental conditions being favourable, particularly during the 2019/20 wet season.



Seagrass Condition 2019

IN BRIEF

This report is the first annual report that will be part of a series that document seagrass condition throughout Townsville as part of the Townsville Channel Upgrade Project (*CU Project*) and the Channel Upgrade Seagrass Program (CUSP). The CU Project is Stage 1 of the Ports' long-term plans and involves capital dredging-related activities of the Platypus and Sea channels, and the construction of a reclamation area. The capital campaign will be over a period of two to three years. The Channel Upgrade Seagrass Program (CUSP) includes the monitoring meadows that form the long-term monitoring and research program, but also includes expanded areas of seagrass in assessments to meet regulatory requirements associated with the CU Project.

Seagrasses have been monitored annually in the Port of Townsville since 2007. Prior to the CUSP, seagrass monitoring meadows representing the range of different seagrass community types found in Townsville have been mapped each year and assessed for changes in area, biomass and species composition. These metrics are then used to develop a seagrass condition index (see Appendix 1 for further details). This Long-term Seagrass Monitoring Program (LTSMP) will continue during the CU project in parallel with the CUSP along with re-mapping of all seagrasses within the greater port limits every 3 years (completed in 2019).

In February 2019, the Townsville region was affected by severe rainfall and flooding as a result of the convergence of a monsoon and slow-moving tropical low. Concerns were raised about how the seagrasses may have responded to the floods and associated sediment plume, and what impact any changes in seagrass distribution and density would have on the animals that rely on them such as dugong and turtles.

A May 2019 whole-of-port survey indicated that the floods did not have as great an impact on seagrass habitat as expected. Seagrass was found throughout much of the Townsville port limits from the tidal zone, extending to subtidal areas (~9.5m below mean sea level). The October whole-of-port survey has, however, indicated there may have been a 'lag effect' or legacy of the February floods, with seagrass density (above-ground biomass) at coastal meadows not 'bouncing back' to typical peak season levels (Figures 4-7). It may be that coastal seagrasses were relying on energy/carbohydrate stores within the below-ground structures (rhizomes) to support them through the floods and post flooding (O'Brien et al. 2018; Unsworth et al. 2015). This redistribution of energy stores may have kerbed new growth and germination which typically drives annual growing patterns and increased late spring above-ground biomass. Despite the impacts on biomass, the overall seagrass extent is above the long-term average likely due to the resilience from previous years of good growing conditions (Figure 2).

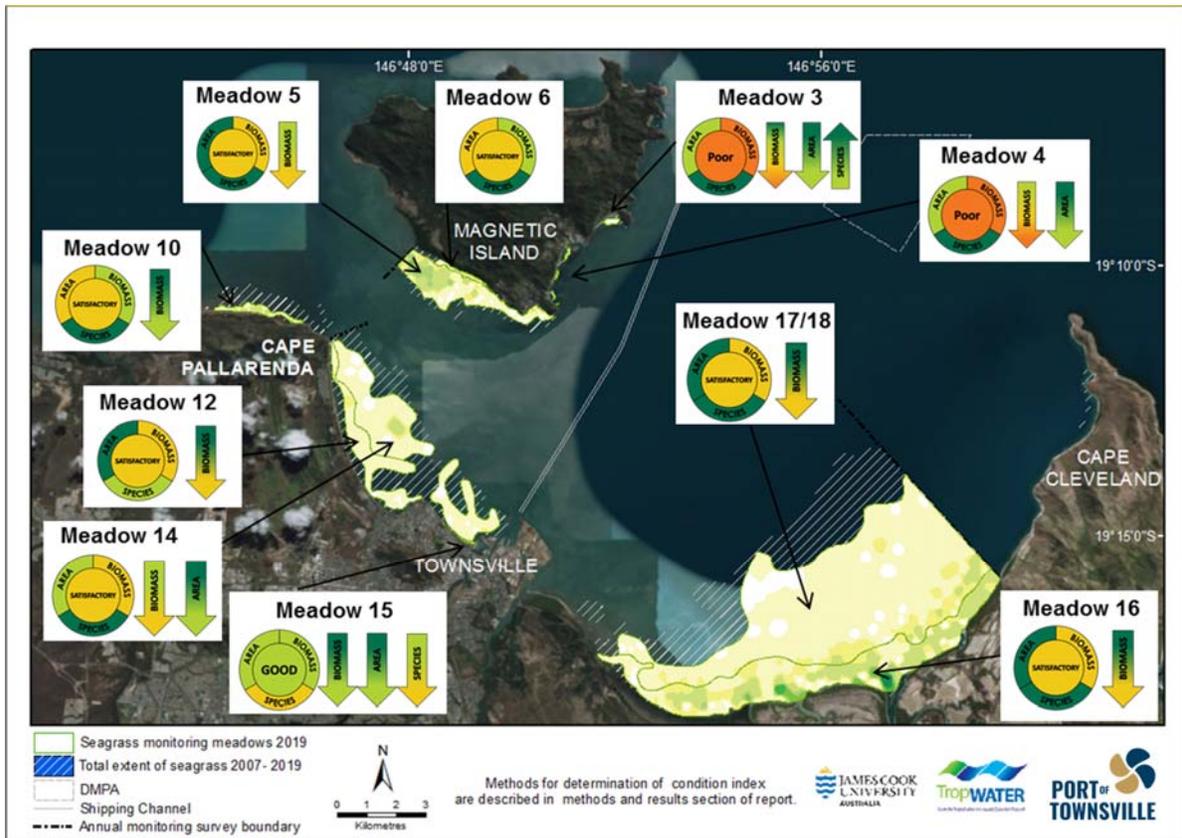


Figure 1. Seagrass condition for meadows monitored as part of the Long-term Seagrass Monitoring Program in 2019.

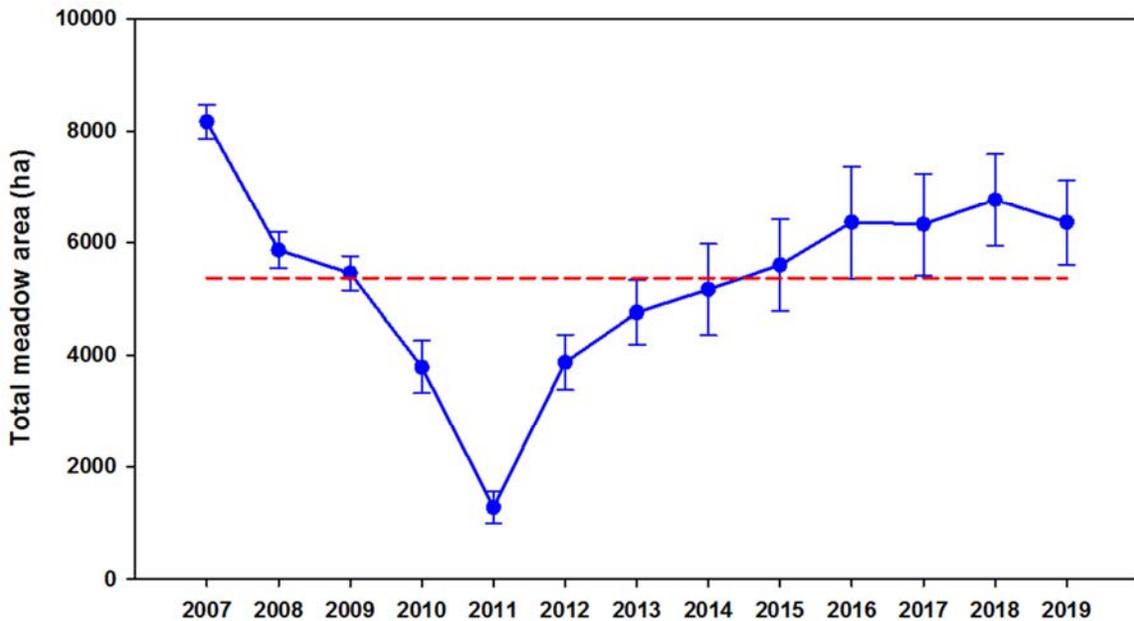


Figure 2. Total area of seagrass within Long-term Seagrass Monitoring Program meadows from 2007-2019 (error bars = “R” reliability estimate), plus long-term average (red dashed line).

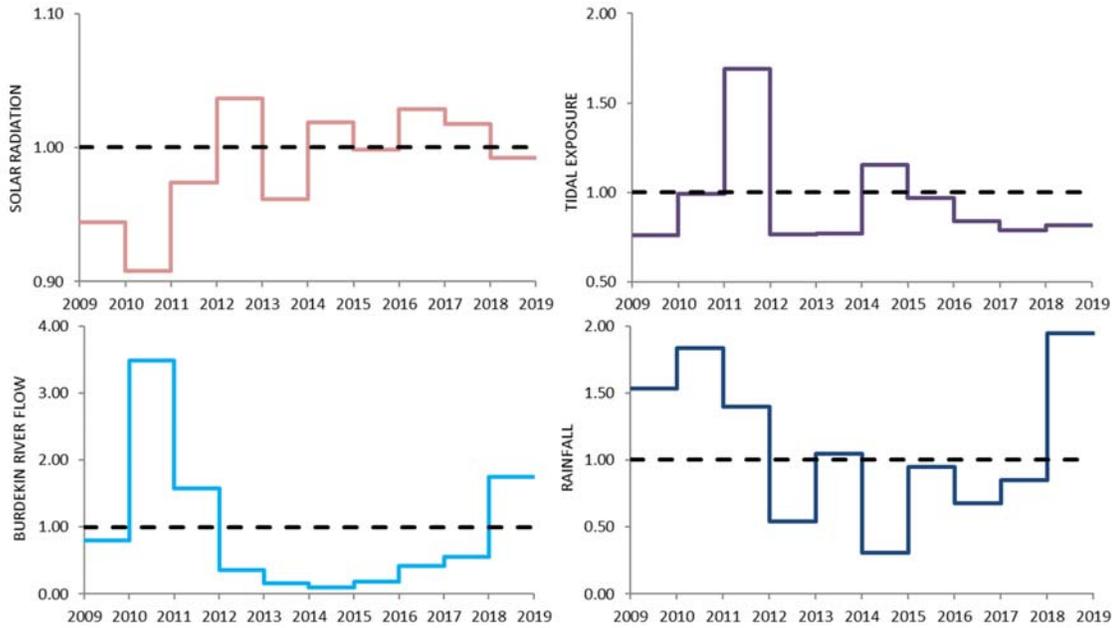


Figure 3. Change in climate variables as a proportion of the long-term (15 year) average in Townsville. See Section 3.3 for detailed climate data for the Townsville region.

The Townsville seagrass monitoring program forms part of a broader Queensland program that examines the condition of seagrasses in the majority of high risk areas for seagrasses in Queensland’s commercial ports, and is a component of James Cook University’s (JCU) broader seagrass assessment and research program. Other locations along the east coast of Queensland monitored as part of this program, such as coastal seagrasses in Cairns and Gladstone have shown signs of improvement in 2013 - 2019 following declines prior to this period. However, seagrasses in some other locations such as the Gulf of Carpentaria were impacted heavily in 2019 by a record flood event. For full details of the Queensland ports seagrass monitoring program see www.jcu.edu.au/portsseagrassqld.

TABLE OF CONTENTS

KEY FINDINGS	4
IN BRIEF	5
1 BACKGROUND & SCOPE OF WORKS	9
1.1 The Channel Upgrade Seagrass Program and the Long-term Seagrass Monitoring Program	9
1.2 Queensland Ports Seagrass Monitoring Program	10
2 METHODS	11
2.1 Sampling approach	11
2.2 Seagrass indicators & sampling techniques	14
2.3 Habitat mapping and Geographic Information System	15
2.4 Seagrass condition assessments & index	17
2.5 Statistical design and analysis	18
2.6 Environmental data	19
3 RESULTS.....	20
3.1 Whole-of-Port Channel Upgrade Seagrass Program Distribution & Abundance	20
3.2 Channel Upgrade Seagrass Program Meadows	23
3.3 Long-term Seagrass Monitoring Program meadow condition	27
3.4 Townsville Climate Patterns	41
4 DISCUSSION	45
4.1 Comparison with state-wide monitoring program	46
4.2 Townsville Seagrass Outlook	46
4.3 Conclusions	47
5 REFERENCES.....	48
6 APPENDICES.....	50
Appendix 1.	50
Baseline Calculations	50
Meadow Classification.....	50
Threshold Definition	50
Grade and Score Calculations.....	51
Score Aggregation	53
Appendix 2.	54
Appendix 3.	55
Appendix 4.	56

1 BACKGROUND & SCOPE OF WORKS

1.1 The Channel Upgrade Seagrass Program and the Long-term Seagrass Monitoring Program

The Port of Townsville Limited (PoTL) is upgrading the approach channel as part of their Port Expansion Project. The Channel Upgrade Project (CU Project) is Stage 1 of the long-term plans and involves capital dredging-related activities of the Platypus and Sea channels, and the construction of a reclamation area. The capital dredge campaign will be over a period of two to three years.

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 seagrass meadows and reefs that begin in the intertidal zone and extend down to ~13m below mean sea level. Seagrasses provide a range of critically important and economically valuable ecosystem services including coastal protection, support of fisheries production, nutrient cycling, and particle trapping (Hemminga and Duarte 2000; Costanza et al. 1997) as well as a key food source for dugong and green turtles (Scott et al 2018). Seagrass meadows show measurable responses to changes in water quality, making them ideal candidates for monitoring the long-term health of marine environments (Orth et al. 2006; Abal and Dennison 1996; Dennison et al. 1993).

As part of their commitment to the environmental health of the port, PoTL in partnership with James Cook University's TropWATER Seagrass Ecology Group have developed a seagrass monitoring program to assess and monitor the seagrass habitat surrounding Townsville and Magnetic Island before, during, and after the planned works. The monitoring program also addresses regulator conditions that have been outlined for the project. This specified monitoring program for the Channel Upgrade Project builds on the already established Long-term Seagrass Monitoring Program (LTSMP) that PoTL and TropWATER have been engaged in since 2007.

The LTSMP was established in 2007 to assess seagrass around Townsville and Magnetic Island annually between October and November when seagrasses are at their peak. Each year the program examines a sub-set of representative seagrass meadows (10 meadows), and in some years (2007, 2008, 2013, 2016, 2019) all seagrass in the entire port limits are re-assessed. The program has mapped up to 1400 ha of seagrass in Townsville. The program provides a regular update of the marine environmental health of Townsville, and an assessment of seagrass condition and resilience to inform port management. Beyond the port-specific applications, the monitoring forms part of JCU's broader Queensland-wide assessment of seagrass condition.

The Channel Upgrade Seagrass Program (CUSP) includes the monitoring meadows that form LTSMP, but also includes expanded areas of seagrass in assessments to meet regulatory requirements associated with the CU Project. The CUSP involves:

- Establishing baseline conditions of seagrass communities before project works begin (seagrass senescent & peak season conditions);
- Monitoring the condition of seagrass communities before, during and after project works;
- Assessing seagrass condition at selected monitoring meadows twice a year and at the whole-of-port scale once a year;
- Delineating changes/impacts to seagrass communities due to project works, weather events or natural background.

This report presents the results of the first year of the CUSP and includes and builds on the results of the LTSMP established in 2007. Results and discussions include:

- Maps of seagrass distribution, abundance and species composition at the whole-of-port scale that encompass both the CUSP meadows and the LTSMP meadows;
- Assessments of the impacts of the February 2019 Townsville floods on seagrass;
- 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 the Cleveland Bay and provide advice for management;
- Discussion of the observed changes in a regional and state-wide context;
- Incorporate results into the Townsville seagrass Geographic Information System (GIS) database.

1.2 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).

A strategic long-term assessment and monitoring program for seagrasses provides port managers and regulators with the key information to ensure that seagrasses and anthropogenic activities can co-exist. Ports use the information collected by this program to support planning and implementing sustainable port operations and development. The program also provides an ongoing assessment of many of the most threatened seagrass communities in the state.

The program delivers key information for the management of port activities to minimise impacts on seagrasses, and also has resulted in significant advances in the science and knowledge of tropical seagrass ecology. It has been instrumental in developing tools, indicators and thresholds for the protection and management of seagrasses and an understanding of the drivers of tropical seagrass change. It provides local information for individual ports as well as feeding into regional assessments of the status of seagrasses.

For more information on the program and reports from the other monitoring locations see <https://www.tropwater.com/research/seagrass-ecology/>



Figure 4. Location of Queensland port seagrass assessment sites.

2 METHODS

2.1 Sampling approach

Sampling techniques followed those used for Townsville’s LTSMP annual surveys and throughout the Queensland Ports Seagrass Monitoring Program (Bryant et al. 2019; Wells and Rasheed 2017). Results are therefore comparable with historical seagrass data across the range of locations frequently monitored.

Seagrass assessments for the Channel Upgrade Seagrass Program (CUSP) occur twice a year; once in the seagrass senescent season (post-wet season; April/May) when natural environmental conditions are most likely to have impacted seagrass and they are at their low point in resilience, then again in October/November at the peak of seagrass distribution and abundance. Long-term Seagrass Monitoring Program surveys occur during the peak season only.

The Channel Upgrade Seagrass Program is structured using two levels of monitoring:

1. *Whole-of-port seagrass assessment* – The annual whole-of-port surveys are conducted across the entire port limits in October/November during the peak seagrass growing season (Figure 5). Assessing seagrass at the “whole-of-port” scale provides better context for the changes observed within the CUSP & LTSMP meadows. Annual “whole-of-port” monitoring ensures trends observed in the “monitoring meadows” represent the larger port limit area and conversely the changes in seagrasses in the wider area add important perspective and confidence to any changes seen in the “monitoring meadows”. It is at this “whole-of-port” scale that the deeper-water highly variable seagrasses between Cleveland Bay and Magnetic Island are assessed (Figure 5).
2. *Channel Upgrade Seagrass Program Biannual Assessment* – These meadows/ meadow sections are monitored biannually (during seagrass growing and senescent seasons) and capture the recommended control and impact regions for the CUSP (Figure 5). These Channel Upgrade surveys complement the annual whole-of-port surveys and the LTSMP by providing more frequent and economical evaluations of seagrass in impact and control sites.

For the CUSP there is a mix of replicated control 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 and zones of influence (Zoi). Meadow-scale monitoring also allows for assessments along a gradient of impact. The design allows for analysis of seagrass change in relation to nearby marine water monitoring sites and comparison of findings with adjacent coral communities. The larger meadow-scale monitoring allows a better ability to assess the impacts of larger scale natural events such as wind/wave driven resuspension of sediments in Cleveland Bay.

See Table 1 & Figure 5 below for the monitoring locations and the seagrass meadows that are common between the CUSP and the LTSMP with some overlap between the programs.

Table 1. Channel Upgrade Seagrass Program meadow monitoring locations

Monitoring Location (Meadow ID)	Monitoring Location Type	Seagrass Meadow Depth	Seagrass Meadow Type (dominant species)	Species Present	Common to CU Program & Long-term Program	Monitoring History	Comments / Considerations
Florence Bay (1)	Impact	Intertidal/shallow subtidal	<i>Halodule uninervis</i>	HU	N	Limited: (2007, 08, 16, 19)	Surveyed approx. every 3 yrs as part of whole-of-port survey
Geoffrey Bay (3)	Impact	Intertidal	<i>Halodule uninervis</i>	HU, HO	Y	Detailed Annual >10 years	
Geoffrey Bay (24)	Impact	Subtidal	<i>Halophila spinulosa</i>	HS	N	Limited: (2013, 16, 19)	Surveyed approx. every 3 yrs as part of whole-of-port survey
Cockle/Picnic Bay (5)	Impact	Intertidal/shallow subtidal	<i>Halodule uninervis</i>	CS, HU, HO, HS, HD	Y	Detailed Annual >10 years	
Cockle Bay (6)	Impact	Intertidal	<i>Zostera muelleri</i>	ZM, HU, HO	Y	Detailed Annual >10 years	
Shelly Beach (10)	Control	Intertidal	<i>Zostera muelleri</i>	ZM, HU, HO	Y	Detailed Annual >10 years	
Rowes Bay (12)	Impact	Intertidal/shallow subtidal	<i>Halophila spinulosa</i>	HS, HU, HO, HD, CS	Y	Detailed Annual >10 years	
Pallarenda inc. Virago Shoal (14)	Impact	Shallow subtidal	<i>Halodule uninervis</i>	HU, HO, HD	Y	Detailed Annual >10 years	
Cleveland Bay (16)	Control	Intertidal	<i>Zostera muelleri</i>	ZM, HU, CS	Y	Detailed Annual >10 years	
Cleveland Bay (17/18)	Control	Subtidal	<i>Halodule uninervis</i> / <i>Cymodocea serrulata</i> / <i>Halophila spinulosa</i>	HU, CS, HD, HS	Y	Detailed Annual >10 years	
Deep-water seagrass -Cleveland Bay to Magnetic Is. (19)	Gradient of Impact - Control	Subtidal	<i>Halophila decipiens</i> / <i>Halophila spinulosa</i>	HD, HS	N	Limited: (2007, 08, 13, 16, 19)	Surveyed approx. every 3 yrs as part of whole-of-port survey

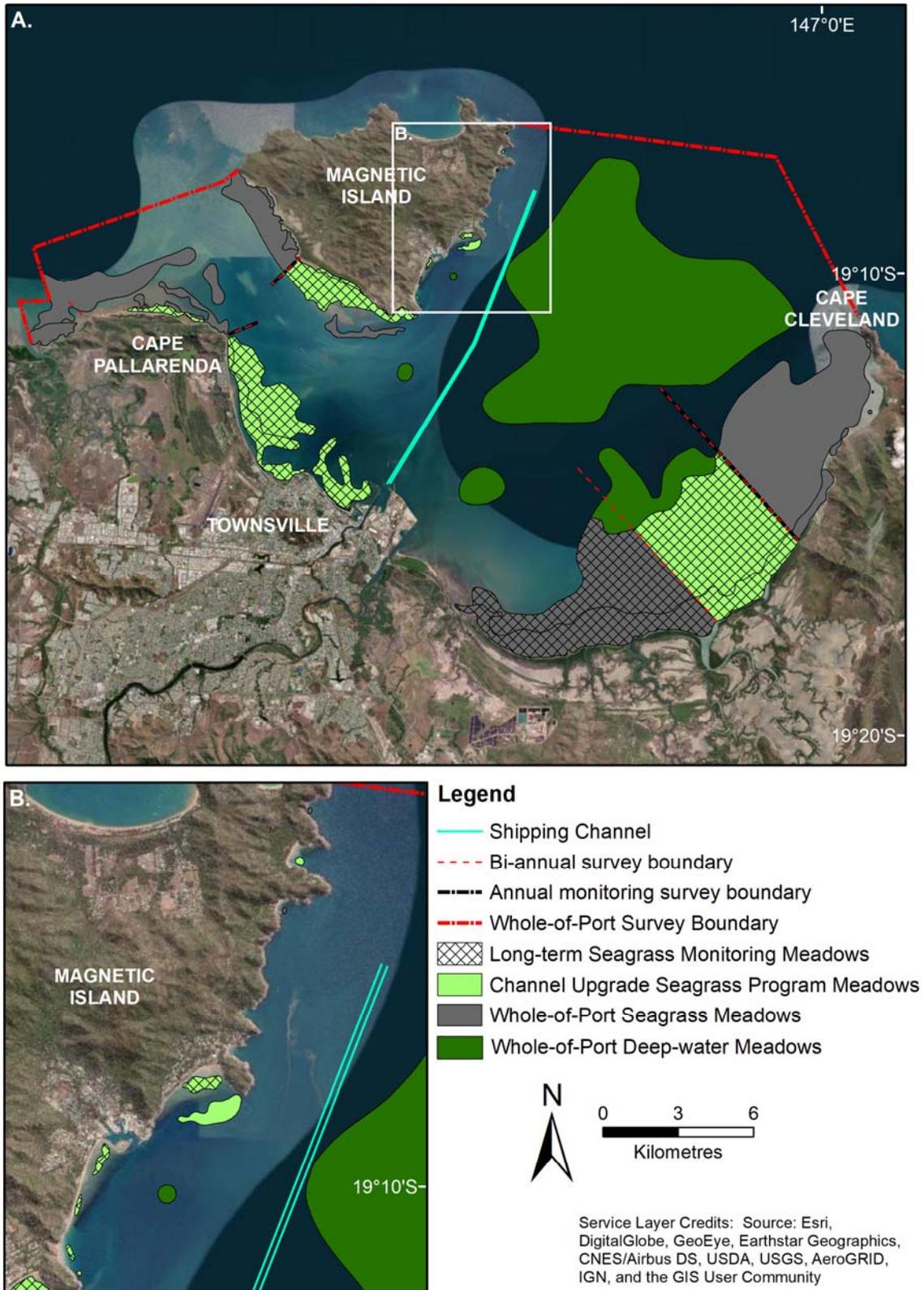


Figure 5. Location of survey extent and meadows assessed in “whole-of-port” CUSP surveys, biannually surveyed CUSP, and the LTSMP. While specific CUSP meadows are monitored biannually, “whole-of-port” CUSP surveys are conducted during the peak seagrass growing season each October/November.

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 included (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 camera drop surveys – sites are sampled perpendicular to the shoreline approximately every 50-500 m or where major changes in bottom topography occur. Sites extend to the offshore edge of seagrass meadows and measure continuity of seagrass communities.
3. *Deep-water seagrass*: boat-based CCTV camera sled tows (Figure 5c) – 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.

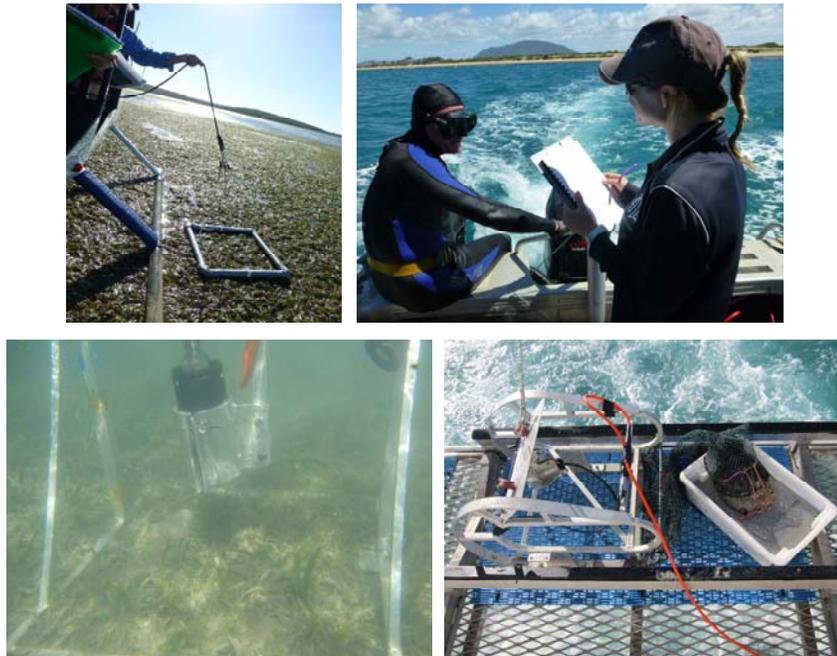


Figure 6. The different seagrass monitoring techniques and methods using helicopter aerial surveillance, boat based free divers and digital, live feed camera systems.

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

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

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 random site locations occasionally falling on one of these isolated patches.

2.3 Habitat mapping and Geographic Information System

Spatial data from the 2019 surveys were entered into the Port of Townsville Geographic Information System (GIS). Three seagrass GIS layers for each survey were created in ArcGIS®:

- *Site Layer*: The site (point) layer contains data collected at each site, including:
 - Site number
 - Temporal details – Survey date and time.
 - Spatial details – Latitude, 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); site benthic cover (percent cover of algae, seagrass, benthic macro-invertebrates, open substrate); dugong feeding trail (DFT) presence/absence.
 - Sampling method and any relevant comments.
- *Meadow layer*: The meadow (polygon) layer provides summary information for all sites within each meadow, including:
 - Meadow ID number – A unique number assigned to each meadow to allow comparisons among surveys
 - Temporal details – Survey date.
 - Habitat information – Mean meadow biomass \pm standard error (SE), meadow area (hectares) \pm reliability estimate (R) (Table 3), number of sites within the meadow, seagrass species present, meadow density and community type (Tables 2 & 3), meadow landscape category (Figure 7).
 - Sampling method and any relevant comments.
- *Interpolation layer*: 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 (g DW m ⁻²)				
	<i>H. uninervis</i> (narrow)	<i>H. ovalis</i> <i>H. decipiens</i>	<i>H. uninervis</i> (wide) <i>C. serrulata</i>	<i>H. spinulosa</i>	<i>Z. capricorni</i>
Light	< 1	< 1	< 5	<15	< 20
Moderate	1.1 – 3.9	1.1 – 4.9	5.1 – 24.9	15.1 – 34.9	20.1 – 59.9
Dense	> 4	> 5	> 25	>35	> 60

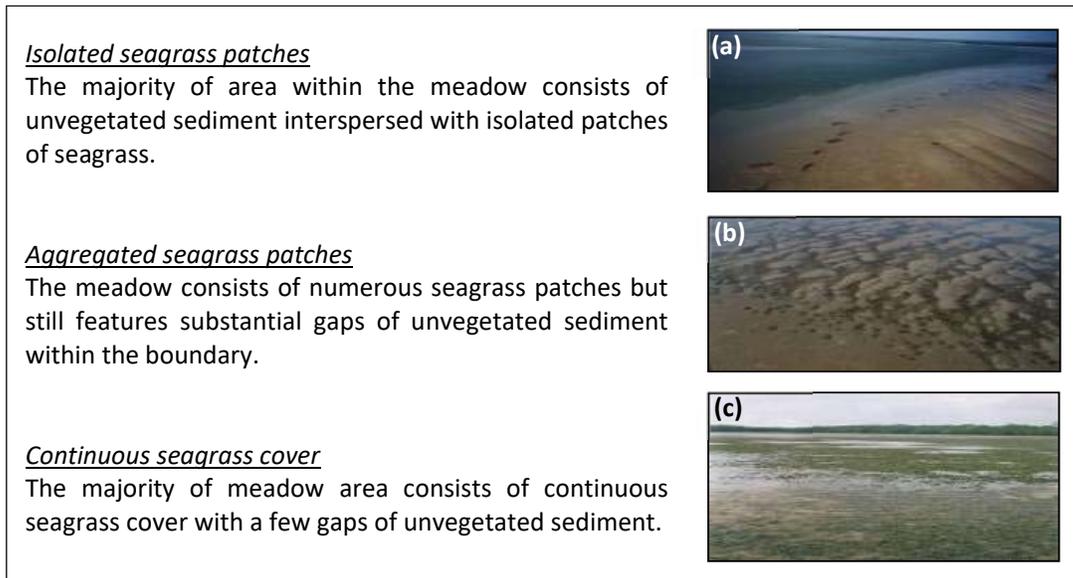


Figure 7. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover

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). Subtidal boundaries were interpreted from a combination of subtidal survey sites and 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, 2019.

Mapping precision	Mapping methodology
3-10 m	<ul style="list-style-type: none"> • 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.
30-50 m	<ul style="list-style-type: none"> • Meadow boundary interpreted from free diver/camera surveys; • Most meadows partially subtidal; • Relatively high density of survey sites; • Recent aerial photography aided in mapping.
100 m +	<ul style="list-style-type: none"> • Subtidal meadow boundaries determined from free diving/camera/grab surveys only; • Most meadows subtidal; • Moderate density of survey sites; • Recent aerial photography aided in mapping.
200 m	<ul style="list-style-type: none"> • Meadows entirely subtidal; • Deepwater meadow; • Meadow boundary interpreted from camera/distance between survey sites and/or presence/absence of seagrass; • Moderate – sparse density of survey sites.

2.4 Seagrass condition assessments & index

A key advantage of the approach to monitoring presented in the CUSP is that there will be multiple avenues to assess seagrass change in relation to capital dredging and natural drivers, including:

1. Examining seagrass condition against the existing long-term (12 year) history for the monitoring meadows(i.e. LTSMP);
2. Analysing changes in relation to the network of control/reference and impact meadows at given points in time (traditional BACI approach);
3. Annual holistic assessment of the total seagrass resource within the wider area to place changes into the local context (i.e. Whole-of-port surveys);
4. Placing changes in the CUSP within the wider context of regional or state-wide seagrass change by direct reference to monitoring conducted using the same methods in other locations (e.g. identify seagrass change due to region-wide events - La Niña climate etc.)

We have already established baseline conditions for seagrass meadow biomass, area and species composition at the eight CUSP meadows that have been monitored as part of the existing LTSMP (Table 1). Baselines were informed by annual means calculated over the first 10 years of monitoring (2007 – 2016) (Figure 8). The 10-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).

For the two CUSP meadows outside of the LTSMP (Meadows 1 & 24; Table 1) where baseline conditions have not been established due to limited data, we will, prior to the dredging commencing develop baseline conditions using the data available at that time.

For the ten seagrass meadows part of the LTSMP, a condition index has been developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline. 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.

The CUSP will continue to report on condition scores for the LTSMP meadows (see section 3.3). These scores however, will not be used to inform whether the CU Project dredging campaign has had a potential impact/no impact on seagrasses in the Townsville area. They will be used however to track the trend in seagrass meadows over time and throughout the CU Project dredging campaign.

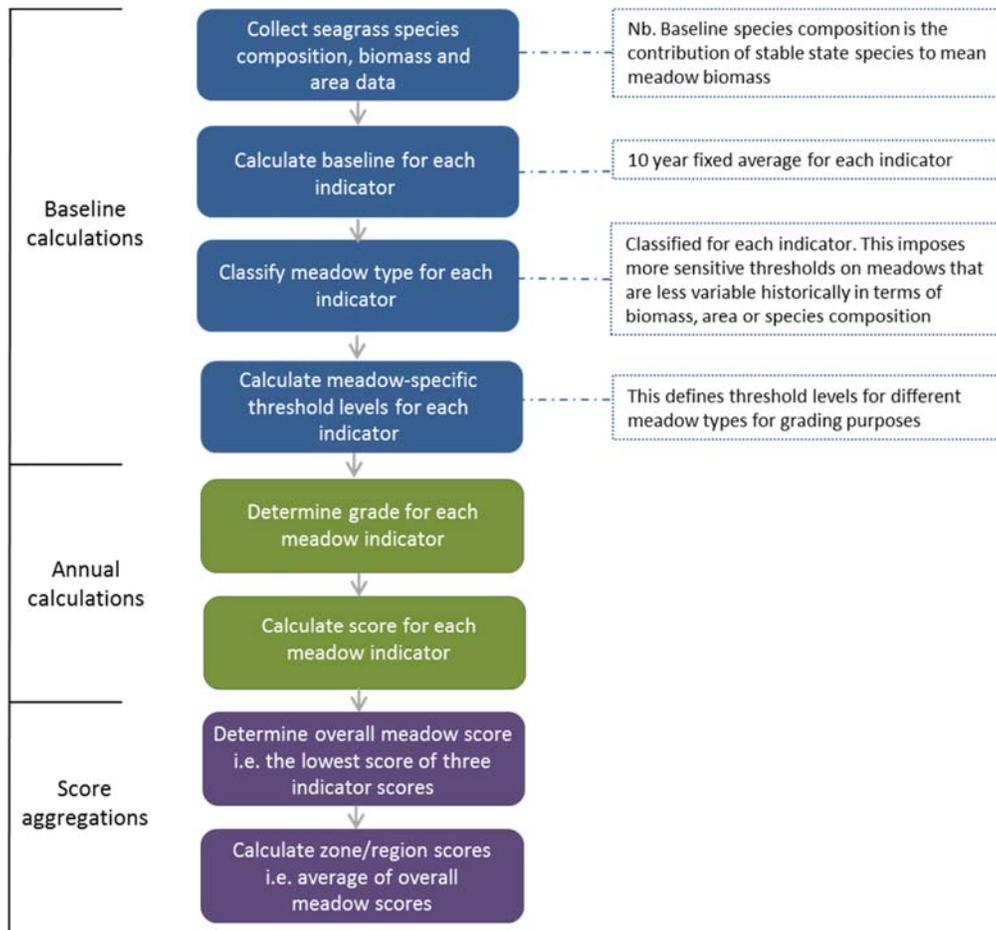


Figure 8. Flow chart to develop Townsville grades and scores.

2.5 Statistical design and analysis

Once the CU Project dredging campaign has begun, our statistical design and analysis will follow the typical BACI design commonly used in impact assessment (before-during-after and control-impact). As a minimum seagrass will be assessed as either a control or impact location, as identified in Table 1. We will also incorporate a finer-scale analysis with several impact levels (zones of influence, low impact, moderate impact

and high impact), and also to analyse capital dredging effects along a gradient of impact for seagrass meadows that span several of these zones, e.g. the deep-water meadow from Magnetic Island to Cleveland Bay, The Strand to Shelly Beach, and Florence Bay to West Point (Figure 1). Analysis at this scale will require access to the marine water monitoring data and knowledge of where the dredge is working, over the life of the CU Project so we can accurately assign impact levels to seagrass meadows.

Seagrass data in tropical Queensland rarely meets the assumptions required to conduct standard statistical analysis used in BACI impact assessments, such as ANOVA. We have however, extensive experience in advanced statistical techniques used to deal with difficult data, including generalised linear mixed models, logistic regression, zero-inflated models and zero-altered gamma models. Our in-house expertise in data visualisation and mapping is also excellent and these skills will be used in all levels of reporting.

2.6 Environmental data

Environmental data were collated for the 12 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 The Queensland Governments Water Monitoring Information Portal <https://water-monitoring.information.qld.gov.au/>.

In future, detailed environmental data for the Townsville area (i.e. Photosynthetically Active Radiation (PAR) mol photons m⁻² day⁻¹) will be supplied by the CU Project Marine Water Monitoring team program.

3 RESULTS

3.1 Whole-of-Port Channel Upgrade Seagrass Program Distribution & Abundance

The first baseline surveys conducted as part of the LTSMP in Townsville were in October 2007 (peak seagrass growing season) and June 2008 (seagrass senescent season) (Rasheed and Taylor 2008). As part of the long-term program a full re-assessment of all seagrasses within the broader port was commissioned in October 2013 and October 2016 to provide updated information of the seagrass distribution (Wells and Rasheed 2017).

Ten seagrass species have historically been identified within the Townsville region. With the exception of *Syringodium isoetifolium*, all species (nine) were present in the two surveys completed in 2019 (Figure 9). The last time *S. isoetifolium* was found in the port was in 2015. *Syringodium isoetifolium* seems to come and go from the Townsville area.

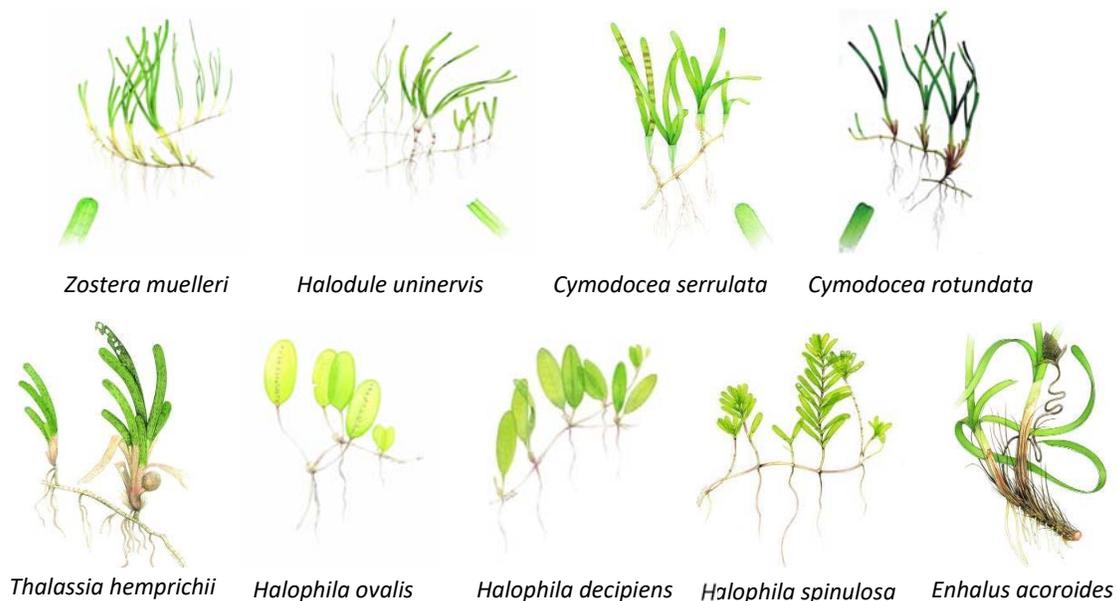


Figure 9. Seagrass species present within the Port of Townsville, 2019.

In 2019 two whole-of-port surveys were conducted in the Port of Townsville (Figure 10);

- April-May; seagrass senescent season (also post February 2019 floods): 1,323 habitat assessment sites/transects;
- September-October; seagrass peak season: 1,683 habitat assessment sites/transects.

Peak season whole-of-port surveys have been conducted previously in 2007/2008, 2013, and 2016 (Figure 10). Seagrass extent around the port has been fairly stable in each of these surveys, particularly around Magnetic Island and Cape Pallarenda while the Cape Cleveland and Deep-water meadows have had a more varied footprint (Figure 10). More notably, whole-of-port 2019 growing season biomass is the lowest for the program across all regions (Figure 10). This port-wide decline in 2019 seagrass biomass is a sharp contrast to meadow biomass recorded in the last four years of the regular LTSMP as well (Figure 11) (Bryant et al. 2019; Wells and Rasheed 2017; Rasheed and Taylor 2008).

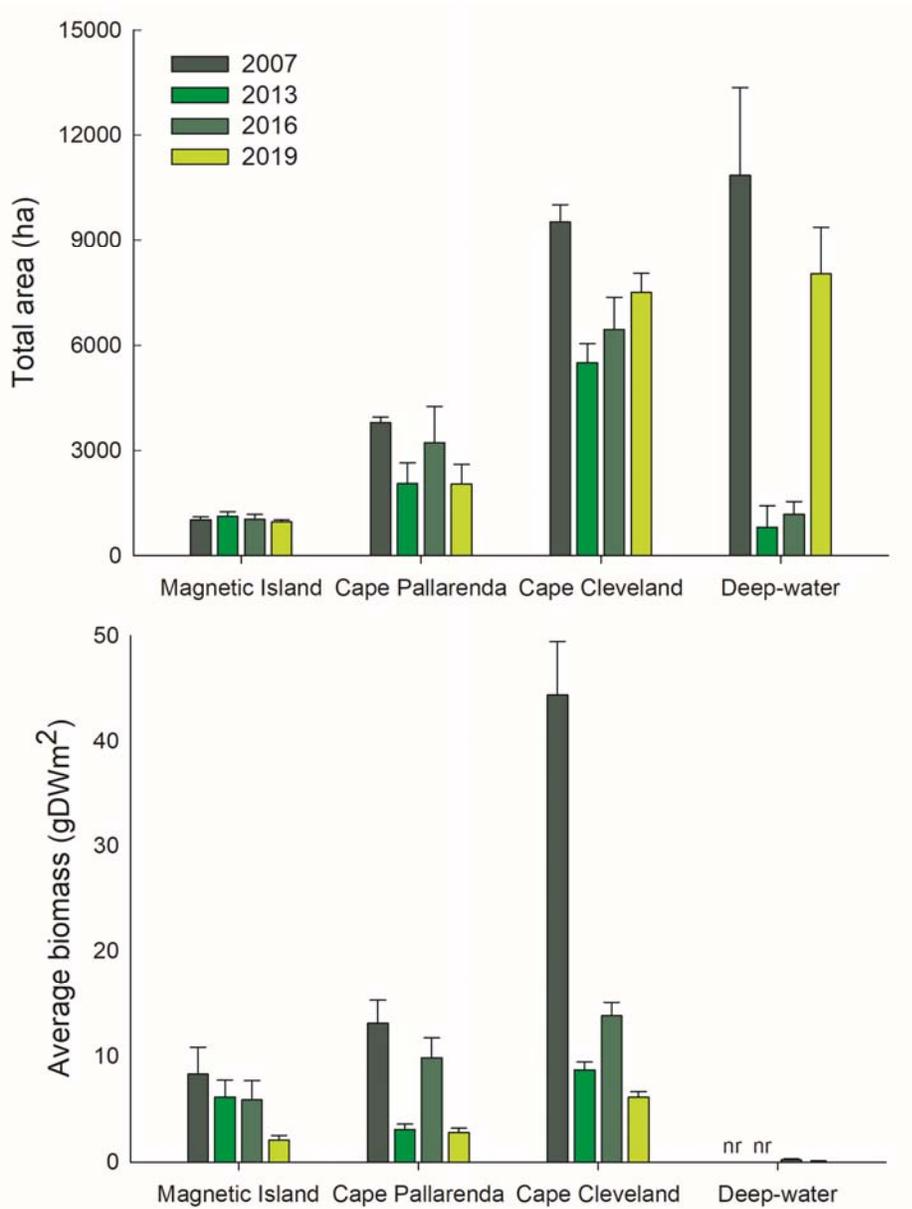


Figure 10. Comparison of meadow area and biomass in four regions within the broader vicinity of the Port of Townsville from growing season (October) baseline surveys in 2007, 2013, 2016 and 2019 (biomass error bars = SE; area error bars = “R” reliability estimate). nr = not recorded as part of survey

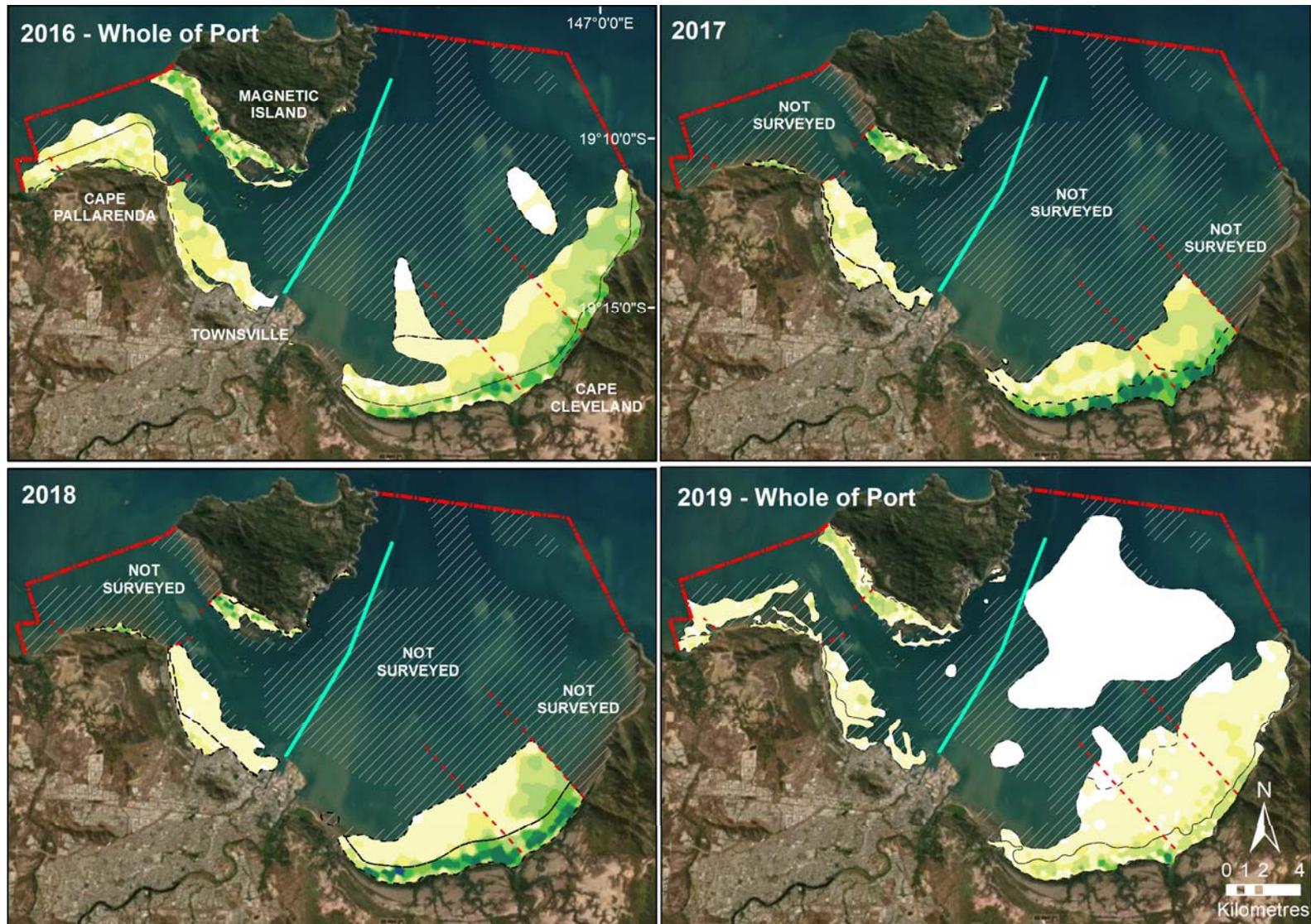


Figure 11. Comparison of growing season seagrass biomass (g DWm^{-2}) and meadow extent from 2016 – 2019. Note 2017 and 2018 surveys assessed LTSMP monitoring meadows only.

CUSP Whole-of-Port Seasonal Comparison

Seagrass habitat mapped across the whole-of-port more than doubled from the senescent to growing season in 2019; 8,805 ± 1,100 in the senescent season versus 18,522 ± 2510 ha of seagrass in peak season (Figure 12).

The senescent season seagrass footprint was solely from inshore seagrass meadows due to the absence of the deep-water (>10m) meadow, which is typical for the time of year (Figure 12). For the species mix present in each meadow, meadows ranged in density from light to moderate cover (according to density nomenclature developed for the broader Queensland ports seagrass monitoring program; see section 2.3), with no dense seagrass meadows present in the April/May survey.

In the peak seagrass growing season, inshore seagrass meadows covered 10,499 ± 1,167ha, a 19% increase in their footprint from the April/May 2019 survey (Figure 12). Individual inshore seagrass meadows ranged in size from relatively small isolated patches to large (~524 ha) mixed species (8 species) meadows of continuous cover with some meadows increasing from moderate to dense cover from the April/May surveys.

The deep-water seagrass meadow (Meadow 19) recorded in the whole-of-port peak season survey covered 8,023 ± 1343ha with seagrass recorded to 14.4m (below mean sea level) (Figure 12 and 13). Such an extent of deep-water seagrass has not been recorded in the Townsville area since 2008 (Wells & Rasheed 2017) (whole-of-port surveys that target deep-water seagrass have been conducted in 2007, 2008, 2013, 2016, May 2019).

Dugong feeding trails in seagrass meadows were observed at 18 survey sites in the senescent season, compared to 24 sites in the peak season. The animals themselves were observed regularly during both field surveys. Green sea turtles were also observed during the field work.

3.2 Channel Upgrade Seagrass Program Meadows

As this is the first of the CUSP assessments, and the dredging campaign has not begun, no statistical analysis in terms of assessing CU Project impacts has been conducted on the data from these surveys. The baseline condition for the CUSP meadows that are also part of the LTSMP will use the 10-year baseline condition established for these meadows. The baseline condition for the CUSP sub-section of the Cleveland Bay meadow (Meadow 17/18) will be extracted from the historical data available. The two CUSP meadows not part of the LTSMP (Meadows 1, and 24), will have all available data analysed up until dredging is underway to ensure the maximum timeframe possible can be used as a reference to “during” and “post” dredging period surveys. Once more data becomes available (i.e. the dredge campaign start date, “during dredging seagrass assessments”, knowing where in the channel the dredge is working, water quality data etc.), we will be able to assign impact levels to individual meadows and analyse potential capital dredging impacts along a gradient of meadows and impact zones.

Eleven seagrass meadows make up the Channel Upgrade Seagrass Program (Figure 13). These meadows range in depth from being intertidal and completely exposed on spring low tides (i.e. Meadow 10 at Shelley Beach), to being subtidal, extending to approximately 11m below mean sea level (i.e. Meadow 24 in Geoffrey Bay, Magnetic Island).

Section 3.3 discusses in greater depth the historical trends for the eight CUSP meadows that are part of the ten meadows assessed in the LTSMP. For CUSP seasonal comparisons, however, six of the eleven meadows either were below or unchanged in biomass from May to October in 2019 (Figure 13). Seagrass biomass typically increases significantly from May when tropical Queensland seagrasses are at their minimum to a peak in late spring (i.e. growing season). Those meadows that did increase in biomass were all *Zostera*

muelleri dominated (Meadows 6, 10, and 16) or *Halophila* spp. meadows that are ephemeral and only present in the growing season (Meadows 12, 19, and 24) (Figure 13). Those meadows that declined or remained at their senescent season levels were dominated by *Halodule uninervis* (Figure 13).

Results from the LTSMP has shown that historically Townsville meadows can vary substantially from year to year and seasonally within years (see section 3.3). The CU Project monitoring meadows and the species that make up these meadows can behave differently to each other in response to different environmental pressures. Capturing the range of species and meadow types ensures that the range of potential responses by seagrasses to the CU Project are adequately captured.

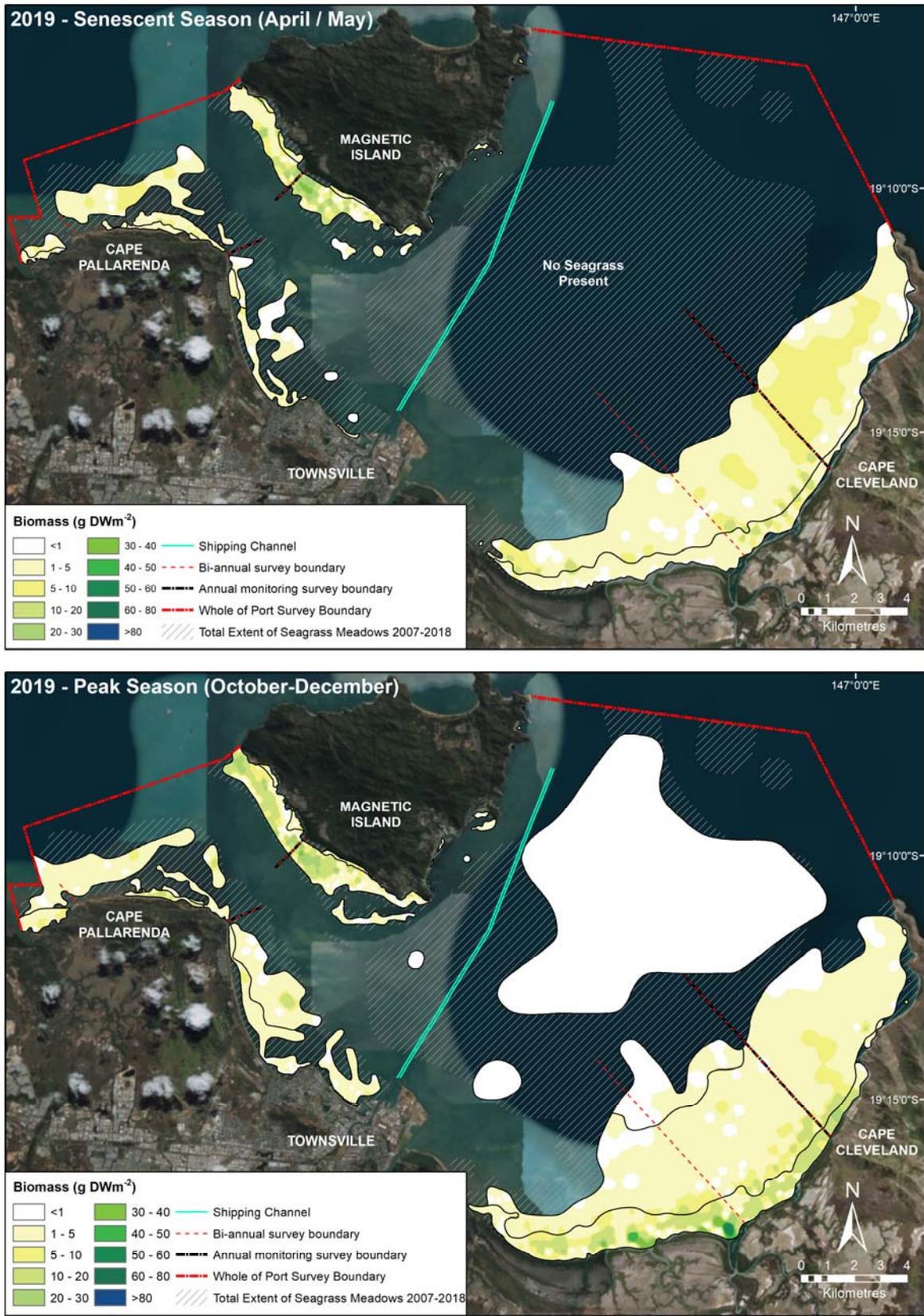


Figure 12. Seagrass density and distribution in the 2019 A) senescent and B) growing season whole-of-port surveys.

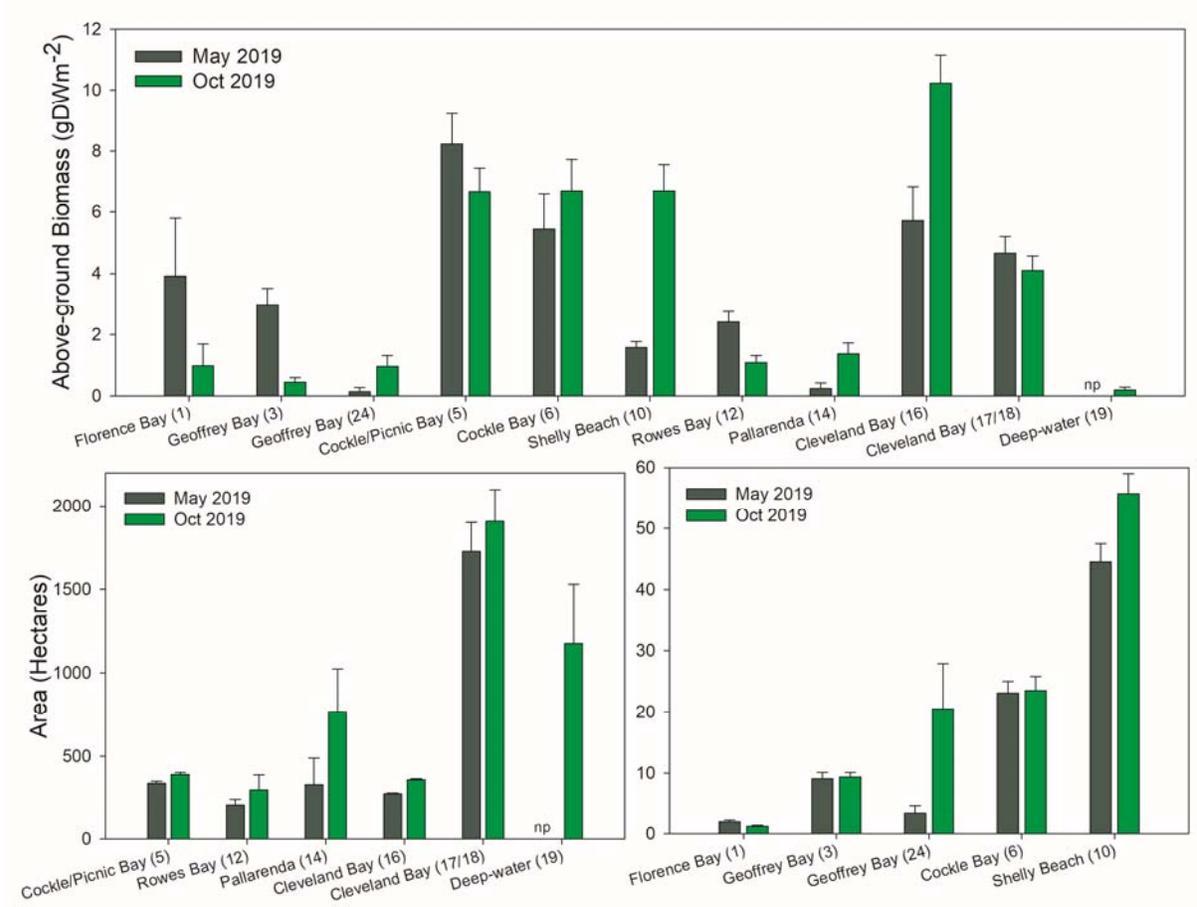


Figure 13. CUSP meadow biomass and area in May and October 2019 surveys.

3.3 Long-term Seagrass Monitoring Program meadow condition

The overall condition of the Townsville 2019 LTSMP meadows was satisfactory, a decline from a good condition in 2018 (Table 7). Only one meadow was classed as good with two meadows in poor condition. In most cases, above-ground biomass declines led to a drop in meadow condition with only three out of ten meadows maintaining their 2018 overall condition. While no scores improved for any meadow metric, species composition shifted very little while meadow area scores dropped in just four of the ten meadows (Table 7).

Despite the extreme flooding event in early 2019, seagrasses have maintained a good foothold compared to previous major flooding impacts in 2010/2011 (Figure 14).

Average above-ground biomass ranged from 0.45 ± 0.14 g DW m⁻² in the intertidal *Halodule uninervis* meadow at Geoffrey Bay (Meadow 3; Figure 15; Appendix 3) to 8.97 ± 0.79 g DW m⁻² in the intertidal *Zostera muelleri* meadow in Cleveland Bay, a 75% decline from its' 2018 peak (Meadow 16; Figure 23; Appendix 3). The only meadow to not decline in biomass score is the intertidal *Z. muelleri* meadow (Meadow 6) at Magnetic Island (Figure 17).

Seagrass landscape coverage within the majority of meadows maintained some continuous cover of seagrass but greater patchiness with aggregated and isolated patches was found throughout (Appendix 3).

The combined area of LTSMP meadows in Townsville remained similar to 2018 and was the second highest total monitoring area ($6,354 \pm 758$ ha) since monitoring began in 2007 (Figure 2). Individual meadow area ranged from 4.16 ha in the intertidal *H. uninervis* meadow at The Strand (Meadow 15) to 3,422 ha in the subtidal Cleveland Bay meadow (Meadow 17/18) (Appendix 3).

In 2019, the proportion of the persistent species *Z. muelleri* remained high and similar to 2018 levels in meadows where it has historically been the dominant species (Meadow 6, 10, and 16; Appendix 4). The proportion of *C. serrulata*, a larger foundation species decreased slightly in intertidal seagrass communities at Magnetic Island and Cleveland Bay (Meadows 5 and 16; Figures 17 and 23; Appendix 4) but increased somewhat at the large subtidal meadow in Cleveland Bay where *H. uninervis* has remained dominant (Meadow 17/18; Figure 24; Appendix 4).

Dugong feeding trails were observed in six out of ten meadows and across all three areas of the port (Pallarenda, Magnetic Island, and Cleveland Bay). Active dugong feeding was also observed in the Cleveland Bay subtidal meadow (Meadow 17/18).

Table 7. Scores for seagrass indicators (biomass, area and species composition) for the CUSP meadows part of the LTSMP and those meadows not part of CUSP; Nelly Bay (Meadow 4) and The Strand (Meadow 15).

Meadow	Biomass	Area	Species Composition	Overall Meadow Score
3	0.28	0.73	0.97	0.28
4	0.41	0.85	0.98	0.41
5	0.60	0.89	0.98	0.60
6	0.66	0.50	0.97	0.50
10	0.68	0.51	0.96	0.51
12	0.60	1.00	0.69	0.60
14	0.55	0.74	0.87	0.55
15	0.73	0.74	0.58	0.65
16	0.59	1.00	0.94	0.59
17/18	0.55	0.88	0.98	0.55
Overall Score for the Port of Townsville 2019				0.52

Magnetic Island monitoring meadows

Average above-ground biomass declined in all four of the LTSMP Magnetic Island meadows (Meadows 3, 4, 5, and 6) leading to a drop in biomass scores in all but the Cockle Bay meadow (Meadow 6; Table 7; Figures 15-18; Appendix 3). The Geoffrey Bay meadow (Meadow 3), declined sharply in biomass to levels last seen in 2015 after which it rebounded and had three consecutive years of good and very good scores (Figure 15). Meadows 4 and 5 had already measured reduced biomass in 2018 but dropped more severely in 2019.

Area also declined somewhat in all but the Cockle/Picnic Bay meadow (Meadow 5) but not as severely as the declines in biomass. In contrast, species composition was stable across all Magnetic Island meadows or improved (Figures 15-18). The *H. uninervis* meadow in Geoffrey Bay (Meadow 3) further receded along both the inshore and offshore boundary following a record distribution in 2017; the only significant change in Magnetic Island meadow area scores yet still deemed to be in good condition (Figure 15).

All Magnetic Island meadows had species compositions that were well above the baseline average conditions with a species mix that reflected a very good condition (Table 7; Appendix 4).

Cape Pallarenda monitoring meadows

Average above-ground biomass at the intertidal *Z. muelleri* meadow at Shelly Beach (Meadow 10) was sharply down in 2019 after general increases over the 2011 to 2017 period (Figure 19). Despite the decline, biomass was still deemed to be in a good condition, near the long-term average while area remained similar to 2018 in a satisfactory condition (Figure 19). Similar to Magnetic Island meadows, despite the biomass losses, species composition remained in a very good condition with >90% of meadow biomass composed of *Z. muelleri* (Figure 19; Appendix 4).

At the Rowes Bay intertidal *H. uninervis* meadow (Meadow 12) biomass declined to levels last recorded in 2015 resulting in a downgrade to a satisfactory score (Figure 20). Similar to Shelley Beach, area and species composition were steady and in a very good condition and good condition respectively (Figure 20; Appendix 4).

At the adjacent deeper *Halophila spinulosa* meadow (Meadow 14), average biomass declined for the third consecutive year, falling to 2015 levels at a satisfactory condition (Table 7; Figure 21). The previous

expansion of this meadow retracted to near long-term average extent and therefore a drop from very good to good condition (Figure 21). Since 2015, *H. uninervis* has become a more substantial proportion of the meadow which is considered to be more persistent or equivalent to *H. spinulosa*. In 2019, *H. uninervis* became the dominant meadow species with only a small proportion of *H. spinulosa* remaining (Figure 21; Appendix 4).

The intertidal *H. uninervis* meadow along the Strand (Meadow 15) has historically been extremely patchy and highly variable, disappearing completely in 2013. The meadow re-established in 2014 and biomass and area subsequently expanded to peak in 2016 and 2018, well above levels described in the initial baseline surveys (Figure 22; Appendix 2). In 2019, average biomass and meadow area decreased to the long-term average which drove the overall good condition score for the meadow (Table 7; Figure 22). A further increased proportion of the less persistent *H. spinulosa* drove a drop in species score (Figure 22; Appendix 4).

Cleveland Bay

At the inshore intertidal *Z. muelleri* meadow (Meadow 16), average biomass declined sharply below the long-term average to a satisfactory score (Figure 23). Despite the loss in biomass, area remained fairly steady with a significant spatial footprint above the long-term average (Figure 23). Species composition did not change substantially however a less persistent species, *Halophila decipiens*, did return to the meadow after being absent in 2018 (Figure 23; Appendix 4).

At the adjacent subtidal meadow (Meadow 17/18), average above-ground biomass continued to decline from 2018, leading to a score of satisfactory (Figure 24; Appendix 3). Although this decline has resulted in a reduction of biomass, the overall presence of *H. uninervis* and *C. serrulata* in Cape Cleveland has remained stable and area remained at a very good level (Figure 24).

During the baseline surveys in 2007 and 2008, two subtidal Cape Cleveland meadows were distinguished based on the species composition, particularly the presence of *C. serrulata* (Meadows 17 and 18). In 2010 the two meadows were merged following the complete disappearance of *C. serrulata* (Figures 24). A four-year decline in meadow area from 2007-2011 left the meadow severely fragmented into four remnant patches of extremely low biomass (Figure 24; Appendix 3). During this time the species composition shifted from a *C. serrulata*-dominated meadow to a *H. uninervis* meadow, with higher proportions of *Halophila* species. In 2013 *C. serrulata* returned as a small proportion (< 1%) of the total biomass and has subsequently increased by spreading from the far eastern boundary of the meadow along the coast and offshore (Figure 24).

Since the initial recovery in 2012, meadow area has increased by around 1500 ha, primarily along the deeper margins as well as the western end south of Alligator Creek (Figure 24). In 2019, area remained stable (Figure 24; Appendix 3) and *H. uninervis* continued to account for around 50% of the biomass, shifting the species composition back from a *C. serrulata* to a *H. uninervis*-dominated meadow since 2018 (Appendix 4).

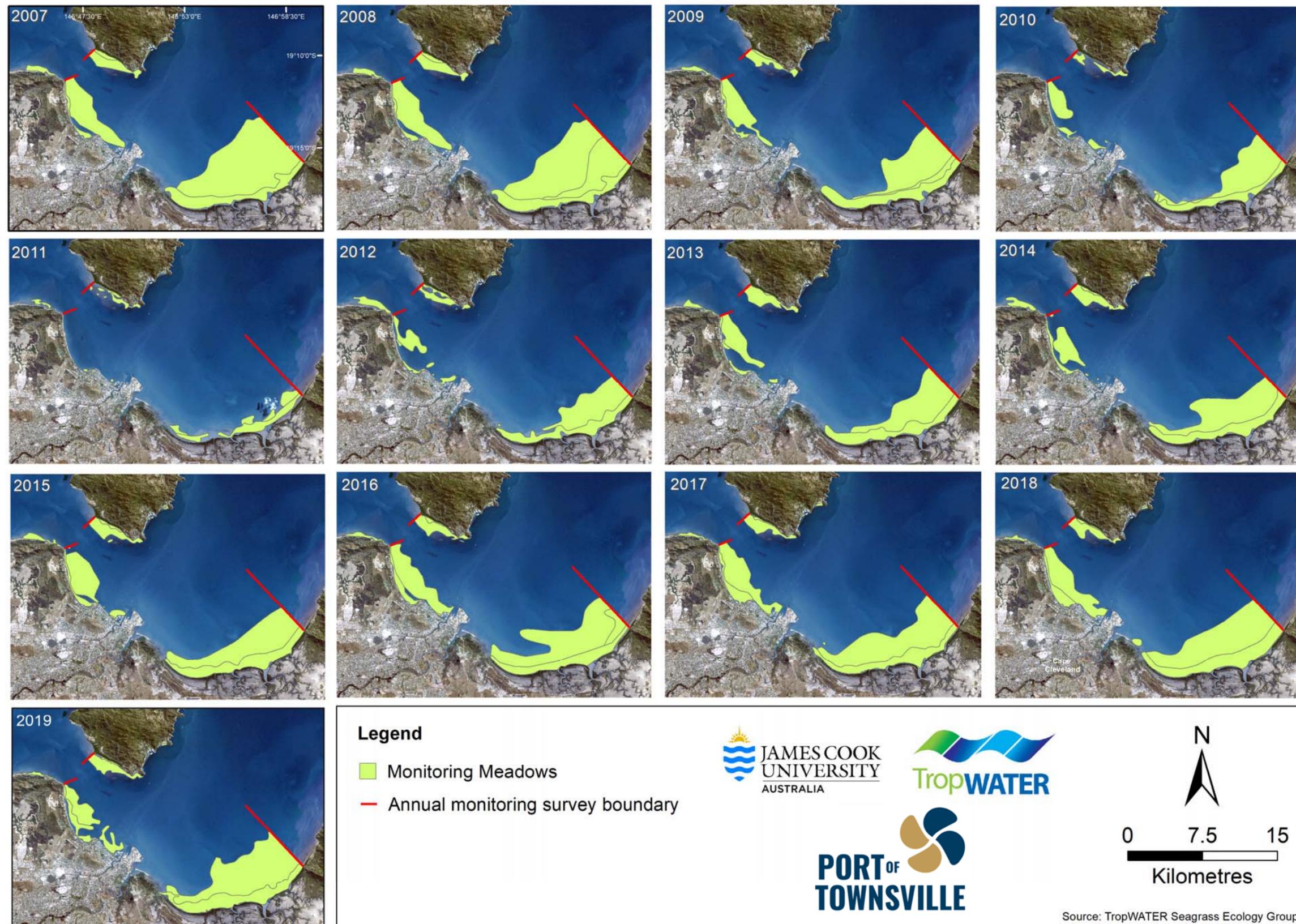


Figure 14. Long-term Seagrass Monitoring Program meadow locations and spatial extent from 2007 – 2019.

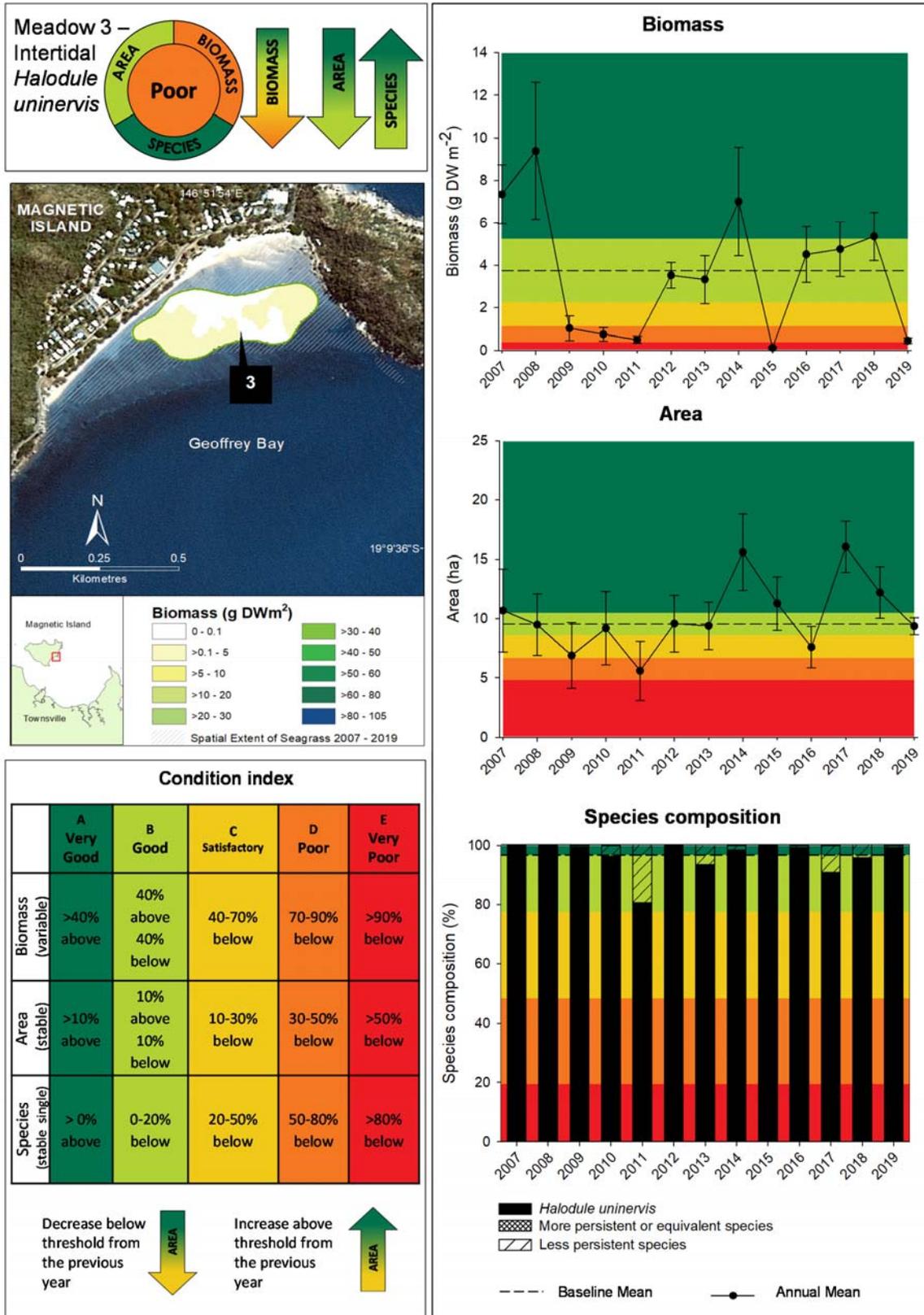


Figure 15. Changes in meadow area, biomass and species composition for seagrass Meadow 3 at Magnetic Island, 2007 – 2019. (biomass error bars = SE; area error bars = “R” reliability estimate).

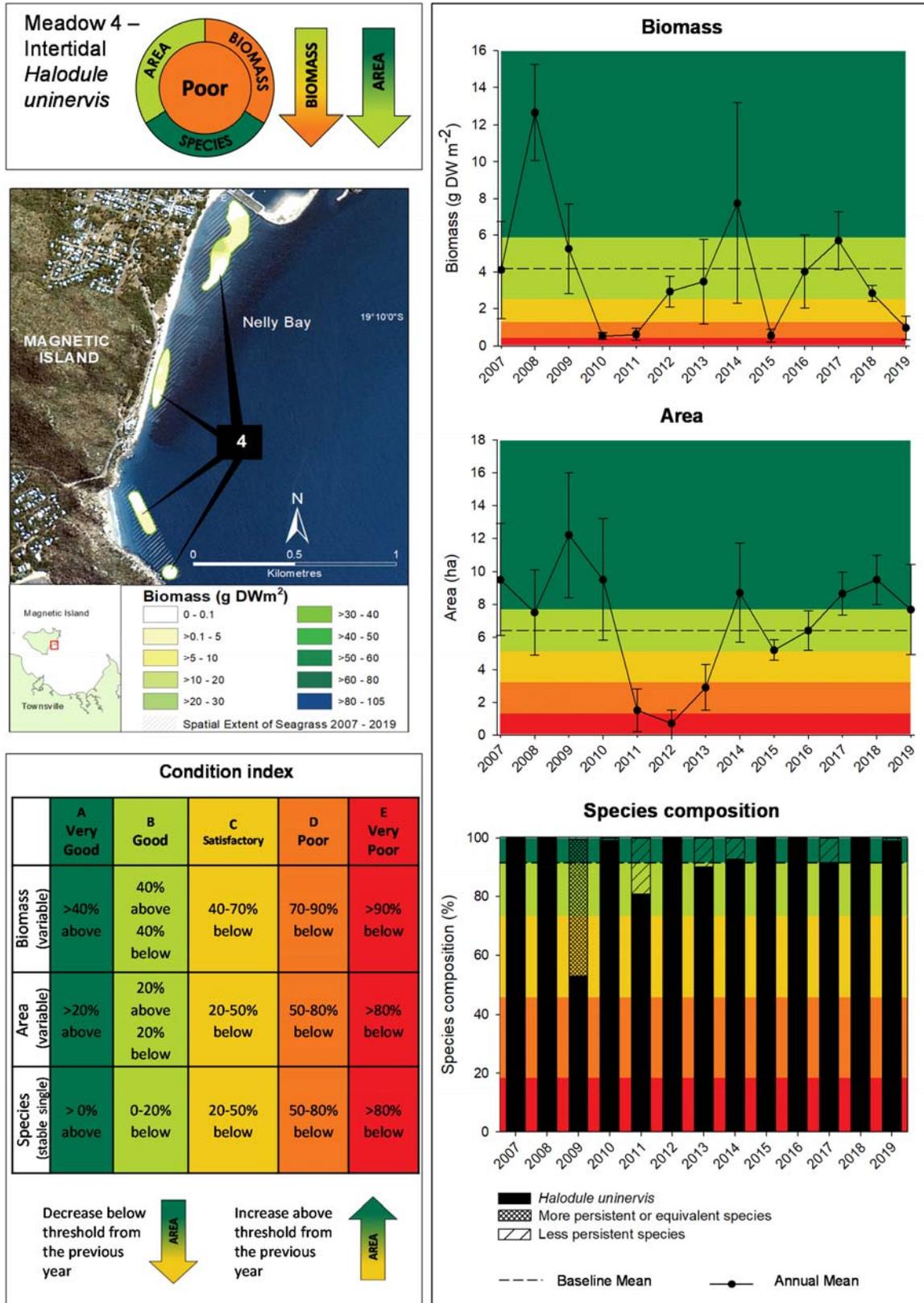


Figure 16. Changes in meadow area, biomass and species composition for seagrass Meadow 4 at Magnetic Island, 2007 – 2019. (biomass error bars = SE; area error bars = “R” reliability estimate).

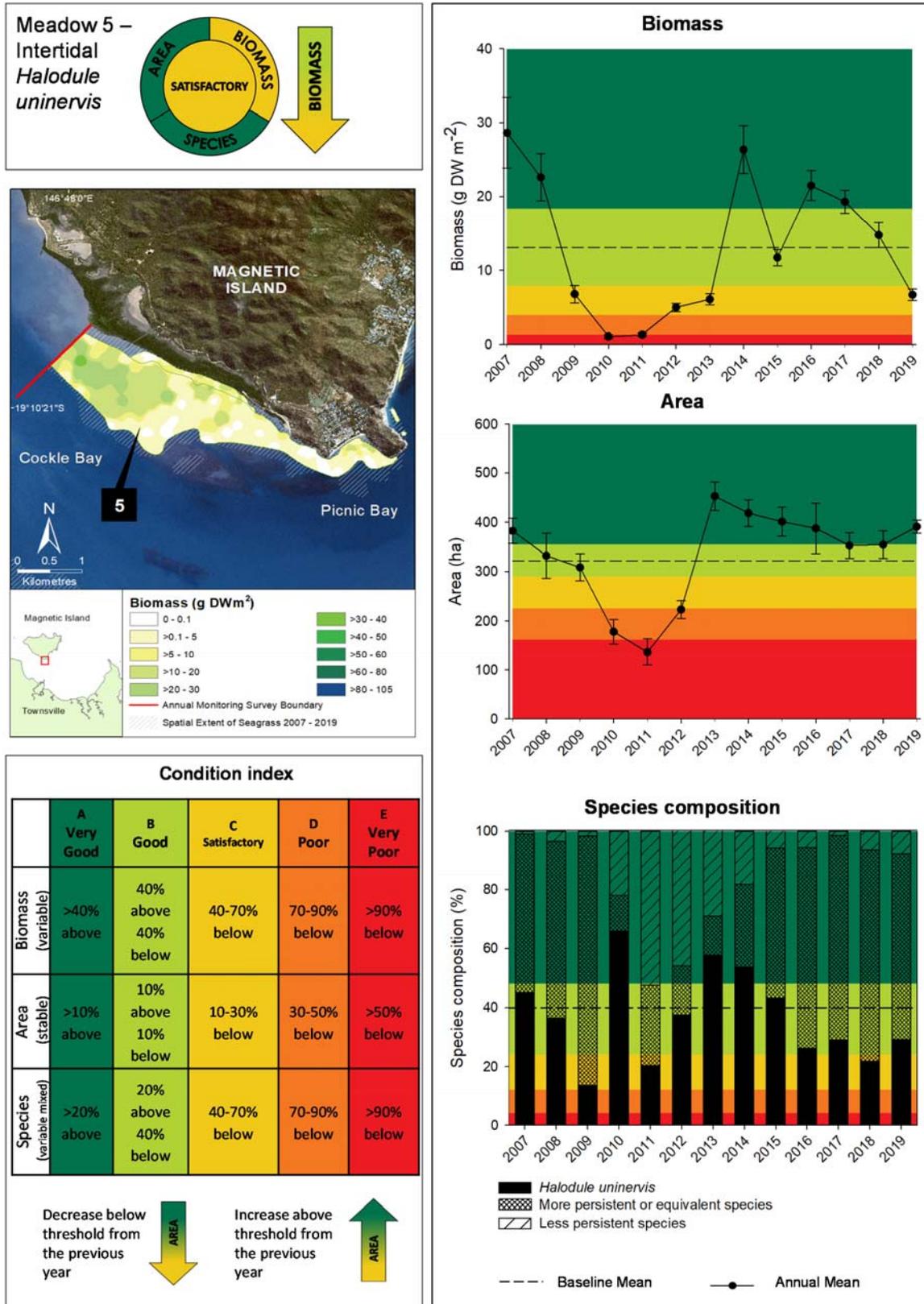


Figure 17. Changes in meadow area, biomass and species composition for seagrass Meadow 5 at Magnetic Island, 2007- 2019. (biomass error bars = SE; area error bars = “R” reliability estimate).

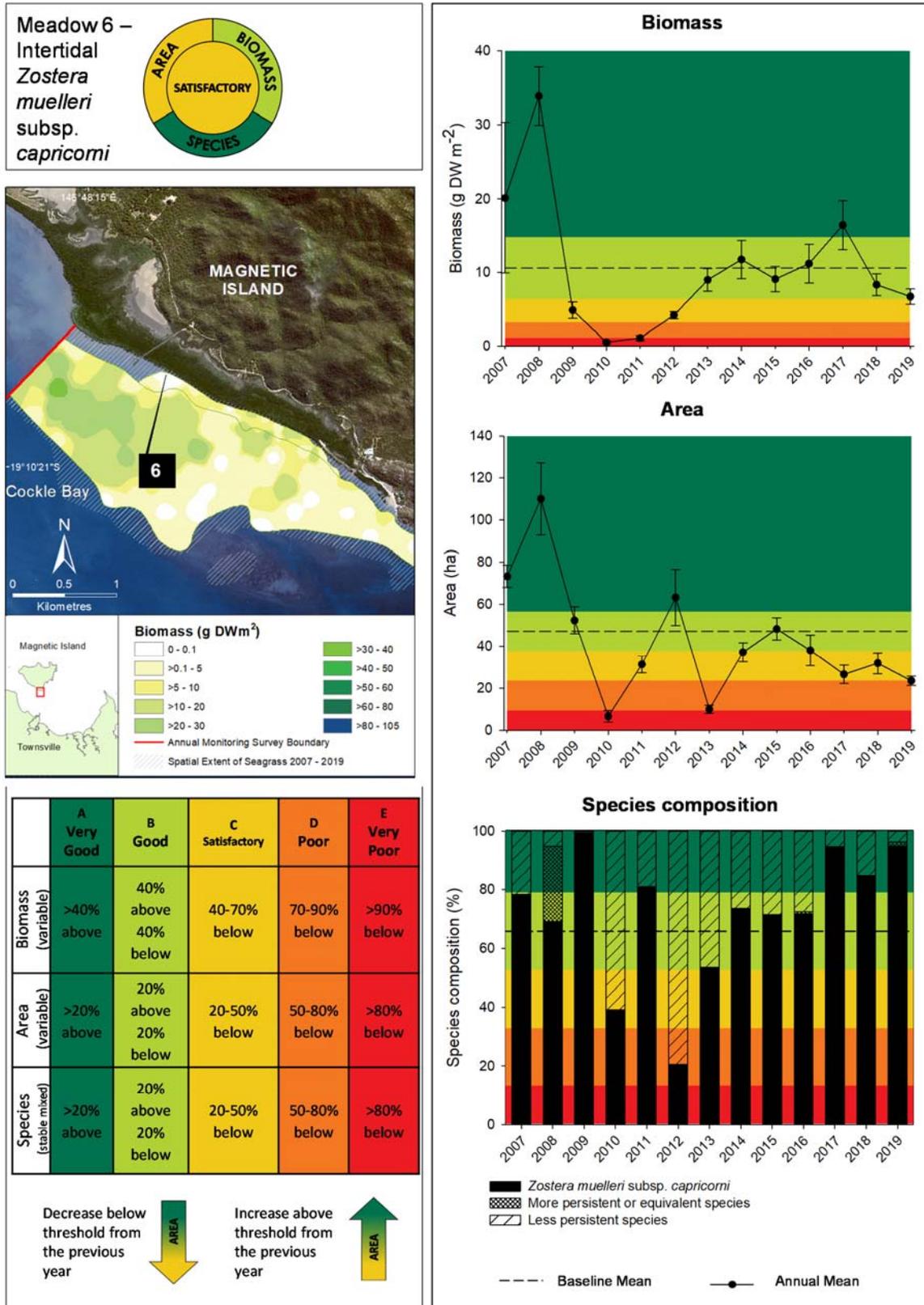


Figure 18. Changes in meadow area, biomass and species composition for seagrass Meadow 6 at Magnetic Island, 2007- 2019. (biomass error bars = SE; area error bars = “R” reliability estimate).

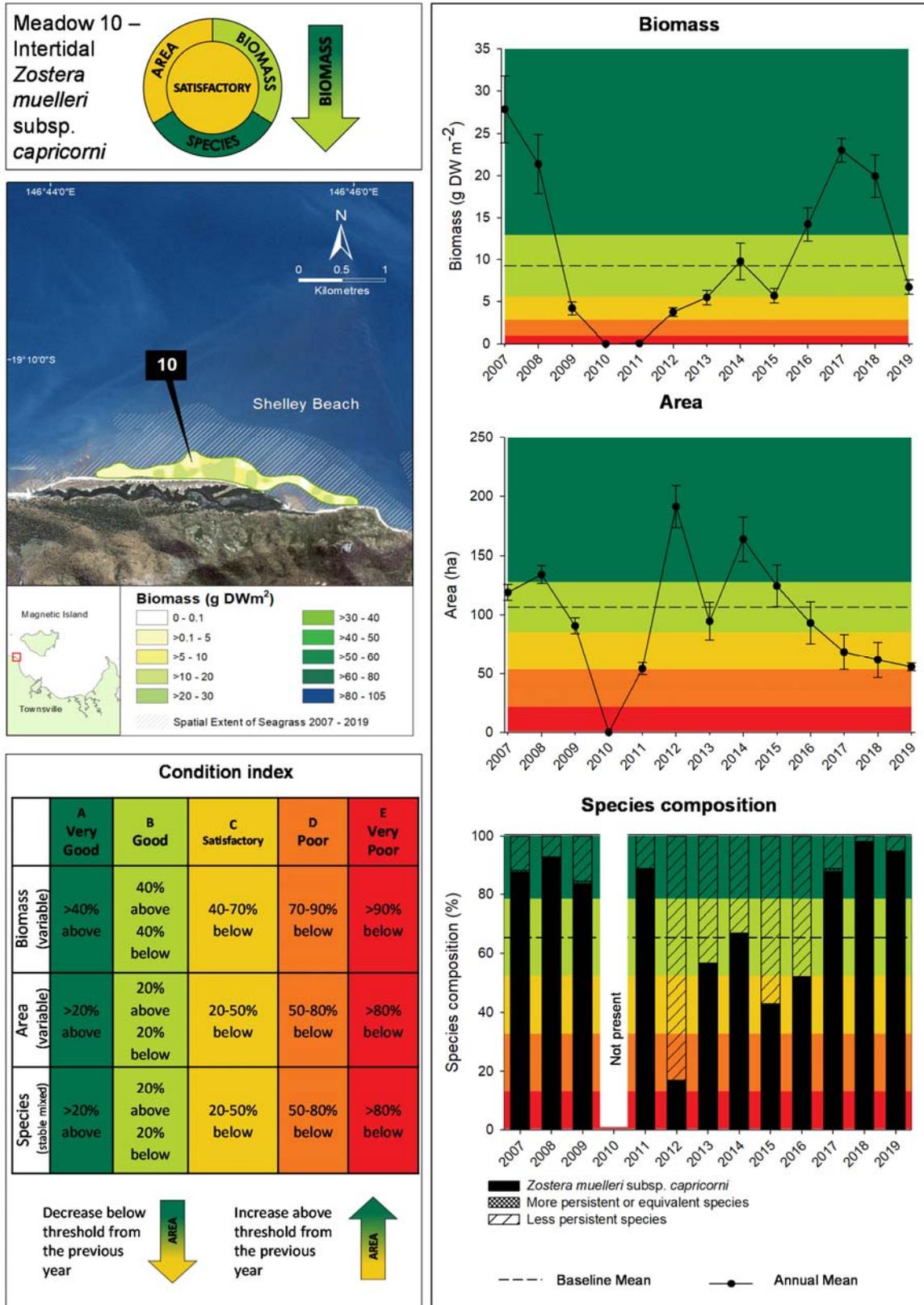


Figure 19. Changes in meadow area, biomass & species composition for seagrass Meadow 10 in Shelley Beach, 2007 – 2019. (biomass error bars = SE; area error bars = “R” reliability estimate).

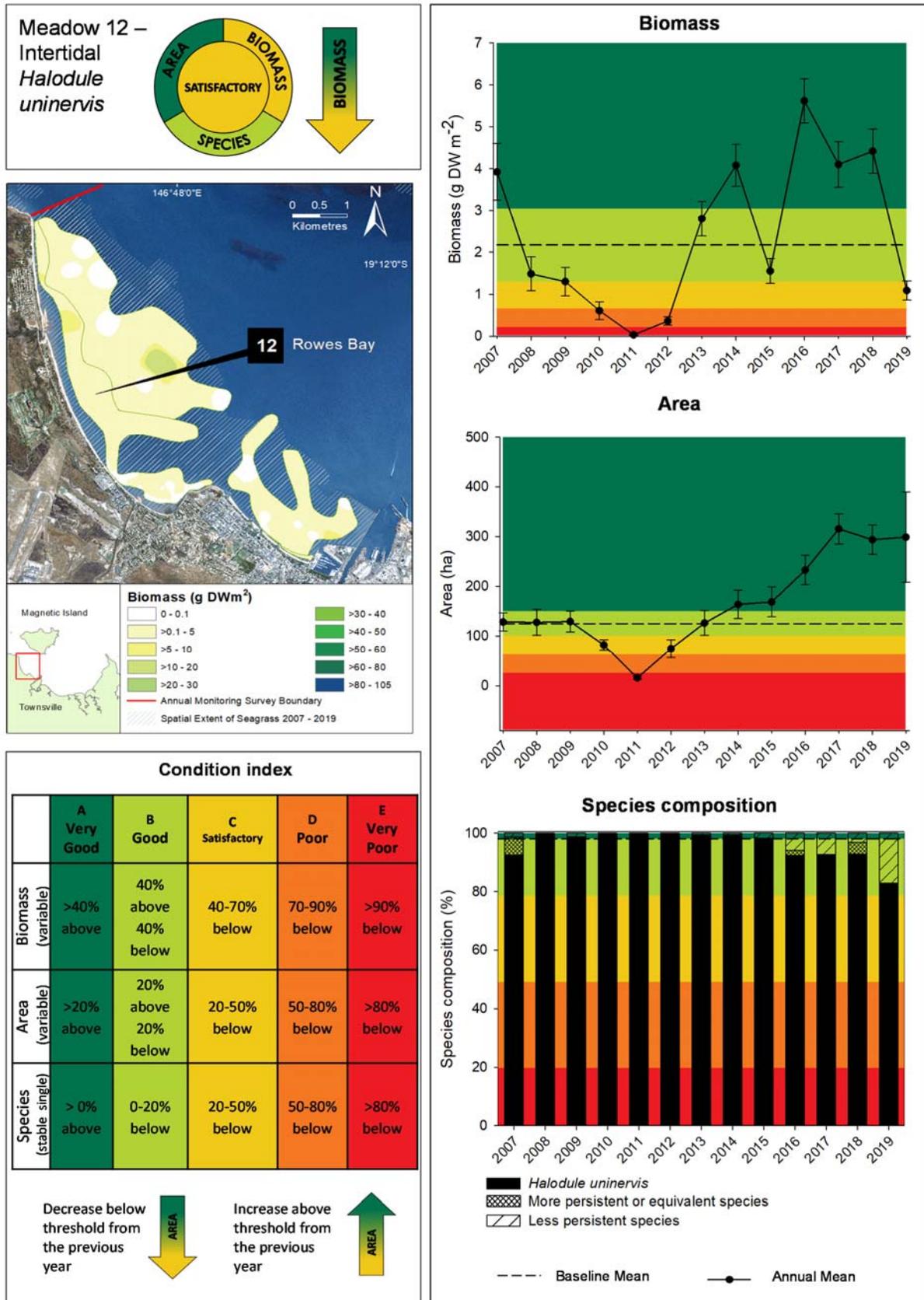


Figure 20. Changes in meadow area, biomass & species composition for seagrass Meadow 12 in Rowes Bay, 2007 – 2019. (biomass error bars = SE; area error bars = “R” reliability estimate).

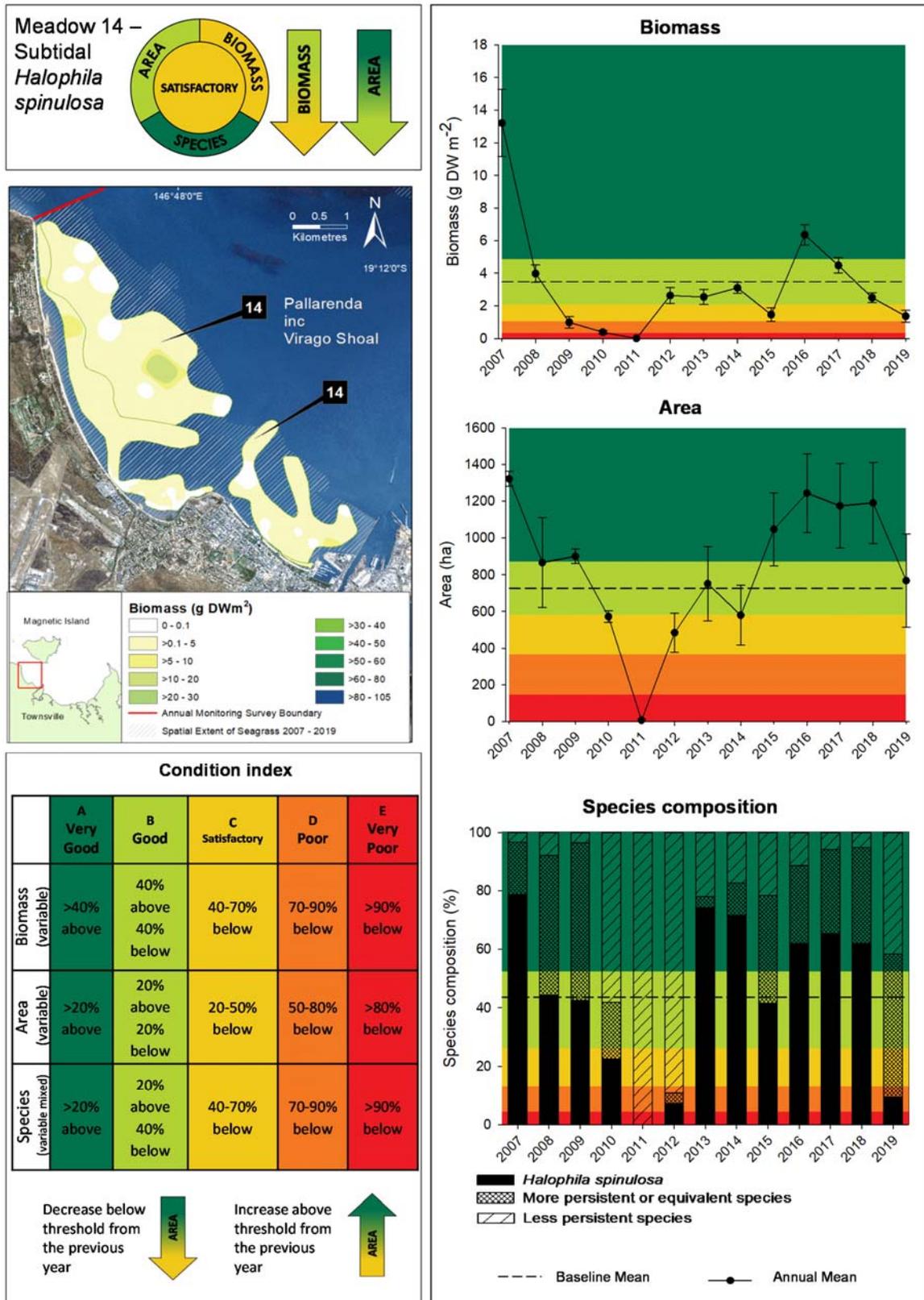


Figure 21. Changes in meadow area, biomass & species composition for seagrass Meadow 14, Pallarenda including Virago Shoal, 2007 – 2019. (biomass error bars = SE; area error bars = “R” reliability estimate).

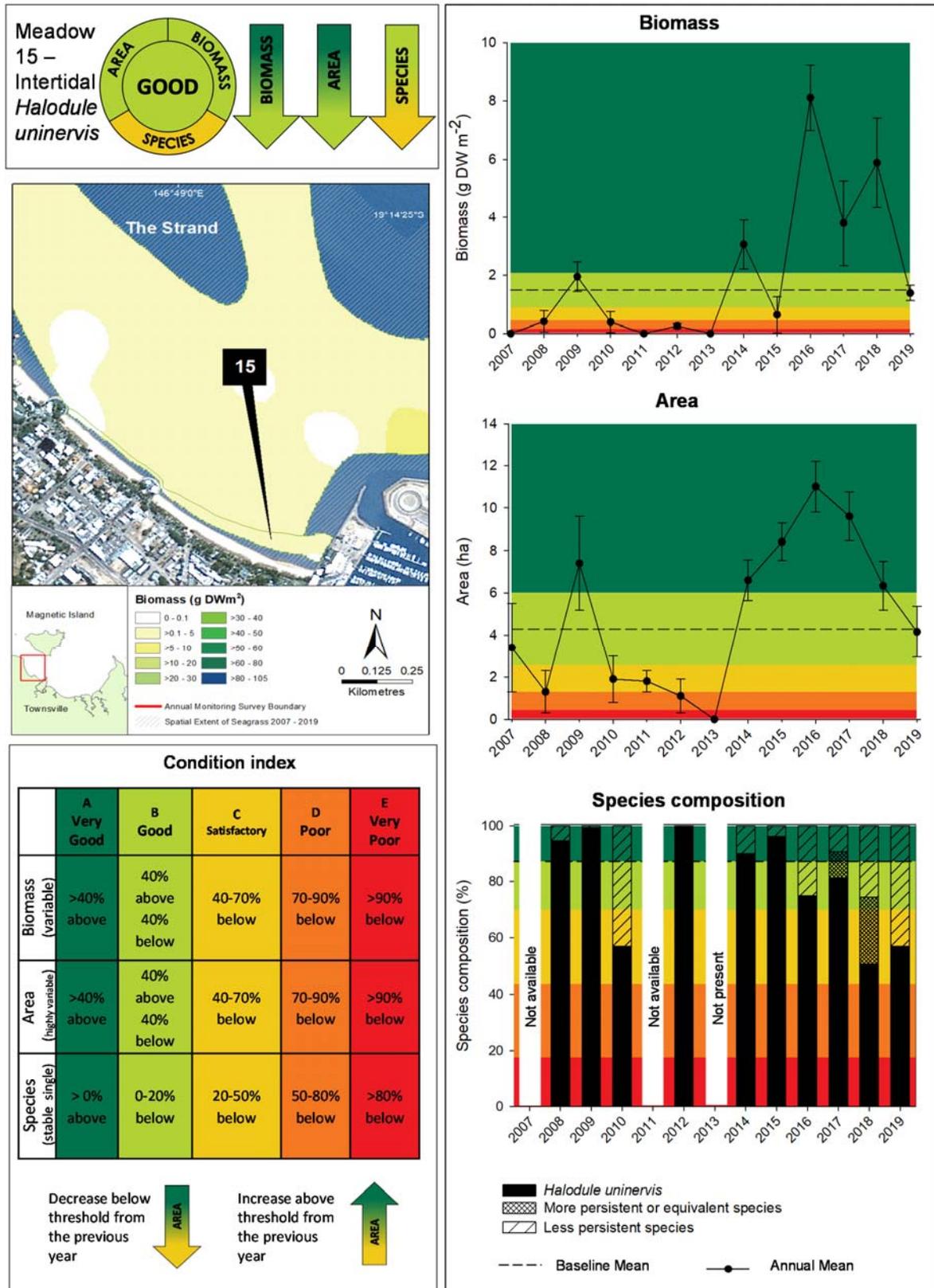


Figure 22. Changes in meadow area, biomass & species composition for seagrass Meadow 15 at the Strand, 2007 – 2019. (biomass error bars = SE; area error bars = “R” reliability estimate).

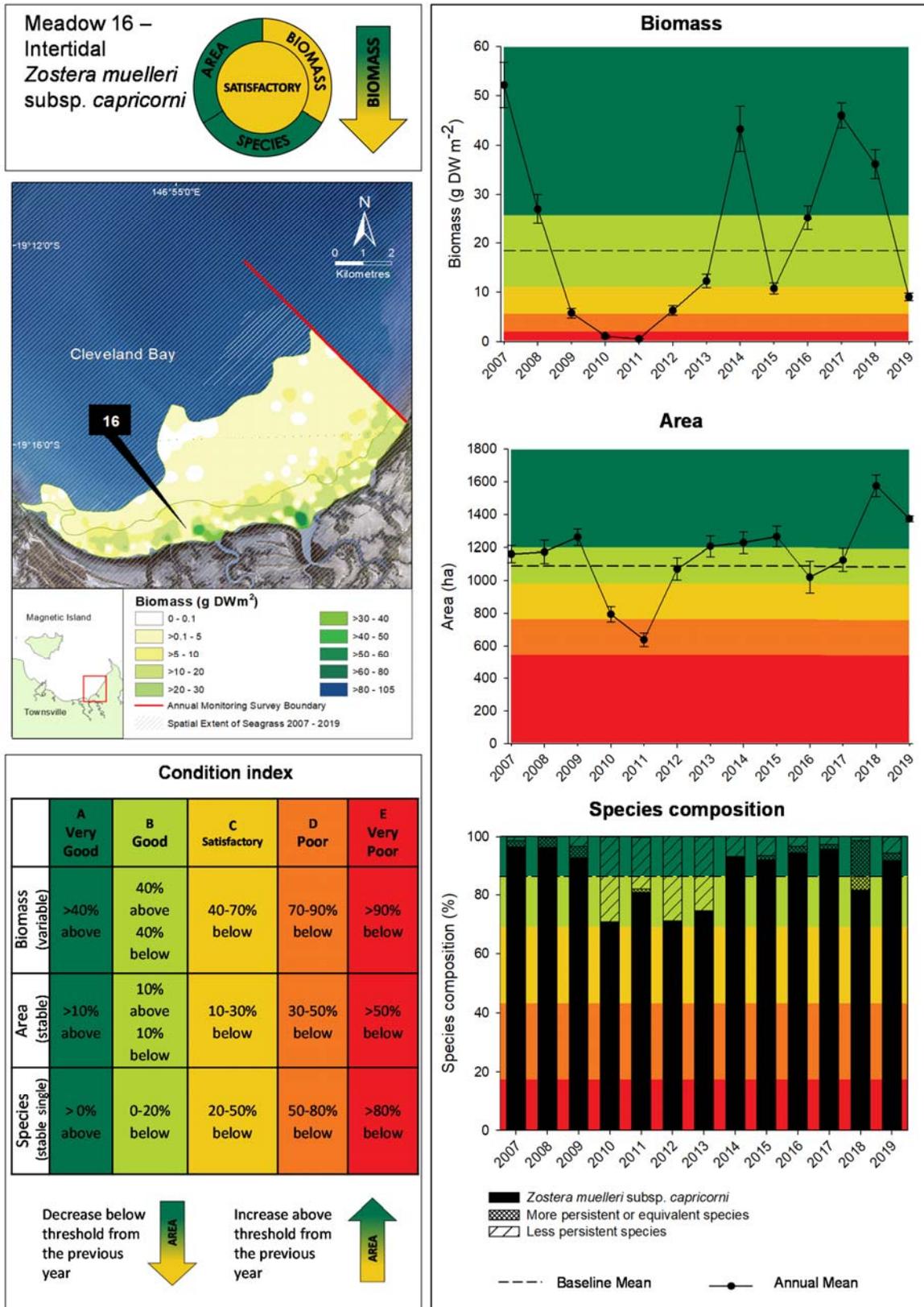


Figure 23. Changes in meadow area, biomass & species composition for seagrass Meadow 16 in Cape Pallarenda, 2007 – 2019. (biomass error bars = SE; area error bars = “R” reliability estimate).

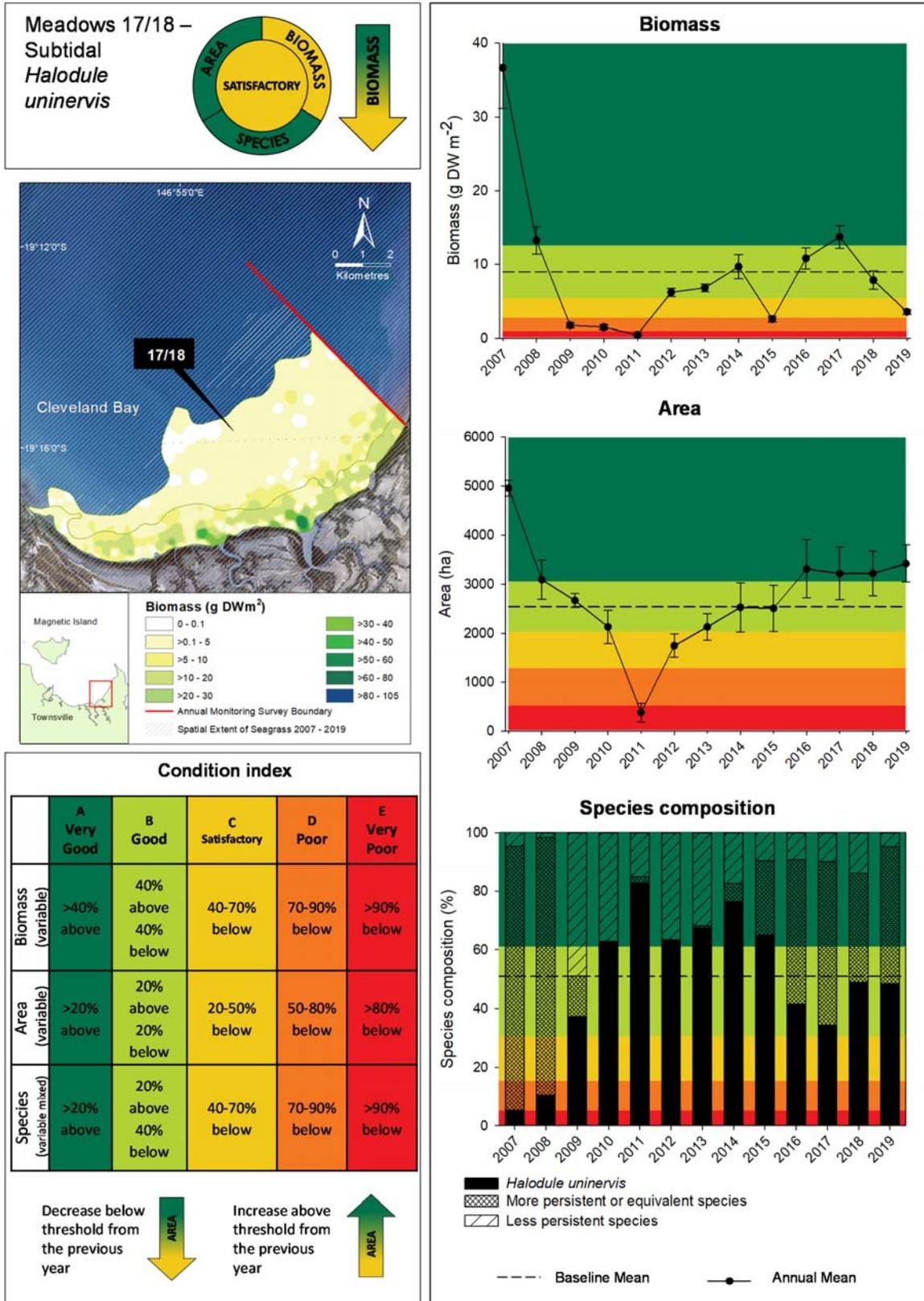


Figure 24. Changes in meadow area, biomass and species composition for seagrass Meadows 17/18 in Cleveland Bay, 2007 – 2019. (biomass error bars = SE; area error bars = “R” reliability estimate).

3.4 Townsville Climate Patterns

Rainfall and River flow

Rainfall in Townsville is highly seasonal with the majority of rainfall typically occurring from December to April (Figure 25a). Monthly rainfall was above the long-term average between December 2018 and March 2019, immediately preceding the April/May 2019 survey and below the long-term average leading up to the October survey (Figure 25a). Total annual rainfall in 2018/19 was the highest recorded yet, well above the long-term average, following four years of below-average annual rainfall (Figure 25b).

River flow from all three of the rivers surrounding Townsville (the Black River, Alligator Creek and the Burdekin River) exceeded long-term averages in 2019 (Figure 26).

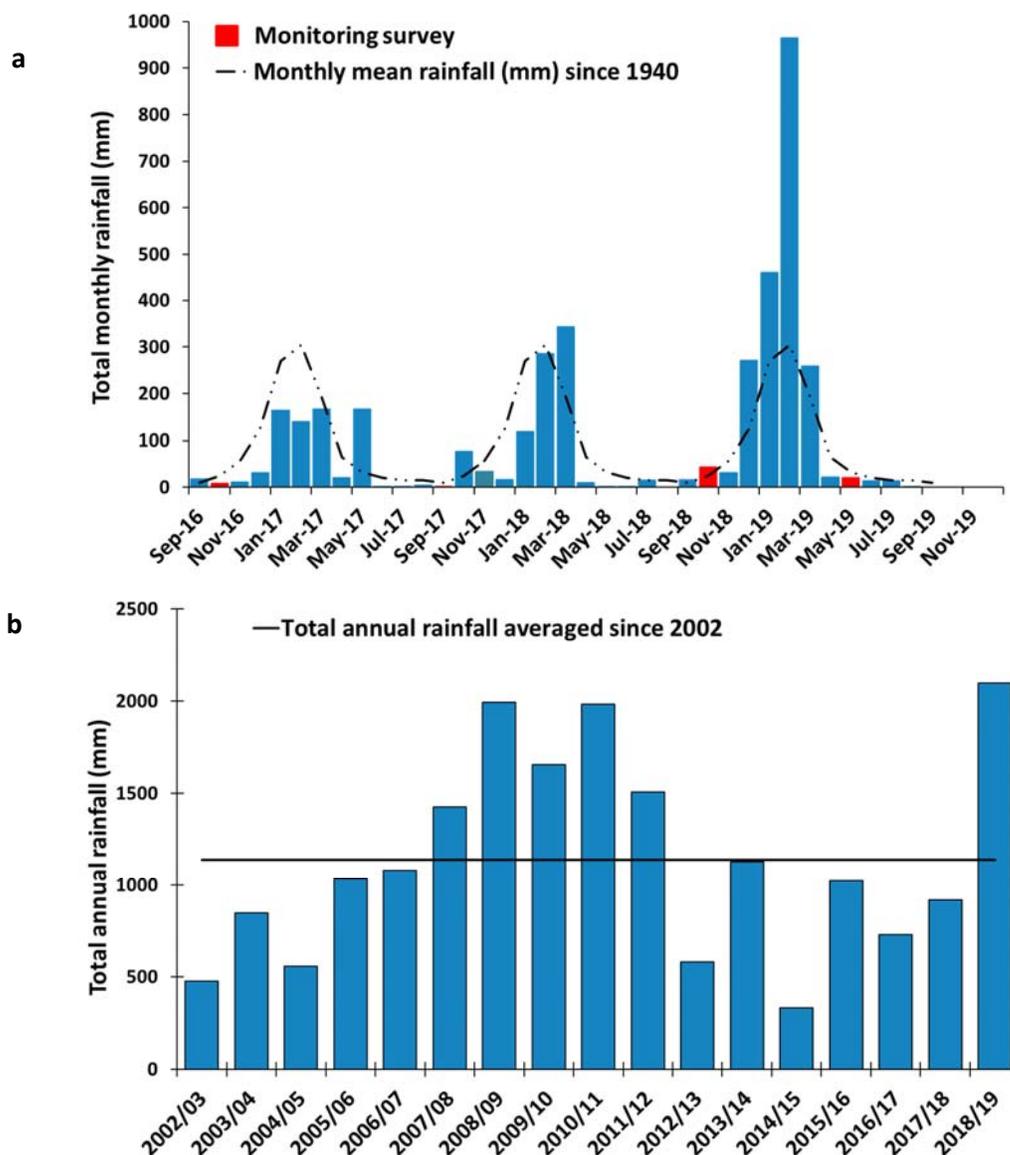
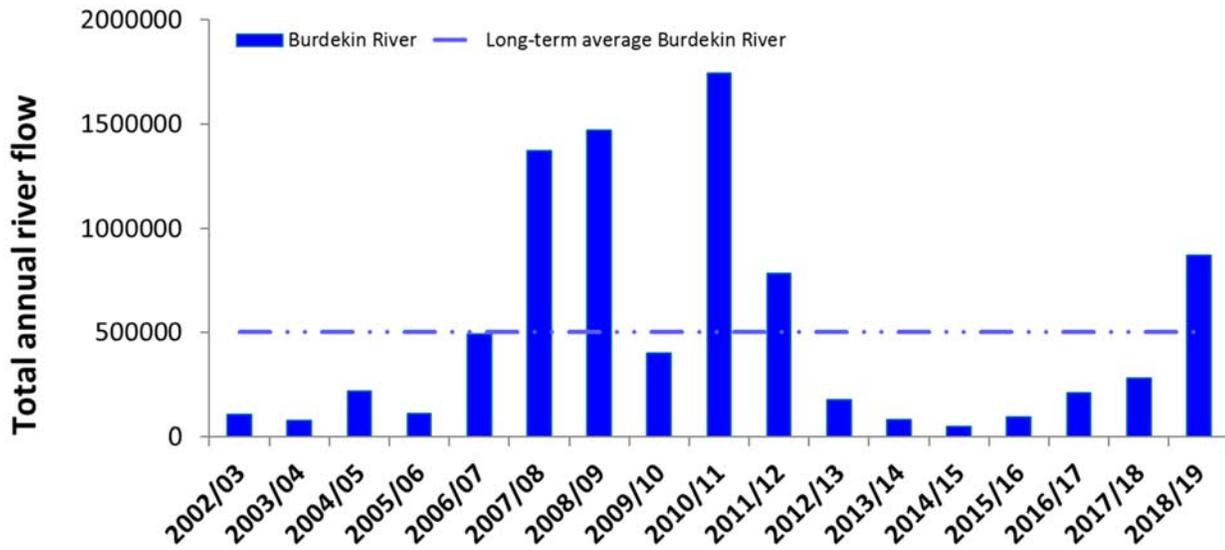
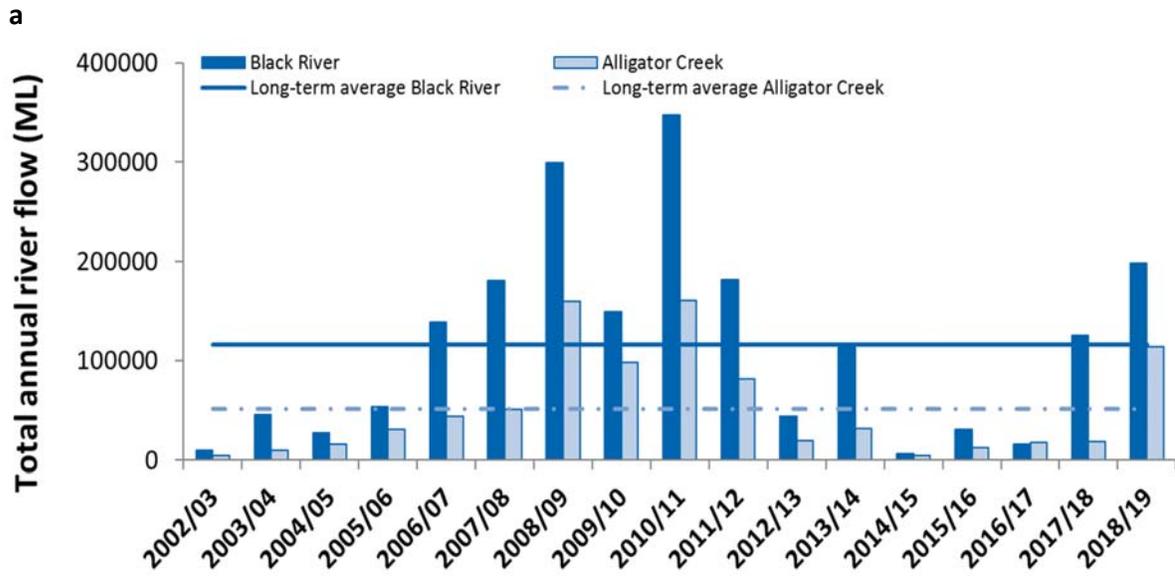


Figure 25. (a) Total monthly rainfall from September 2016 and (b) total annual rainfall from 2002/2003 to 2018/2019 recorded at Townsville airport (Data from the Bureau of Meteorology, Station 032040 <http://www.bom.gov.au>).



b

Figure 26. (a) Total annual flow of the Bohle, Black and Alligator Creek from 2002/2003 to 2018/19, and (b) total annual flow of the Burdekin River from 2002/2003 to 2018/19. The volume of the Burdekin River reported here is 5% of the volume at the outflow source and represents an estimate of the amount of discharge reaching Cleveland Bay (Bainbridge et al. 2012). River flow data from the Bohle River is unavailable past 2013. (Department of Environment and Resource Management, <https://water-monitoring.information.qld.gov.au/>).

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 2018/19 fell below the long-term average (annual solar radiation since 2002) (Figure 27) however remained close to the long-term average.

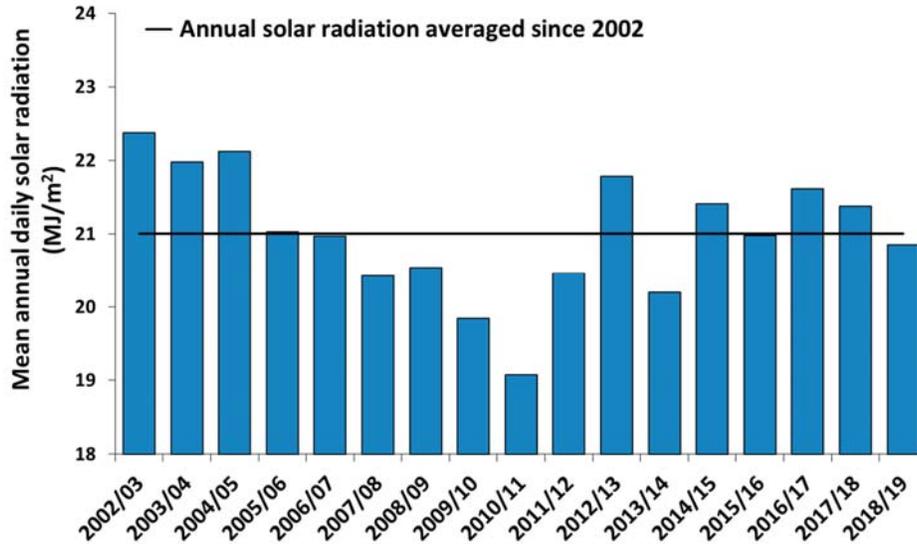


Figure 27. Mean annual daily solar radiation recorded at Townsville airport 2002/03 to 2018/19. (Data from the Bureau of Meteorology, Station 032040 <http://www.bom.gov.au>).

Air Temperature & Tidal Exposure of Seagrass Meadows

Mean annual daily maximum air temperature for 2017/18 was 29.6°C, slightly above the long-term average of 29.4°C (Figure 28).

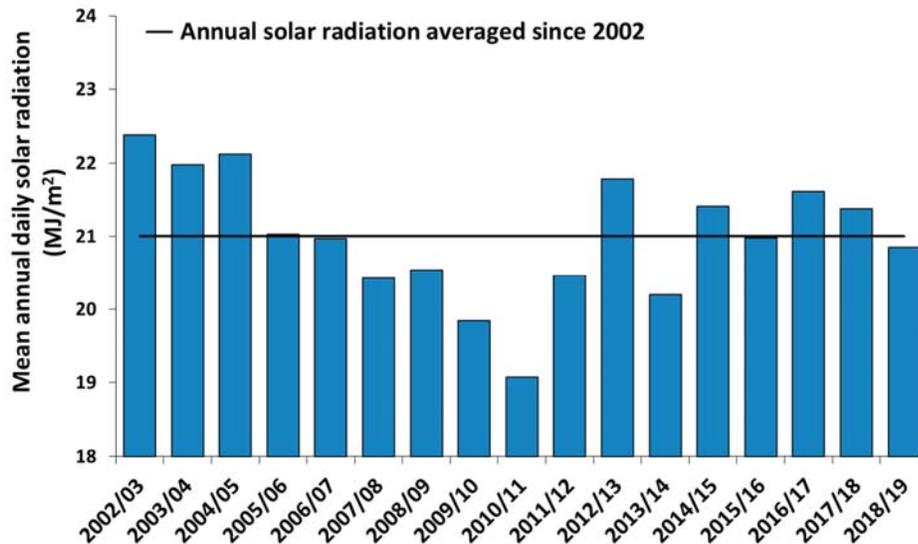


Figure 28. Mean annual maximum daily air temperature (°C) recorded at Townsville Airport, 2002/03 to 2018/19. (Data from the Bureau of Meteorology, Station 032040 <http://www.bom.gov.au>).

Total daytime exposure to air of intertidal seagrasses in Townsville is generally higher during the winter months, three to four months prior to annual monitoring surveys, and lower over summer. Total hours of tidal exposure in the one month and three month periods prior to the 2019 monitoring survey were similar to the previous year (Figure 29). The total time seagrass meadows were exposed in the months preceding the 2019 survey was lower than the long-term average (Figure 30).

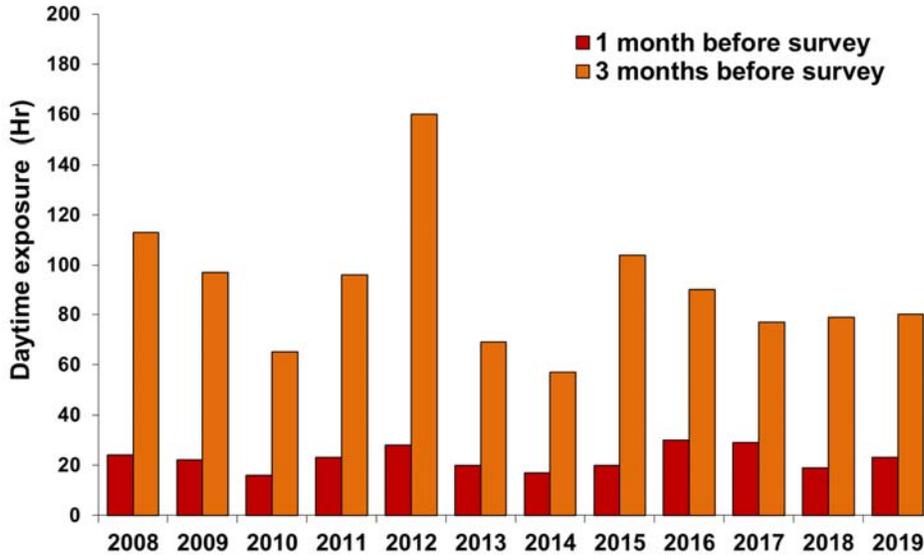


Figure 29. Total daytime intertidal exposure (<0.8m tidal height) one month and three months prior to growing season monitoring in Townsville (October 2019) (Maritime Safety Queensland, www.msq.qld.gov.au). The data for 2015 one month prior to survey was the survey month (September) as the survey took place at the end of the month.

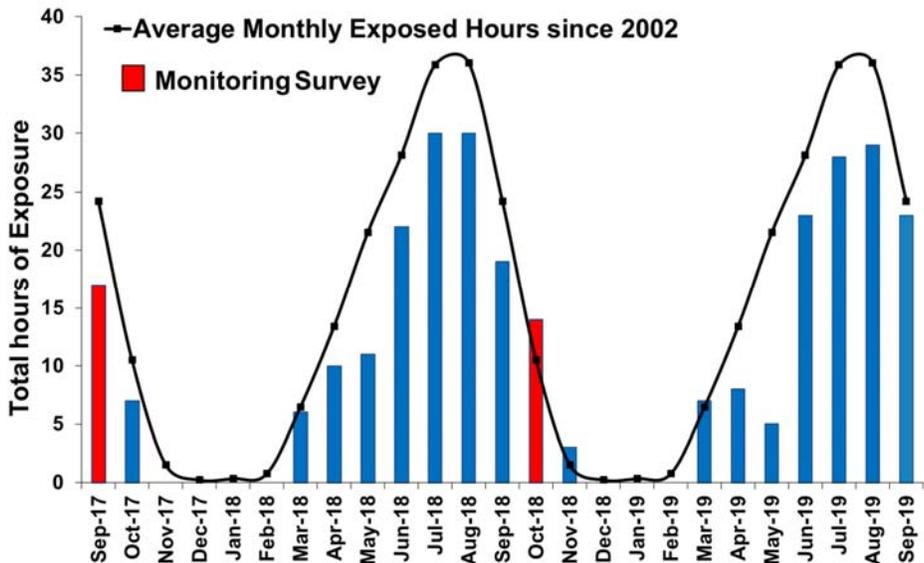


Figure 30. Total monthly daytime intertidal exposure (<0.8m tidal height) prior to monitoring in Townsville 2019 (October 2019 survey only) (Maritime Safety Queensland, www.msq.qld.gov.au).

4 DISCUSSION

In February 2019, the Townsville region was affected by severe rainfall and flooding as a result of the convergence of a monsoon and slow moving tropical low. Concerns were raised about how the seagrasses may have responded to the floods and associated sediment plume, and what impact any changes in seagrass distribution and density could have on the animals that rely on them such as dugong and turtles.

Results of the May 2019 survey indicated that the floods did not have as great an initial impact on seagrass habitat as expected. Seagrass was found throughout much of the Townsville port limits from the tidal zone, extending to subtidal areas (~9.5m below mean sea level) (Figure 12). The subsequent October whole-of-port survey has however, shown that there may have been a 'lag effect' or legacy of the February floods, with seagrass density (above-ground biomass) at coastal meadows not being able to 'bounce back' to typical peak season levels (Figure 12). It is likely that coastal seagrasses were relying on energy/carbohydrate stores within the below-ground structures (rhizomes) to support them through the floods and post flooding (O'Brien et al. 2018; Unsworth et al. 2015). Because of this, it is possible that inshore seagrasses did not have the energy stores to then commit to new growth and germination to increase total above-ground biomass.

Flooding and associated sediment plumes can change and shift the availability of benthic light, a major driver of seagrass condition and distribution (Chartrand et al. 2018; Collier et al. 2016; Ralph et al. 2007). Light loggers deployed as part of the CU Project marine water monitoring program showed a clear signal of low light during the floods (GHD 2020). However, the persistence, and in fact dominance of some of the higher light requiring species; *Thalassia hemprichii*, *Cymodocea serrulata* and *C. rotundata* in the subtidal meadows indicates that it is likely the duration of light deprivation was not long enough to cause meadow-scale losses in Townsville. Larger species such as those listed above also tend to respond more slowly to change (disturbance) and have a higher resistance capacity (O'Brien et al. 2018).

No deepwater (>10m) seagrass was recorded in May 2019 (Figure 2). This was not an unusual outcome for that time of year because of the species that make up the deepwater meadows (*Halophila* species). *Halophila* spp. are ephemeral and may only be present for part of the year in deepwater areas and can have distinct year to year variability in their presence and location (Chartrand et al. 2017; York et al 2015). *Halophila* spp. 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 (Rasheed et al. 2014; Hammerstrom et al. 2006; Hammerstrom and Kenworthy 2003; McMillan 1991). Deepwater seagrass meadows therefore, were unlikely to have been affected by wet season activity such as the February floods as adult plants are not typically present at that time of year. The presence of such a large deepwater meadow in this survey indicates that later during the year conditions in Townsville were favourable for the germination and seasonal recruitment of these seagrasses.

Continued persistence and growth of seagrass in Townsville will be contingent on environmental conditions being favourable, particularly during the 2019/20 wet season which they enter at a reduced level of resistance to further impacts with below average biomass across their range. On the positive side, seagrasses remained present throughout most of their historical range and although at reduced biomass there were no substantial losses of species within meadows. This places them in a much better position to rapidly recover their biomass losses provided they are not subjected to another major climate impact. A very different scenario to the last major weather related impact to seagrasses in 2011 when large spatial scale losses of meadows and species occurred.

One of the primary drivers of seagrass distribution, abundance and productivity is the availability of light (Chartrand et al. 2012; Collier et al. 2012b; Bjork et al. 1999). Although not directly measured as part of this monitoring program, studies conducted at Magnetic Island show increases in light are positively correlated with seagrass growth and that very low light intensities significantly contributed to the loss of seagrasses in 2011 (Collier et al. 2012a). Coastal seagrasses in Townsville are significantly influenced by local environmental conditions such as rainfall and river flow (Petus et al. 2014; Lambrechts et al. 2010). Riverine

inputs become particularly important during strong trade winds when resuspension of fine sediments can increase turbidity and reduce the availability of light (Bainbridge et al. 2012; Lambrechts et al. 2010). Analysis of Cleveland Bay seagrasses has shown that declines in seagrasses were highly correlated with turbid water conditions associated with flood plumes (Petus et al. 2014). In 2019 the prevailing environmental conditions were likely to have created generally unfavourable conditions for seagrass growth with river flow and rainfall above long-term averages and largely driven by the significant weather event in February 2019.

4.1 Comparison with state-wide monitoring program

Seagrass declines in Townsville in 2019 are part of a trend seen in other parts of the state hit by extreme flooding in 2019. In particular, Karumba seagrasses are in a poor condition in 2019 due to the widespread flooding in the Gulf of Carpentaria in early 2019. The Townsville area flooding in 2019 was somewhat isolated to the Townsville region on the East Coast with smaller impacts to the south at Abbot Point and none recorded in Cairns seagrass meadows.

In 2009 to 2011, Townsville seagrasses were part of region-wide declines that occurred in the wet and dry tropics and more broadly in the urbanised eastern coast of Queensland, linked to flooding, storms and cyclones that occurred as part of extended La Niña climate patterns (Rasheed et al. 2014; Petus et al. 2014). Declines in seagrass meadows were detected along the east coast of Queensland between 2007 and 2011, largely attributed to broad-scale climate patterns and a series of tropical cyclones (Tasha in December 2010, Anthony in January 2011 and Yasi in February 2011) (McKenna et al. 2015; Rasheed et al. 2014; Collier et al. 2012a).

Townsville was one of the first areas in the wet and dry tropics monitored annually where substantial improvements in seagrass meadow area and above-ground biomass were recorded. Coastal seagrass meadows in other monitoring locations such as Cairns (Reason and Rasheed 2018a) and Gladstone (Wells et al. in prep) have shown positive signs of recovery in recent years; foundation species have begun to return in Cairns and meadow area has expanded in some parts of Gladstone (Chartrand et al. 2018). However, in general these sites have lagged behind Townsville in their recovery. Mourilyan Harbour in the wet-tropics has yet to see the return of some of the foundation seagrass species (Reason and Rasheed 2018b) and may require these species to be re-introduced locally for restoration of the meadows as no local sources of propagules remain (York et al. 2015).

4.2 Townsville Seagrass Outlook

After the February 2019 severe flood event, the significant plume that was documented extended from the Burdekin River 60 kilometres out to sea (Robertson 2019). Flood plumes, carrying heavy loads of sediment and nutrients have the potential to impact on seagrasses through a loss of light and the addition of fresh water, nutrients and contaminants such as herbicides from the catchment (Collier et al. 2014). In the past, the coastal seagrass meadows in Townsville have been able to recover relatively quickly (within 5 years) from climate related impacts, likely due to remnant seagrasses providing a source population to initiate recovery and from sediment seed banks. Where entire meadows were lost in other monitoring locations along the Queensland coast however, recovery has been much slower or in some cases has failed to occur at all.

The impact on local seagrasses from the February floods was not as severe as in previous major flood events due to the period of recovery and overall good growing conditions leading up to 2019 over the previous 6-7 years. Following several years of meadow growth and expansion in Townsville, seagrasses were likely near their peak of resilience with robust biomass and seagrasses covering a large spatial extent.

While not measured as part of this program, it is also likely that seed banks have had time to be replenished with foundation species now being present in the meadows for several years. In the absence of a further extreme weather event in the 2019/2020 wet season, the relatively large footprint of seagrasses and

continued presence of key species despite the decline in overall biomass, places the Townsville meadows in a good position for rapid recovery.

4.3 Conclusions

In 2019 the declines in seagrass condition, while significant, was likely muted by the healthy and resilient seagrass community leading up to the 2019 flood event. The overall satisfactory condition of seagrasses means while they are more susceptible to future pressures than previously, their good spatial coverage and species composition across all meadows indicates they have the ability to return to better biomass condition if favourable conditions are present through 2020.

The Channel Upgrade Seagrass Program will continue to establish baseline conditions in all CUSP meadows. The established baseline conditions for the majority of these meadows through the LTSMP provides a strong foundation to assess the potential impacts from dredging activities versus climate related drivers.

In summary, results of the 2019 seagrass monitoring found:

1. The overall condition of seagrasses in Townsville was satisfactory.
2. The first baseline information for the eleven Channel Upgrade Seagrass Program meadows has been established across both senescent and growing season periods with continued plans to establish baseline conditions in those meadows not previously monitored.
3. The majority of the Long-term Seagrass Monitoring Program meadows were classed as satisfactory with two deemed poor and only one meadow remaining in good condition.
4. Decline in above-ground biomass was the major driver of lower meadow condition scores across the port.
5. The total seagrass area in Townsville remains high despite overall biomass losses. A number of years with generally favourable climate conditions for seagrass growth likely helped establish a high level of resistance protecting seagrasses from any severe losses from the February floods.
6. Seagrass species composition for Townsville meadows has returned to be dominated by the more persistent species expected to occur in each meadow. In particular the larger growing *Cymodocea serrulata* and *Zostera muelleri* subsp. *capricorni* have made a full recovery from their 2011 losses.
7. Dugong feeding trails were observed throughout all areas of the Port of Townsville in 2019 and indicate a relatively high use of the area by dugongs.

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6 APPENDICES

Appendix 1.

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). This Cleveland Bay baseline was set based on results of the Gladstone Harbour 2014 pilot report card (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 $\geq 80\%$ 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	-	$< 40\%$	$\geq 40\%$	-
Area	$< 10\%$	$\geq 10, < 40\%$	$\geq 40, < 80\%$	$\geq 80\%$
Species composition	-	$< 40\%$	$\geq 40\%$	-

Threshold Definition

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

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

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

Grade and Score Calculations

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

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

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

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

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

Grade	Description	Score Range	
		Lower bound	Upper bound
A	Very good	≥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).

(b) Directional change assessment

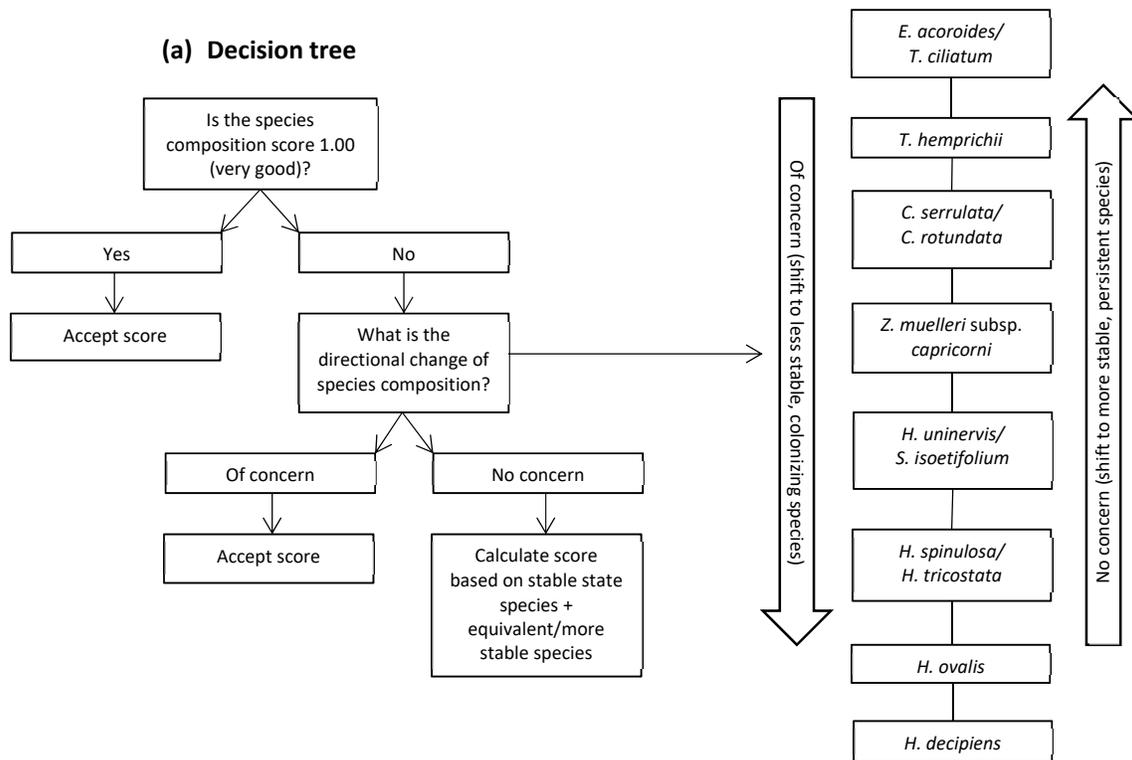


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in Townsville.

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.

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 2018 biomass value (B_{2018}) and the area value of the lower threshold boundary for the satisfactory grade ($B_{satisfactory}$):

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

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:

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

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_{2018} takes up:

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

5. Determine the biomass score for 2018 ($Score_{2018}$) by scaling B_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

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

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

Appendix 3.

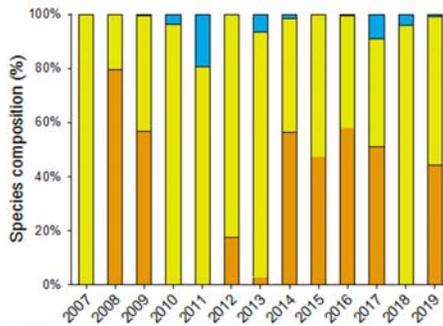
Mean above-ground biomass and meadow area within monitoring meadows in the Port of Townsville, 2007-2019. (SE= Standard error, n= number of sampling sites, R= reliability estimate)

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	
Magnetic Island	Geoffrey Bay (3) Intertidal/subtidal <i>Halodule</i> dominated	Aggregated patches	7.3 ± 1.4	9.4 ± 3.2	1.0 ± 0.6	0.7 ± 0.3	0.5 ± 0.2	3.5 ± 0.6	3.3 ± 1.1	7.0 ± 2.6	0.11 ± 0.06	4.51 ± 1.32	4.76 ± 1.28	5.36 ± 1.14	0.45 ± 0.1
	Nelly Bay (4) Intertidal/subtidal <i>Halodule</i> dominated	Aggregated patches	4.1 ± 2.7	12.6 ± 2.6	5.2 ± 2.4	0.5 ± 0.2	0.6 ± 0.3	NA	3.5 ± 2.3	7.7 ± 5.5	0.5 ± 0.3	4.01 ± 1.98	5.70 ± 1.60	2.83 ± 0.44	0.95 ± 0.6
	Cockle Bay Reef (5) Intertidal <i>Halodule</i> dominated	Continuous cover	28.7 ± 4.8	22.6 ± 3.2	6.8 ± 1.2	1.0 ± 0.3	1.3 ± 0.2	5.0 ± 0.6	6.1 ± 0.7	26.4 ± 3.2	11.7 ± 1.1	21.5 ± 2.02	19.31 ± 1.58	14.79 ± 1.7	6.61 ± 0.8
	Cockle Bay Reef (6) Intertidal <i>Zostera</i> dominated	Aggregated patches	20.1 ± 10.2	33.9 ± 3.9	4.8 ± 1.1	0.5 ± 0.2	1.1 ± 0.4	4.2 ± 0.5	9.0 ± 1.6	11.7 ± 2.6	9.0 ± 1.7	11.16 ± 2.61	16.40 ± 3.33	8.3 ± 1.5	6.69 ± 1.0
Bohle River to Ross Creek	Shelly Beach (10) Intertidal <i>Zostera</i> dominated	Aggregated patches	27.8 ± 4.0	21.4 ± 3.5	4.2 ± 0.8	Not present	0.1 ± 0.0	3.7 ± 0.5	5.5 ± 0.9	9.8 ± 2.2	5.7 ± 0.9	14.19 ± 2.02	23.0 ± 1.42	19.94 ± 2.54	6.7 ± 0.9
	Rowes Bay (12) Intertidal/Subtidal <i>Halodule</i> dominated	Aggregated patches	3.9 ± 0.7	1.5 ± 0.4	1.3 ± 0.3	0.6 ± 0.2	0.03 ± 0.0	0.4 ± 0.1	2.8 ± 0.4	4.1 ± 0.5	1.6 ± 0.3	5.62 ± 0.53	4.10 ± 0.54	4.42 ± 0.53	1.09 ± 0.2
	Pallarenda (14) Subtidal <i>Halophila</i> dominated	Aggregated patches	13.2 ± 2.1	4.0 ± 0.5	1.0 ± 0.4	0.4 ± 0.1	NA	2.6 ± 0.4	2.5 ± 0.4	3.1 ± 0.3	1.5 ± 0.4	6.35 ± 0.62	4.48 ± 0.47	2.51 ± 0.29	1.34 ± 0.4
	Strand (15) Intertidal/Subtidal <i>Halodule</i> dominated	Continuous cover	NA	NA	1.9 ± 0.5	0.4 ± 0.4	NA	NA	NA	3.1 ± 0.8	0.6 ± 0.6	8.11 ± 1.11	3.79 ± 1.47	5.89 ± 1.53	1.38 ± 0.3
Cleveland Bay	Cleveland (16) Intertidal <i>Zostera</i> dominated	Continuous cover	52.1 ± 4.6	27.0 ± 3.0	5.7 ± 1.0	1.1 ± 0.3	0.5 ± 0.1	6.2 ± 1.0	12.2 ± 1.4	43.3 ± 4.6	10.7 ± 1.13	25.16 ± 2.43	46.01 ± 2.52	36.16 ± 2.94	8.97 ± 0.8
	Cleveland (17&18) Subtidal <i>Halodule</i> dominated	Continuous cover	36.6 ± 5.5	13.2 ± 1.4	1.7 ± 0.3	1.5 ± 0.3	0.4 ± 0.2	6.2 ± 0.6	6.8 ± 0.6	9.6 ± 1.6	2.5 ± 0.4	10.77 ± 1.46	13.80 ± 1.53	7.82 ± 1.25	3.6 ± 0.3
Monitoring Meadow (ID number)	Meadow Cover	Total Meadow Area ± R in hectares													
Magnetic Island	Geoffrey Bay (3) Intertidal/subtidal <i>Halodule</i> 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	9.38 ± 0.71
	Nelly Bay (4) Intertidal/subtidal <i>Halodule</i> dominated	Aggregated patches	9.5 ± 3.4	7.5 ± 2.6	12.2 ± 3.8	9.5 ± 3.7	1.5 ± 1.3	0.6 ± 0.7	2.9 ± 1.4	8.69 ± 3.04	5.23 ± 0.6	6.43 ± 1.2	8.7 ± 1.3	9.5 ± 1.5	7.68 ± 2.75
	Cockle Bay Reef (5) Intertidal <i>Halodule</i> dominated	Continuous cover	382.4 ± 25.5	332.3 ± 30.3	308.8 ± 27.2	178.3 ± 2.9	136.7 ± 26.8	223.3 ± 24.3	452.9 ± 28.7	418.44 ± 27.15	401.12 ± 29.23	387.46 ± 50.95	352.7 ± 25.9	354.4 ± 27.8	390.9 ± 13.48
	Cockle Bay Reef (6) Intertidal <i>Zostera</i> 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 ± 13.2	9.9 ± 1.8	37.11 ± 4.49	48.18 ± 5.28	38.01 ± 7.18	26.6 ± 4.4	31.9 ± 5.0	23.54 ± 2.3
Bohle River to Ross Creek	Shelly Beach (10) Intertidal <i>Zostera</i> dominated	Aggregated patches	118.9 ± 6.7	134.0 ± 7.6	90.6 ± 6.9	Not present	54.1 ± 5.1	191.0 ± 17.7	94.5 ± 16.0	163.6 ± 18.79	124.37 ± 17.6	93.01 ± 17.78	68.3 ± 14.9	61.6 ± 15.1	55.70 ± 3.3
	Rowes Bay (12) Intertidal/Subtidal <i>Halodule</i> 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	126.02 ± 24.6	163.57 ± 28.79	168.53 ± 29.87	232.75 ± 29.69	315.4 ± 30.4	293.6 ± 29.2	298.77 ± 90.33
	Pallarenda (14) Subtidal <i>Halophila</i> 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	714.6 ± 155.9	579.78 ± 162.76	1047.16 ± 198.38	1243.42 ± 214.6	1174.2 ± 230.1	1190.5 ± 220.3	767.92 ± 254.15
	Strand (15) Intertidal/Subtidal <i>Halodule</i> 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	6.59 ± 1.0	8.4 ± 0.9	10.95 ± 1.2	9.6 ± 1.1	6.3 ± 1.1	4.16 ± 1.21
Cleveland Bay	Cleveland (16) Intertidal <i>Zostera</i> 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 ± 63.5	1228.56 ± 64.7	1265.49 ± 64.13	1020.51 ± 97.88	1124.3 ± 69.4	1575.1 ± 65.5	1373.91 ± 17.49
	Cleveland (17&18) Subtidal <i>Halodule</i> dominated	Continuous cover	4952.9 ± 61.2	3097 ± 400.7	2673.4 ± 44.2	2132.0 ± 41.1	376.2 ± 193	1749.2 ± 242.2	2133.3 ± 271.8	2533.34 ± 497.85	2511.48 ± 470.21	3315.01 ± 590.39	3221.8 ± 533.8	3223.3 ± 456.2	3422.13 ± 372.44

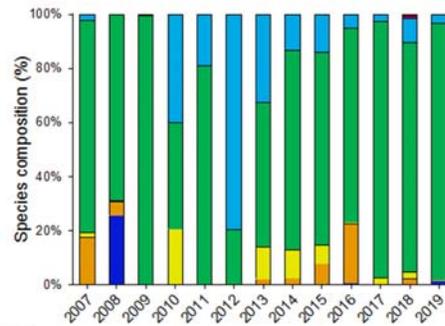
Appendix 4.

Species composition of monitoring meadows in the Port of Townsville; 2007 – 2019.

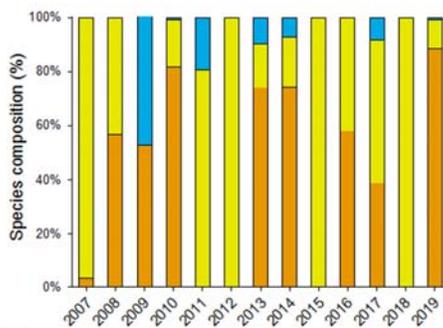
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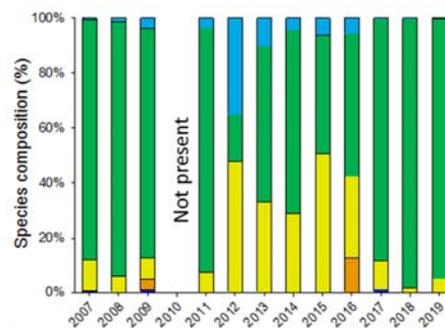
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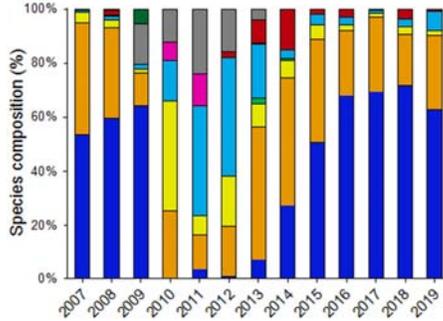
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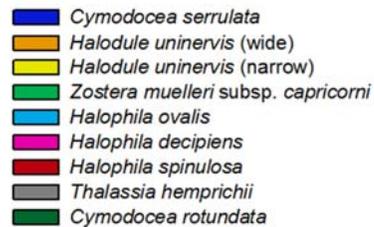
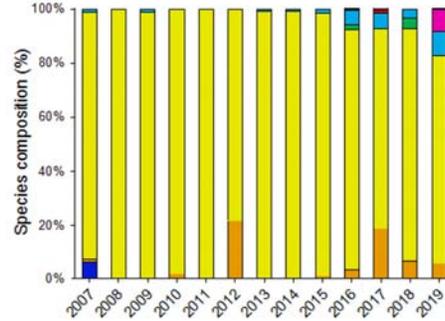
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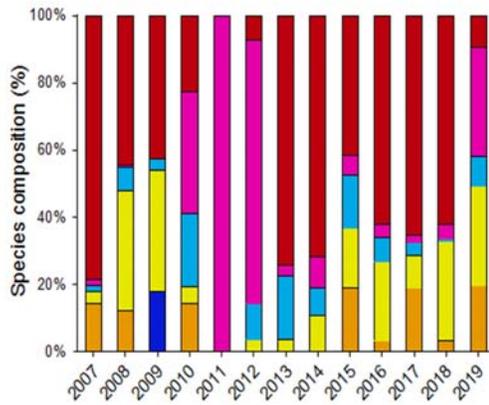
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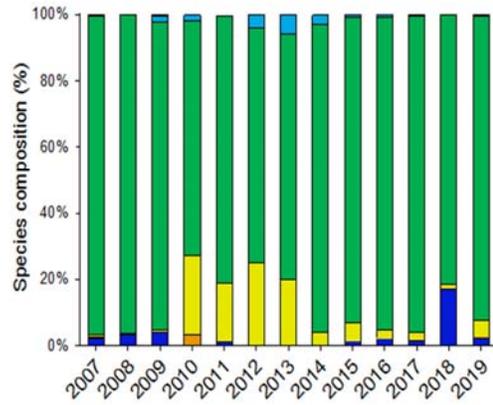
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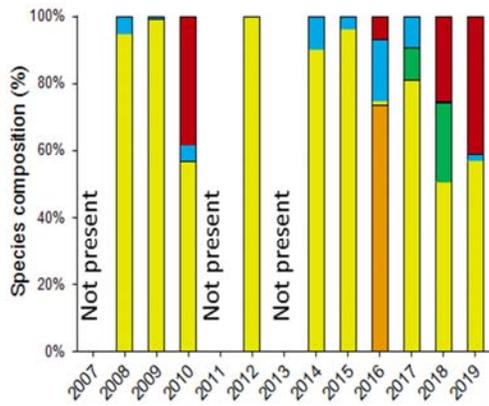
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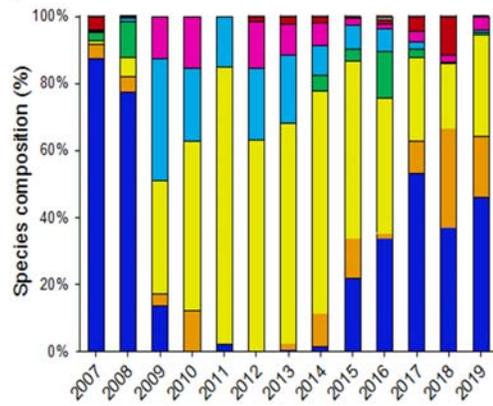
M16



M15



M17/18



- *Cymodocea serrulata*
- *Halodule uninervis* (wide)
- *Halodule uninervis* (narrow)
- *Zostera muelleri* subsp. *capricorni*
- *Halophila ovalis*
- *Halophila decipiens*
- *Halophila spinulosa*
- *Thalassia hemprichii*
- *Cymodocea rotundata*