 

PORT OF WEIPA LONG-TERM SEAGRASS MONITORING PROGRAM: 2000 - 2019

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Report No 20/15

April 2020

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Information should be cited as:
Rasheed, MA, Hoffmann LR, Reason CL & McKenna, SA 2020, 'Port of Weipa long-term seagrass monitoring program, 2000 - 2019'. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 20/15, JCU Cairns, 39pp.

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

Acknowledgments:
This project was funded by North Queensland Bulk Ports Corporation (NQBP). We wish to thank John Clark and Rob Olsen (NQBP) for their assistance in Weipa deploying and helping to maintain data logging equipment. We also wish to thank the many James Cook University staff for their invaluable assistance in the field and laboratory.

KEY FINDINGS

Seagrass Condition

Good

Likely causes of seagrass condition:

↑ *Favourable seagrass resilience leading into the 2018/2019 wet season*

↓ *Unfavourable light conditions during wet season followed by good light for the rest of the year*

↑ *Favourable climate conditions for seagrasses following the wet season events*

- Monitoring in 2019 found seagrasses in the Port of Weipa were in good condition.
  - All monitoring meadows were in good or very good condition for all three indicators measured; biomass, area and species composition.
  - Total area of seagrass meadows in the region closest to the port (Intensive Monitoring Area (IMA)) was above the long term average for the four consecutive year.

- The Weipa region experienced an extreme wet season in 2018/2019 with three tropical cyclones between December 2018 and March 2019. This lead to an extended period of low light in the seagrass meadows, 48 consecutive days were recorded with light levels below the 5 mol m^{-2} day^{-1} threshold.

- Seagrass meadows did not suffer any dramatic or sustained impacts from the wet season storm and flooding events, due to their high level of resilience leading into the 2018/2019 wet season and the return of higher light conditions following the wet season for the remainder of the year.

- Seagrass light requirements were maintained in the monitoring meadows throughout the extended 2019 maintenance dredging activities despite 3-4 times the normal annual sediment load dredged as a result of the extreme wet season.

IN BRIEF

Seagrasses have been monitored annually in the Port of Weipa since 2000. Each year all seagrasses within the Intensive Monitoring Area (IMA) around the major areas of port activity are mapped and five core seagrass meadows representing the range of different seagrass community types found in Weipa are assessed for changes in biomass, area and species composition. Changes to biomass, area and species composition are then used to develop a seagrass condition index (see section 2.3). Every three years all seagrasses within the port limits are remapped; the last completed in 2017.

Seagrasses in the Port of Weipa were in an overall good condition in 2019. Seagrasses maintained an extensive footprint within the IMA with total area above the long term average recorded during the 20 year monitoring program (Figure 2). The species composition of meadows was maintained with the expected mix and dominance of foundation species occurring and area and biomass of all meadows was rated as good or very good compared with their long-term baseline history (Figure 1).

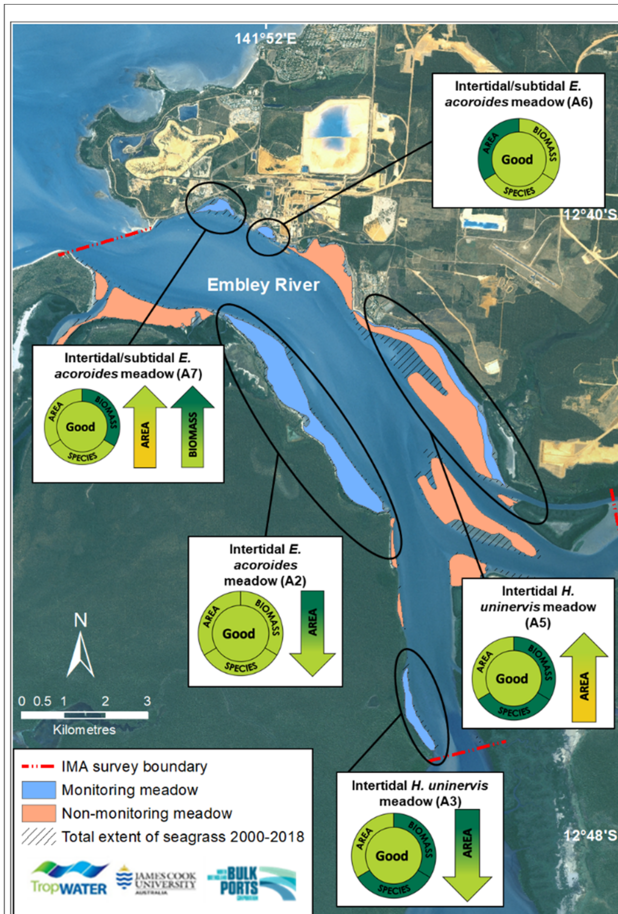

Figure 1. Seagrass meadow condition in the Port of Weipa 2019.

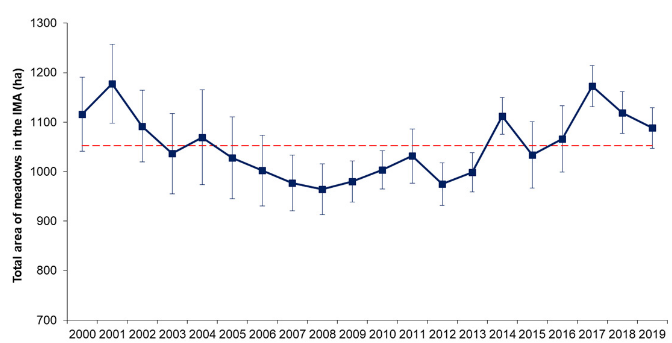

Figure 2. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2019. (error bars = "R" reliability estimate). Red dashed line indicates 19-year mean of total meadow area.

The healthy condition of Weipa seagrasses in August 2019 occurred despite intense wet season conditions in 2018/2019 with three tropical cyclones (TC); TC Owen, TC Penny and TC Trevor, and an extensive monsoonal system affecting the region between December 2018 and March 2019. These conditions resulted in a longer than normal period of low light for seagrass meadows with 48 consecutive days of light levels below the 5 mol m^{-2} day^{-1} threshold. A significant sedimentation of the navigational channels in the port was also seen, requiring an extended period (40 days) and volume (2.4M m^3) of maintenance dredging.

Seagrasses were able to maintain a good condition despite these impacts due to their high level of resilience leading up to the wet season, the return of favourable light conditions following the wet season with no further periods of light below the seagrass growth threshold, and the management of maintenance dredging to ensure seagrasses received adequate light during dredging operations. The fact that seagrasses entered the wet season with high levels of biomass and meadow area meant they were in a strong position to resist wet season pressures utilising stored energy reserves, but critically there were also no further reductions of light below their likely light requirements for the remainder of the year.

Other environmental conditions that can effect seagrass growth were generally favourable following the wet season, and likely contributed to the sustained good condition of seagrass (Figure 3). Tidal exposure was around the long-term average protecting seagrasses from air exposure stress including "burning" of seagrass leaves that has been observed during the monitoring program. Annual rainfall was also below average.

The good condition of seagrass in 2019 means they are likely be resilient to planned annual maintenance dredging during 2020, providing there are no major weather events that could lead to their decline prior to scheduled maintenance dredging.

The Weipa seagrass monitoring forms part of a broader Queensland program that examines seagrasses in the majority of Queensland commercial ports and areas where seagrasses face the highest levels of cumulative risk. It also forms a component of James Cook University's (JCU) broader seagrass assessment and research program (see https://www.tropwater.com).

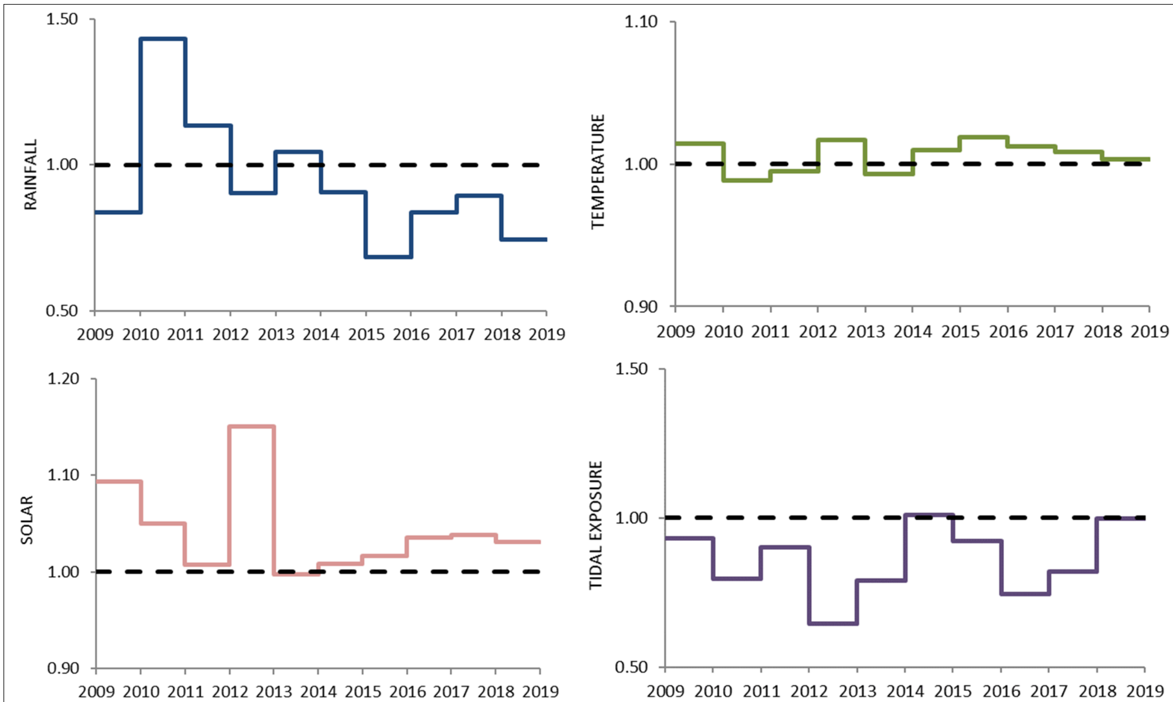

Figure 3. Recent climate trends in Weipa: Change in climate variables as a proportion of the long-term average. (See section 3.2 for detailed climate data).

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1 INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem functions and services including nutrient cycling and particle trapping that improves water quality, coastal protection, support of fisheries production and the capture and storage of carbon (Hemminga and Duarte 2000; Orth et al. 2006; Barbier et al. 2011; Fourqurean et al. 2012; Costanza et al. 2014). Seagrass meadows show measurable responses to changes in water quality, making them ideal candidates for monitoring the long term health of marine environments (Dennison et al. 1993; Abal and Dennison 1996; Orth et al. 2006).

Globally, seagrasses have been declining due to both natural and anthropogenic causes (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). The hot spots with highest threat exposure for seagrasses occur in areas where multiple threats accumulate including urban, port, industrial and agricultural runoff (Grech et al. 2012). These hot spots arise as seagrasses preferentially occur in the same sheltered coastal locations that 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 and ensure impacts are minimised (Coles et al. 2015).

1.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program has been 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. Each location is funded separately, but the common methods and rationale between locations provides a network of seagrass monitoring locations comparable across the State (Figure 4).

Figure 4. Location of Queensland Port seagrass assessment sites.

This strategic long-term assessment and monitoring program for seagrass 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 also has 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 Weipa Seagrass Monitoring Program

Diverse and productive seagrass meadows and benthic macro- and mega-fauna occur in the Port of Weipa. North Queensland Bulk Ports (NQBP) commissioned the TropWATER Seagrass Ecology Group to establish a long-term seagrass monitoring program for Weipa's port in 2000 (Roelofs et al. 2001; 2003; 2005). The first three years (2000 to 2002) of the seagrass monitoring program provided important information on the distribution, abundance and seasonality of seagrasses within the greater port limits. Due to the large area of the port, the approach for long-term monitoring has been to focus monitoring efforts on seagrass meadows located near the port and shipping infrastructure and activities. This area is known as the Intensive Monitoring Area (IMA); Figure 5). Meadows within the IIMA represent the range of seagrass meadow communities identified in the region. Every three years (i.e., 2000, 2002, 2005, 2008, 2011, 2014, 2017) seagrass monitoring surveys are extended to cover all meadows in the greater port limits, with a focus on mapping seagrass meadow distribution, meadow cover type and species composition (Figure 5).

Results from seagrass monitoring surveys are used by NQBP to assess the health of the port marine environment, and help identify any possible detrimental effects of port operations (e.g. dredging) and other activity on seagrass meadows. Seagrass monitoring surveys satisfy environmental monitoring requirements as part of the port's Long-Term Dredge Management Plan and are used by management agencies to assess the status and condition of seagrass resources in the region.

As part of the seagrass monitoring program in Weipa, light (Photosynthetically Active Radiation (PAR)) and temperature conditions within the seagrass meadows have been assessed quarterly since September 2010 at three sites; and increased to four sites in 2017 (Figure 14). In 2015, the program was expanded to incorporate quarterly seagrass assessments at permanent transects sites alongside the logging stations in Meadow A2 (Figure 14). The aim of conducting seagrass assessments coupled with collecting light and temperature data is to produce biologically relevant light requirement values for the dominant seagrass species in the Weipa area that can be used as a management tool for future port activities.

This report presents the results of the long-term seagrass monitoring assessments conducted in August 2019. The objectives were to:

1. Map seagrass distribution and determine biomass and meadow area in core monitoring meadows;
2. Assess changes in seagrass meadows with previous monitoring surveys;
3. Assess light and temperature conditions within seagrass meadows;
4. Assess light alongside the dominant seagrass species *Enhalus acoroides* to better understand light requirements;
5. Incorporate the results into the Geographic Information System (GIS) database for the Port of Weipa.

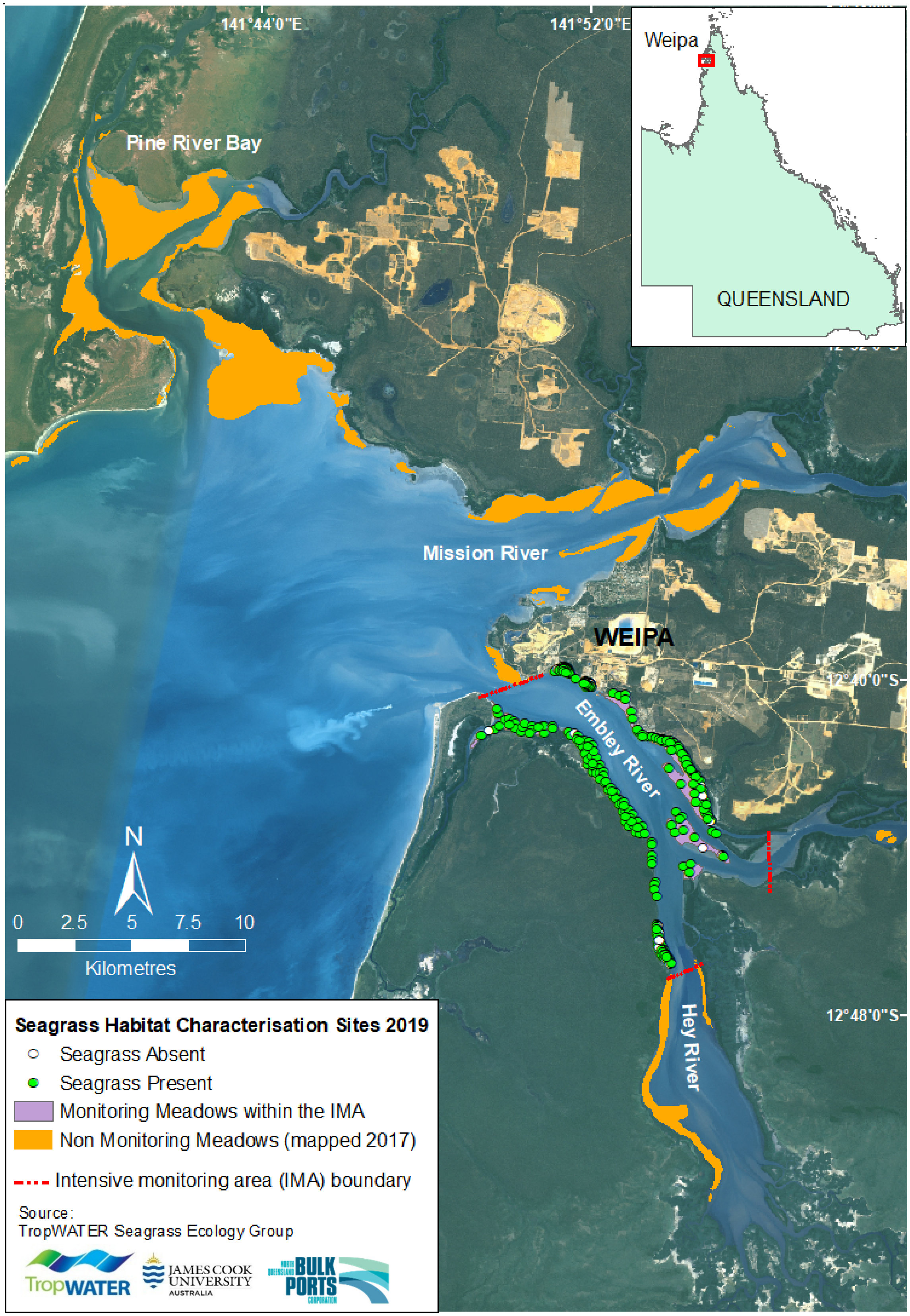


Figure 5. Location of 2019 seagrass survey sites and seagrass meadows in the Port of Weipa.

2 METHODS

2.1 Annual monitoring within the Intensive Monitoring Area

Annual monitoring of seagrass within the Port of Weipa was conducted between August 29th – 31st 2019. Annual monitoring focuses on five core monitoring meadows selected from baseline surveys within the Intensive Monitoring Area (IMA) (Figure 5 &13) (Roelofs et al. 2001). These meadows were selected for detailed assessment because they were representative of the range of seagrass meadow communities identified in the baseline survey, and because they were located in areas likely to be vulnerable to impacts from port operations and developments.

Two levels of sampling were used in the September 2019 survey:

1. Assess and map seagrass distribution, species composition and biomass in the five core monitoring meadows (A2, A3, A5, A6, and A7; Figure 14);
2. Map seagrass distribution and species composition in non-core monitoring meadows within the IMA (Figure 5 & 14).

Seagrass meadows were surveyed using a combination of helicopter aerial assessments and boat-based camera surveys (Figure 6). At each site surveyed seagrass meadow characteristics including seagrass species composition, above-ground biomass, seagrass and algal percent cover, sediment type, position fixes (GPS; ±5m) and depth below mean sea level for subtidal meadows were recorded. A detailed outline of these methods can be found in Roelofs et al. (2001).

Figure 6. Seagrass methods using (A) helicopter aerial surveillance, and (B, C) boat-based camera surveillance.

Results from previous baseline surveys suggested the analysis of biomass for meadows where the large growing species *E. acoroides* was present but not dominant required a different method compared to meadows where *E. acoroides* was dominant (Roelofs et al. 2003). The dry weight biomass for *E. acoroides* is many orders of magnitude higher than other tropical seagrass species and dominates the average biomass of a meadow where it is present. Historically therefore, isolated *E. acoroides* plants occurring within the *Halodule* dominated meadows A3 and A5 were excluded from all biomass and species composition analyses in order to track the dynamics of the morphologically distinct *Halodule* species in these two meadows.

Seagrass biomass (above-ground) was determined using a "visual estimates of biomass" technique (as described by Kirkman 1978 and Mellors 1991). This technique involves an observer ranking seagrass biomass in the field in three random placements of a 0.25m^2 quadrat at each site. Ranks are made in reference to a series of quadrat photographs of similar seagrass habitats for which the above-ground biomass has previously been measured. The relative proportion of the above-ground biomass (percentage) of each seagrass species within each survey quadrat was also recorded. Field biomass ranks are then converted into above-ground biomass in grams dry weight per square metre (g dw m^2). At the completion of sampling, each observer ranks a series of calibration quadrats that represented the range of seagrass biomass in the survey. After ranking, seagrass in these quadrats is harvested and the actual biomass determined in the laboratory.

A separate regression of ranks and biomass from these calibration quadrats is then generated for each observer and applied to the field survey data to determine above-ground biomass.

2.2 Habitat mapping and Geographic Information System

All survey data were entered into a Geographic Information System (GIS) using ArcGIS 10.7®. Three GIS layers were created to describe seagrass in the survey area: a site layer, meadow layer and biomass interpolation layer.

- *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 ± standard error (SE), meadow area (hectares) ± reliability estimate (R) (Table 3), number of sites within the meadow, seagrass species present, meadow density and community type (Tables 1 & 2), meadow landscape category (Figure 14).
  - 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 1). Community density was based on mean biomass of the dominant species within the meadow (Table 2).

Table 1. 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 with Species B/Species C	Species A is 50% of composition
Species A/Species B	Species A is 40-60% of composition

Table 2. Density categories and mean above-ground biomass ranges for each species used in determining seagrass community type in Weipa.

Density	**Mean above ground biomass (grams dry weight per meter square (gdw m^2))**				
	***H. uninervis* (narrow)**	***H. ovalis* *H. decipiens***	***H. uninervis* (wide) *S. isoetifolium***	***T. hemprichii***	***E. acoroides***
Light	< 1	< 1	< 5	< 15	< 40
Moderate	1 - 4	1 - 5	5 - 25	15 - 35	40 - 100
Dense	> 4	> 5	> 25	> 35	> 100

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

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

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

Figure 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 3). 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 3. Mapping precision and methods for seagrass meadows in the Port of Weipa 2018.

Mapping precision	Mapping method
5m	Meadow boundaries determined from helicopter and camera/grab surveys; Inshore boundaries mapped from helicopter; Offshore boundaries interpreted from survey sites and recent satellite imagery; Relatively high density of mapping and survey sites; Recent satellite imagery aided in mapping.

2.3 Seagrass meadow condition index

A condition index was developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline. Seagrass condition for each indicator in each meadow was scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). Overall meadow condition is the lowest indicator score where this is driven by biomass or area. Where species composition is the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50%. 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.

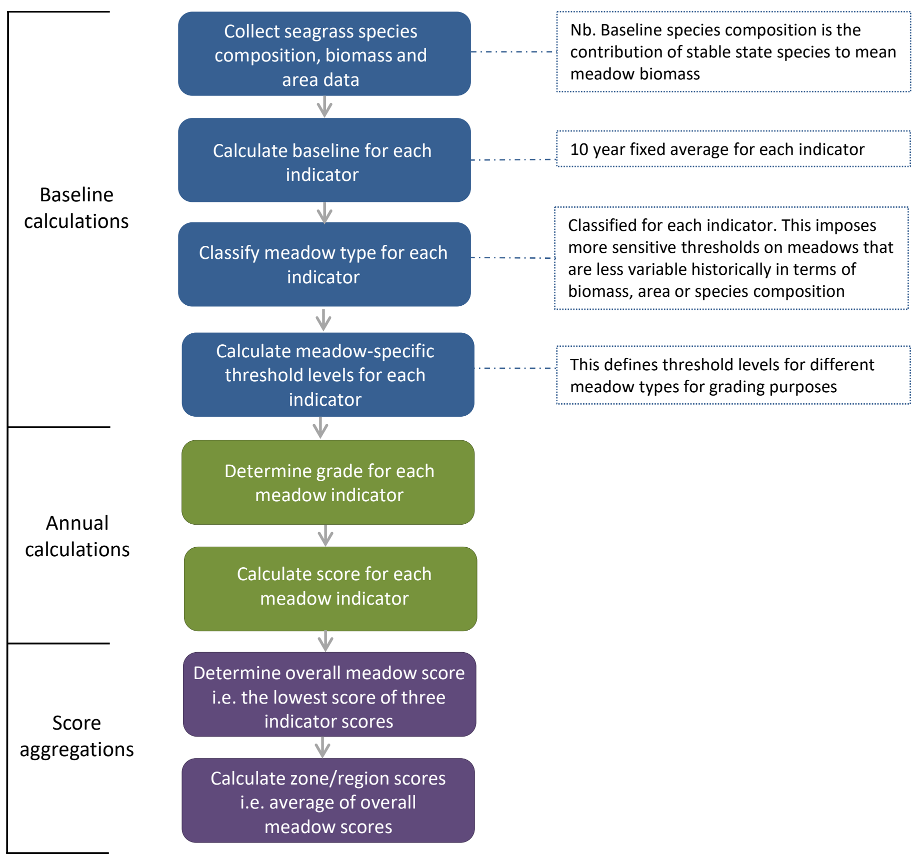


Figure 8. Flow chart to assess seagrass monitoring meadow condition.

2.4 Environmental data

Environmental data was collated for the twelve months preceding each survey. Tidal data was provided by Maritime Safety Queensland (MSQ) for Weipa (MSQ station # 100281). Total daily rainfall (mm) and global solar exposure was obtained for the nearest weather station from the Australian Bureau of Meteorology (Weipa Airport station #027045; http://www.bom.gov.au/climate/data/).

Irradiance (Photosynthetically Active Radiation (PAR) mol photons m^{-2} day^{-1}) conditions and temperature within the seagrass meadows at Weipa have been assessed at a northern and southern site within the intertidal A2 meadow, and at one site in the subtidal/intertidal A7 meadow (Figure 14) since September 2010 using custom built benthic data logging stations (Figure 9). An additional site was set up in meadow A6 in 2017. A PAR logger has also been placed on land at the NQBP work shed that acts as a control logger. Each independent logging station within the meadows consists of 2π cosine-corrected irradiance loggers (Submersible Odyssey Photosynthetic Irradiance Recording Systems) with supporting electronic wiper units. Irradiance loggers were calibrated using a cosine corrected Li-Cor underwater quantum sensor (LI-190SA; Li-Cor Inc., Lincoln, Nebraska USA) and corrected for immersion effect using a factor of 1.33 (Kirk 1994). Readings were made at 15 minute intervals and used to estimate total daily irradiance (PAR) reaching seagrasses. The electronic wiper unit fitted to each irradiance logger automatically cleaned the optical surface of the sensor every 15 minutes to prevent marine organism fouling. Autonomous Thermodata® iBTag submersible temperature loggers were deployed with each of these units, recording seabed temperature every 30 minutes.

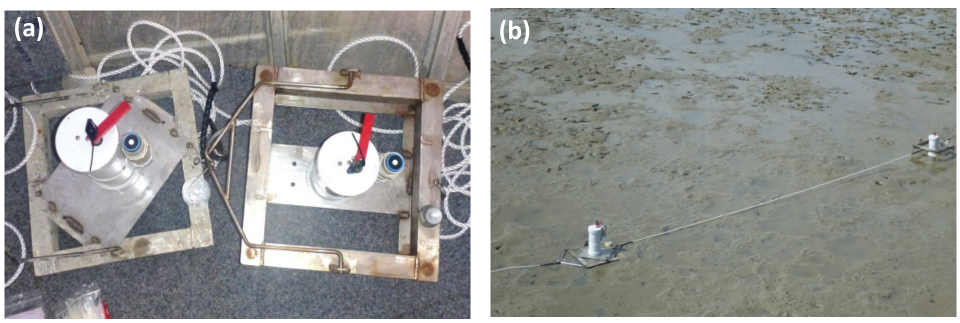


Figure 9. (a) Logging station consisting of a stainless steel frame with PAR loggers and temperature loggers attached, and wiper units (b) deployment of logging stations on the A2 meadow.

2.5 Light (PAR) and intertidal seagrass change

Quarterly seagrass assessments at permanent transect sites were established in 2015 to monitor the dominant species in the Weipa area; *E. acoroides,* coupled with the already established PAR and temperature monitoring. The goal of these assessments is to produce a better understanding of the local biologically relevant light requirements for *E. acoroides.*

Three permanent transect sites are located alongside logging stations in meadow A2; two sites at the northern end of the meadow (A2-1a and A2-1b) and one at the south end (A2-2) (Figure 14). For further information, see McKenna et al. (2017).

Key information collected for seagrass at the quarterly assessment sites includes:

- Above-ground biomass
- Percent cover
- Species composition
- Notes taken of the presence of *E. acoroides* reproductive structures.

To avoid damaging seagrass from repeated sampling in highly muddy sites such as Weipa, the methodology was adapted to use a helicopter/boat (camera drops) to sample the intertidal sites. Each permanent transect site comprised a 50m x 50m area of a relatively homogenous section of the seagrass meadow. The site contained three 50m transects which were monitored to determine the above listed key information. Eleven 0.25 m^2 quadrats were examined on each transect. Photos of each quadrat were also taken for further assessment.

3 RESULTS

3.1 Seagrass in the Port of Weipa

A total of 310 seagrass habitat characterisation sites were surveyed in the IMA in 2019, with seagrass present in 93% of sites (Figure 5). Four species of seagrass were identified in the survey (Figure 10).

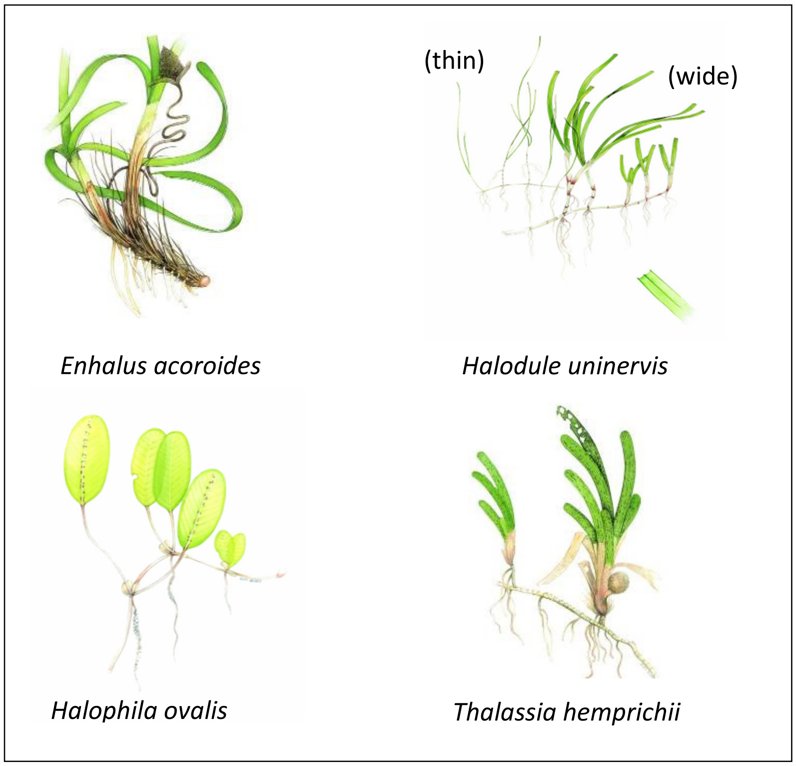


Figure 10. Seagrass species present in the Port of Weipa 2019.

3.1.1 Seagrass in the Intensive Monitoring Area

Fourteen seagrass meadows were mapped in 2019 within the IMA (Figure 14). The total combined seagrass meadow area was 1088 ± 41 ha, which remains above the 20-year average of monitoring in Weipa (Figure 11). Area has been above the IMA long-term average for the last four years although it has declined from the peak recorded in 2017 (Figure 11).

Enhalus acoroides dominated nine out of the fourteen meadows within the IMA (Figure 14), all with light density cover. *Halodule uninervis* was the dominant species in three of the fourteen meadows, two of those being core monitoring meadows A5 and A3, consisting of continuous cover and aggregated patches respectively (Figure 14). *Thalassia hemprichii* was the dominant species in two of the IMA meadows, meadow A1 and the meadow north of A1, both at the mouth of Leithen Creek (Figure 14).

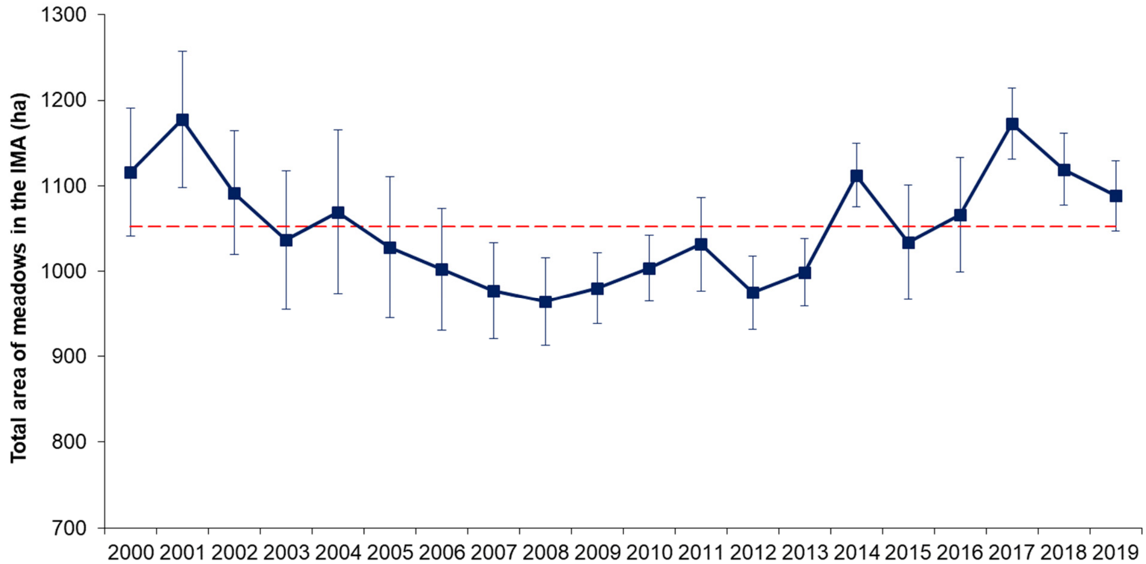


Figure 11. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2019 (error bars = "R" reliability estimate). Red dashed line indicates 19-year mean of total meadow area.

The condition known as burning, i.e. the browning and subsequent death of seagrass blades (Figure 12), was observed at 7% of sites across all meadows within the IMA in 2019; one of the lowest occurrence years to date (Figure 12).

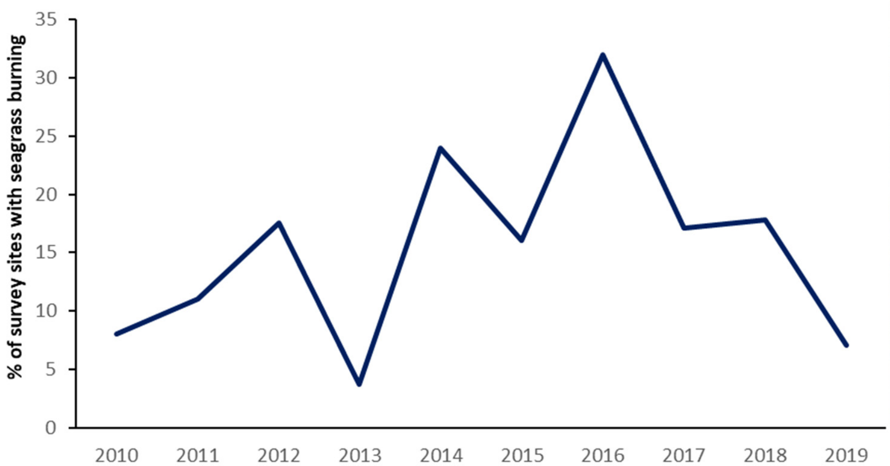


Figure 12. Percentage of sites within the IMA that have evidence of *Enhalus acoroides* burning in the Weipa IMA meadows.

Dugong feeding trails (Figure 13) are not commonly observed within the IMA having only been recorded in two previous surveys, in 2016 meadows A3, A5 and the large meadow between Lorim Point and Napranum (Figure 14). In 2018 Dugong feeding trails were observed in meadow A5 and in one area of A2 (southern end) where a higher density of *H. uninervis* was recorded in the meadow. In 2019 the amount of *H. uninervis* in this meadow reduced substantially, back to more typical levels (0.09gDW.m^{-2} compared to 0.16gDW.m^{-2} in 2018) explaining lack of trails observed. This year's IMA survey saw dugong feeding trails observed again in the A5 meadow.

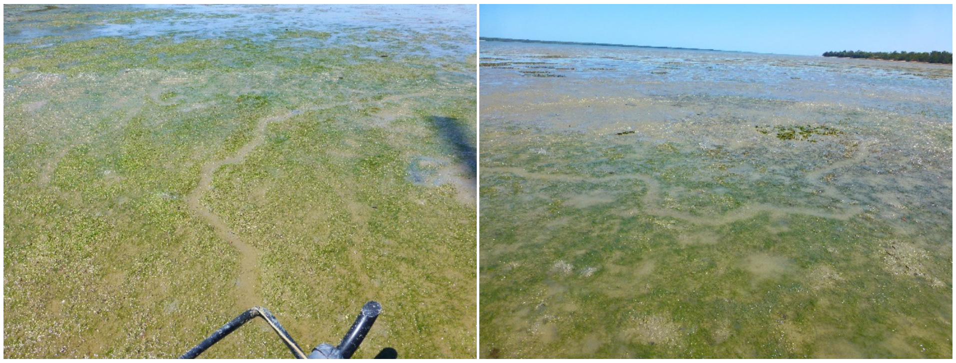


Figure 13. Examples of Dugong feeding trails in the A5 Weipa monitoring meadow in 2019.

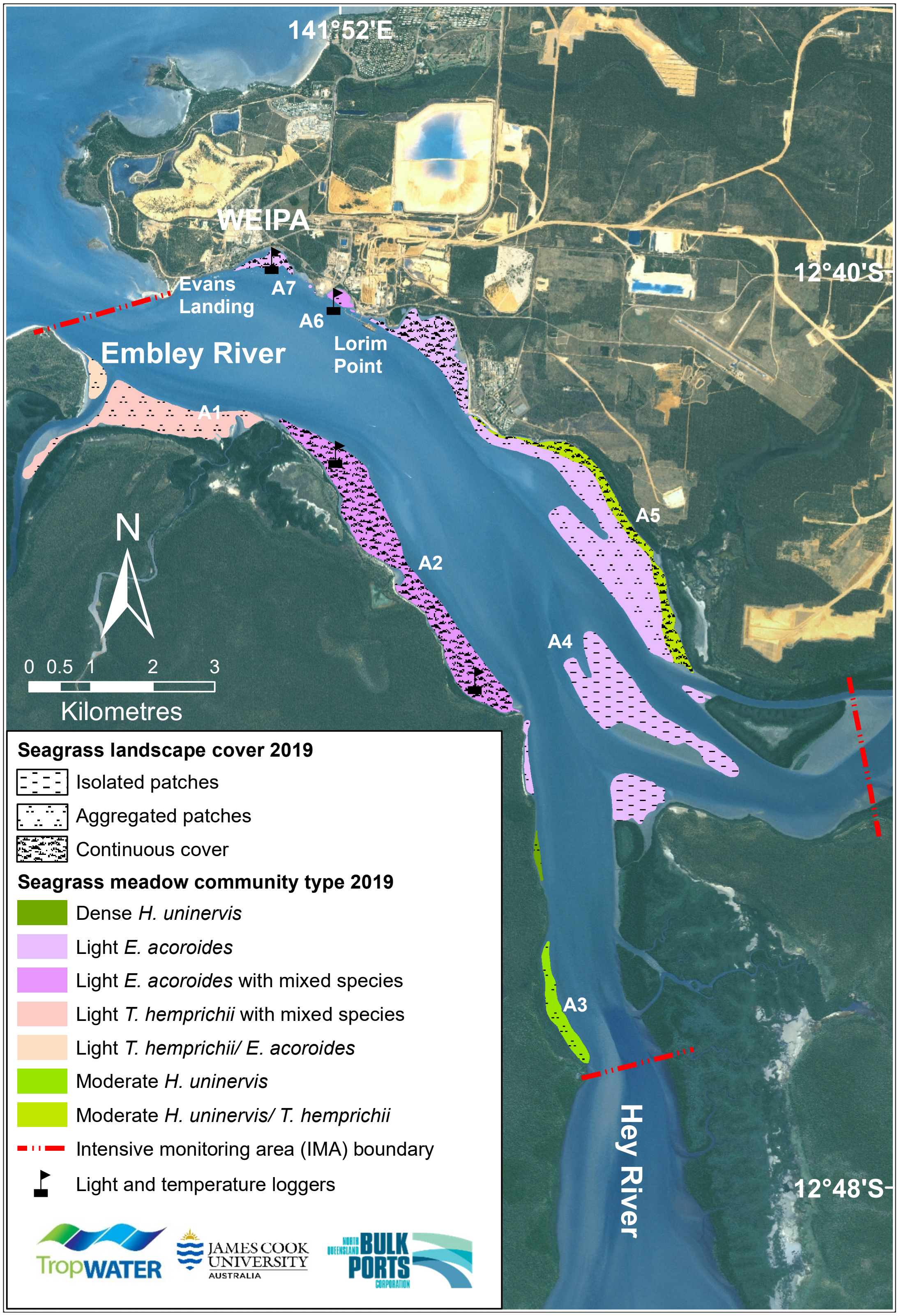


Figure 14. Meadow type and landscape cover for seagrass within the Intensive Monitoring Area 2019.

3.1.2 Seagrass condition in the core annual monitoring meadows

The overall condition of seagrass monitoring meadows in Weipa was classed as good in 2019 (Table 4). The last three years have been an improvement in condition from 2016 when meadows were classed as satisfactory overall. For all monitoring meadows all three indicators; seagrass biomass, area and species composition are now in a good or very good condition.

***Enhalus acoroides* dominated meadows (Meadows A2, A6, A7)**

All *E. acoroides* dominated meadows had a light seagrass cover that was continuous for meadow A2 and A7, and consisted of aggregated patches for meadow A6 (Figure 14). *Enhalus acoroides* maintained its dominance of the species composition for all of these meadows (Figures 16; 19; 20) and increased from aggregated patches in 2018 to continuous cover in 2019 in the IMA A7 meadow. Both meadow A6 and A7 sit adjacent to port infrastructure.

Meadow A2:

Biomass, area and species composition for meadow A2 remained in a good condition for 2019; similar to the previous three years (Figure 16). Meadow area has been at or above the long-term average for the last seven years (Figure 16). Biomass has maintained a good condition for the last eight years, being around the 10 year baseline average during this year's survey. *E. acoroides* female and male flowers and pollen were seen throughout this meadow during the survey (Figure 15).

Figure 15. (a) Male *E. acoroides* flowers/pollen sacs and (b) female flowers in the A2 meadow.

Meadow A6:

Area was classed in a very good condition, while biomass and species composition was classed as being in a good condition (Table 4). A decline in seagrass area for meadow A6 (along with neighbouring meadow A7) was noted in 2015 and 2016 (Figure 19). Between 2016 and 2018 meadow area increased, leading to condition increasing from satisfactory to very good, which was maintained in 2019 (Figure 19). Biomass has increased since 2018, returning to levels observed in the four years prior to the decline (Figure 19).

Meadow A7:

The area of the A7 meadow has recovered in the years following the 2015-2016 declines (Figure 20) increasing to a good condition this year. Species composition remained as it has been for the last seven years (Figure 20). Biomass condition has increased from 2018, improving from a good to a very good score in 2019 (Table 4; Figure 20). There was a significant increase in biomass at the western end of the meadow, where declines were observed in 2018 (Figure 21).

***Halodule uninervis* dominated meadows (A3, A5)**

Both *Halodule uninervis* dominated monitoring meadows consisted of aggregated patches to a continuous cover of seagrass, with a moderate biomass for the species (Figure 14). Both meadows had other species of seagrass in the meadows including *E. acoroides, Thalassia hemprichii* and *Halophila ovalis* (Figure 10). Dugong feeding trails were observed throughout Meadow A5.

Meadow A3:

The seagrass biomass within the A3 meadow continued to follow the increase seen over the last few years (Figure 17) maintaining a very good condition. Species composition also maintained a very good condition, with a minor increase in the dominance of *H. uninervis* compared to last year's survey (Figure 17). Area reduced from very good to good in 2019 (Table 4), however area remains above the 10 year baseline average (Figure 17).

Meadow A5:

The overall condition of meadow A5, south of Napranum, increased from a satisfactory to a good condition in 2019 (Table 4; Figure 18). This improvement in condition was due the meadow continuing to recover in area, showing a 40% increase over the last three years (Table 4; Figure 18). Seagrass composition maintained a very good score, with an increase in the abundance of more stable species, primarily *Thalassia hemprichii* (Figure 18). Biomass has remained in very good condition for at the last four years (Figure 18).

Table 4. Grades and scores for seagrass indicators (biomass, area and species composition) for 2019 in the Port of Weipa.

Meadow	Biomass	Area	Species Composition	Overall Meadow Score
A2	0.74	0.78	0.68	0.71
A3	0.88	0.80	0.99	0.80
A5	0.89	0.69	0.99	0.69
A6	0.85	0.86	0.69	0.77
A7	0.86	0.66	0.85	0.66
Overall Score for the Port of Weipa				**0.73**

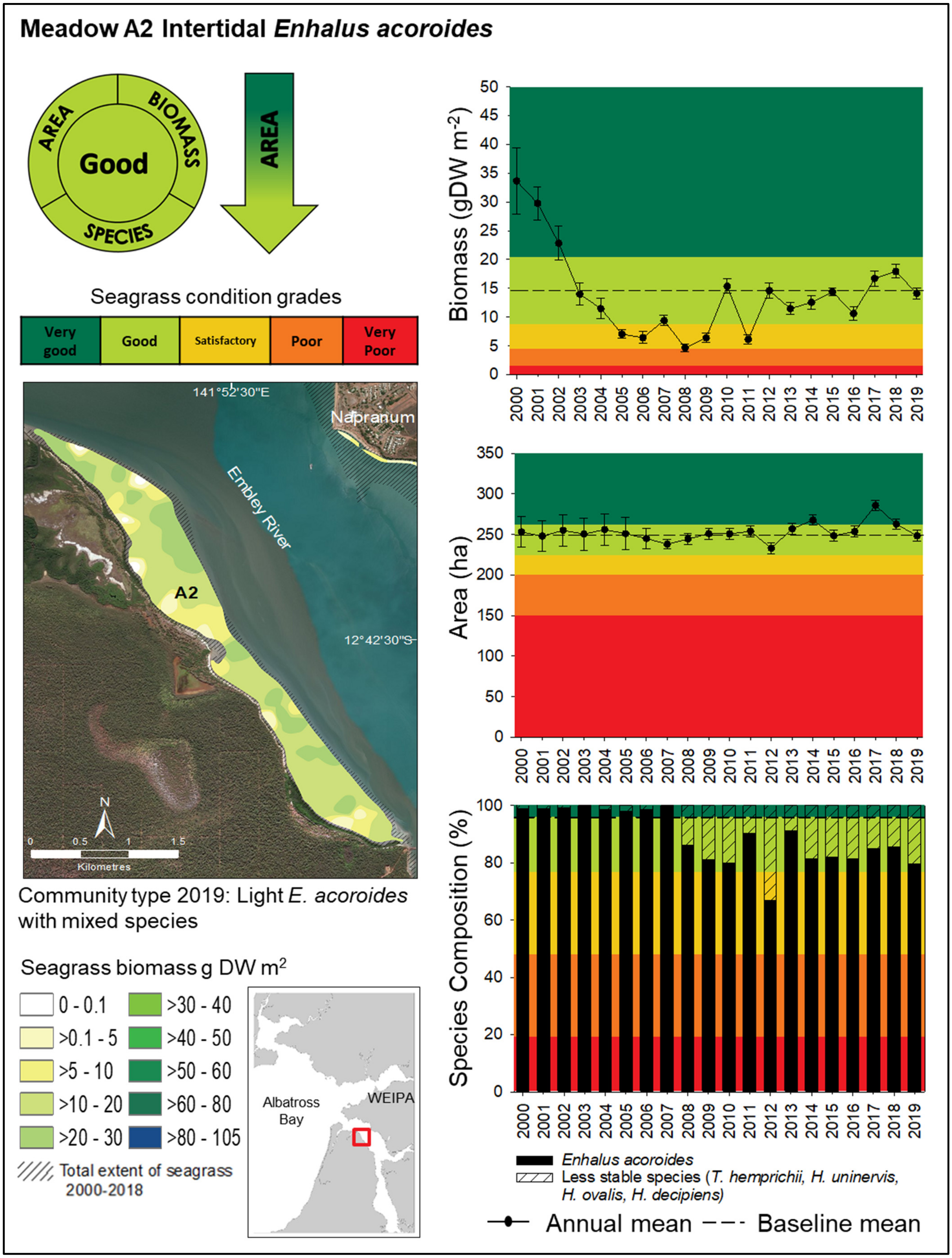


Figure 16. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A2 in Weipa; 2000 to 2019 (biomass error bars = SE; area error bars "R").

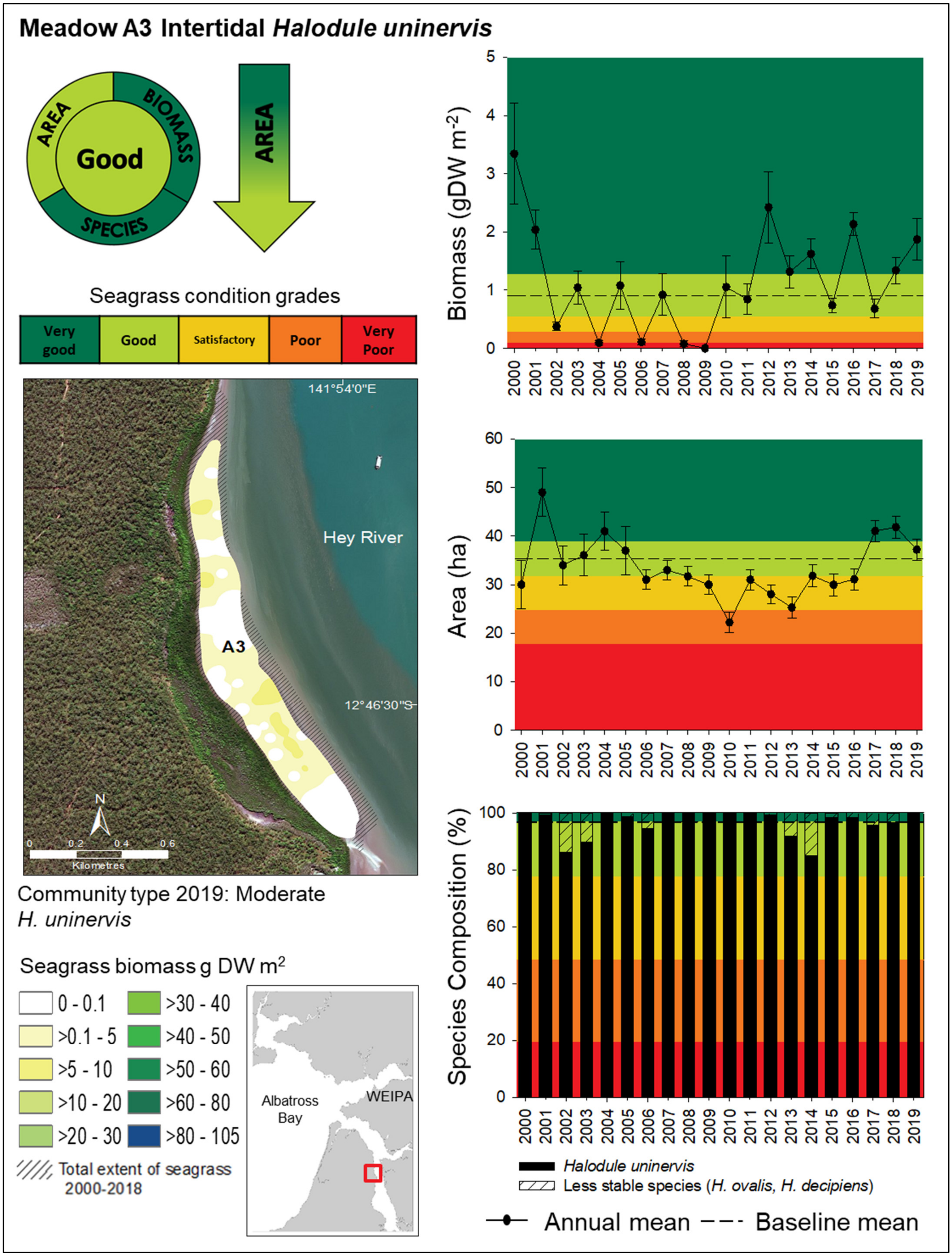


Figure 17. Changes in biomass, area and species composition for the *H. uninervis* dominated core monitoring meadow A3 in Weipa; 2000 to 2019 (biomass error bars = SE; area error bars "R").

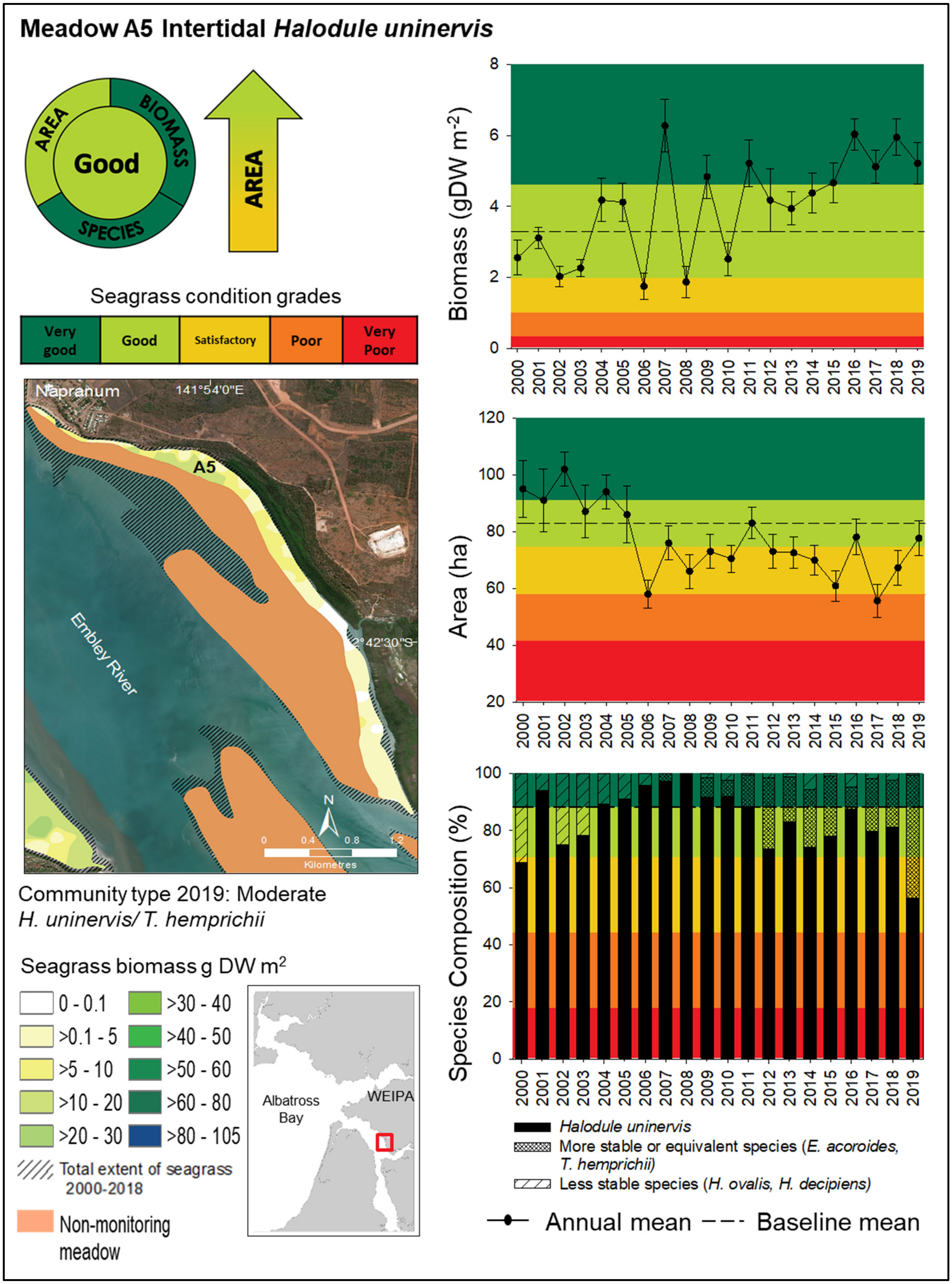


Figure 18. Changes in biomass, area and species composition for the *H. uninervis* dominated core monitoring meadow A5 in Weipa; 2000 to 2019 (biomass error bars = SE; area error bars "R").

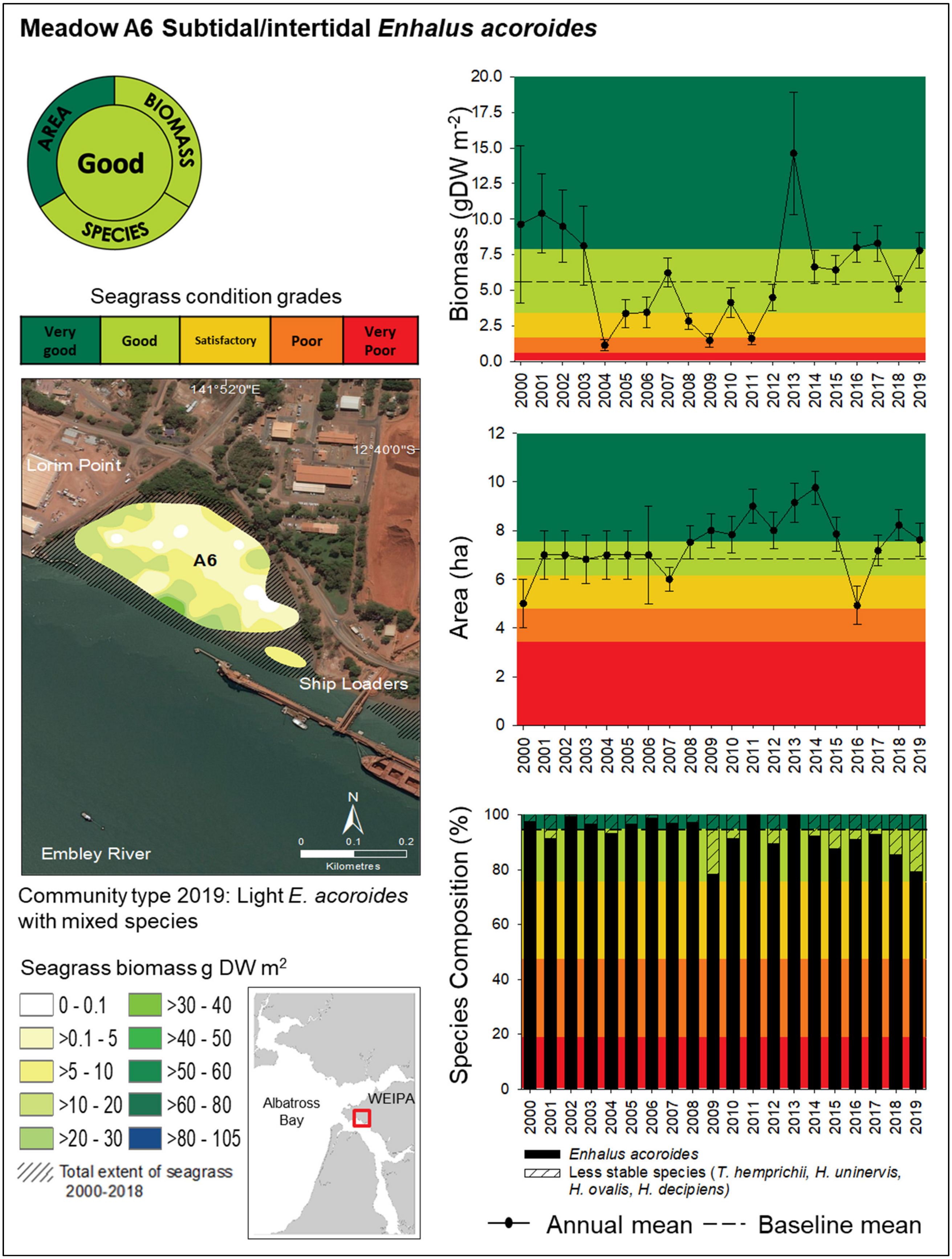


Figure 19. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A6 in Weipa; 2000 to 2019 (biomass error bars = SE; area error bars "R").

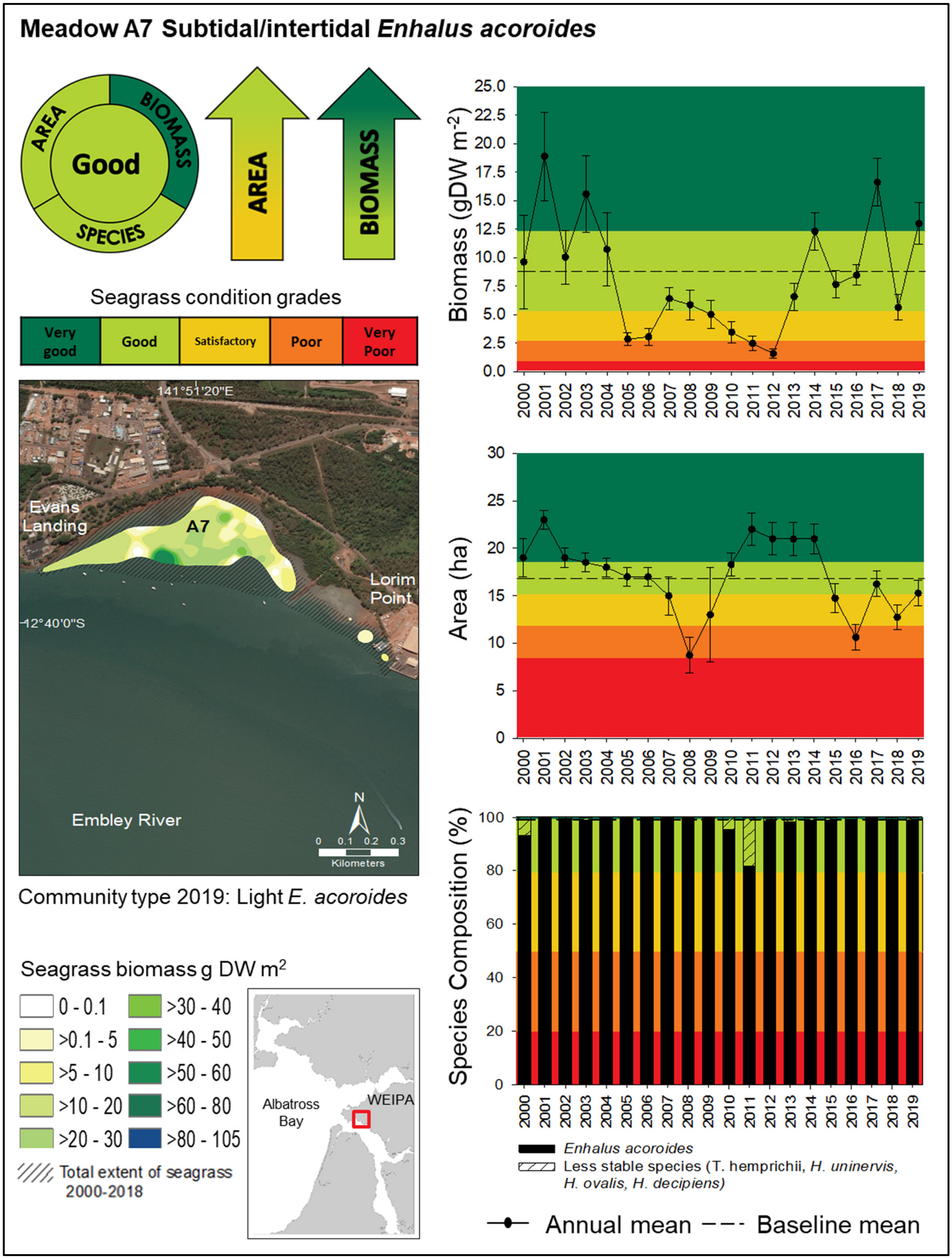


Figure 20. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A7 in Weipa; 2000 to 2019 (biomass error bars = SE; area error bars “R”).

3.1.3 Seagrass pre and post maintenance dredging

Due to significant inputs of sediments during the 2018-2019 wet season a larger than normal maintenance dredging campaign was required in 2019 to maintain the ports' navigational channel, berth and apron areas. This campaign lasted 40 days and removed 2.4M m^3 of sediment compaired to the usual 400,000 – 700,000 m^3. As part of the planning for the dredging NQBP comissioned additional meadow scale seagrass surveys in May 2019 prior to maintainace dredging to assess likely levels of resilience for seagrass measows prior to dredging. Full results of that survey can be found in McKenna & Rasheed (2019a). There was no indication that the severe wet season had a major impact on seagrass in the Port of Weipa (Figure 21). Seagrass in the three meadows surveyed were in a good overall condition in May 2019 prior to dredging, maintained an extensive footprint and maintained a similar meadow composition of the dominant species, *Enhalus acoroides*, to the 2018 annual survey (Figure 21; McKenna & Rasheed 2019b). The annual monitoring conducted in August 2019 provided a post-dredging assessment of the same meadows and as reported in the section above seagrass condition remained good for all of these meadows with no indications of residual impacts from either the dredging or the 2018/19 wet season events (Figure 21).

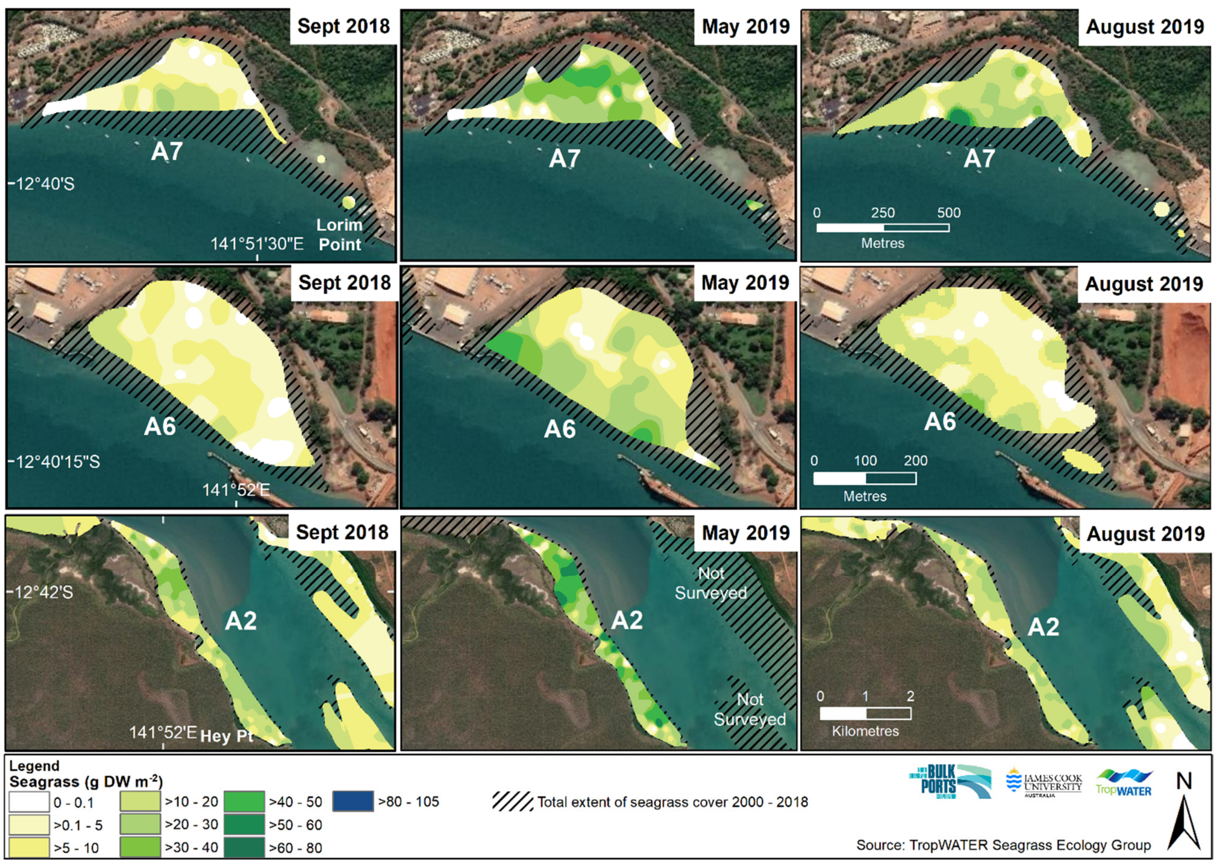


Figure 21. Seagrass distribution and biomass for the three seagrass meadows closest to dredging avctivity and port operations (A6, A7 & A2) in Embley River; pre-wet season (September 2018); post wet season and pre-dredging (May 2019); and post dredging (August 2019).

3.2 Weipa Environmental Data

3.2.1 Rainfall

Total annual rainfall in Weipa (2018/19) was 1426mm and has been below the long-term average for the last five years (Figure 22a). Rainfall followed similar wet season trends leading up to the annual survey, with January having the highest rainfall of 384mm (Figure 22b). This peak was less than previous years despite two extreme weather events affecting the Weipa area. Tropical cyclone Penny made landfall in the 2018/19 New Year period, and cyclone Trevor later in March.

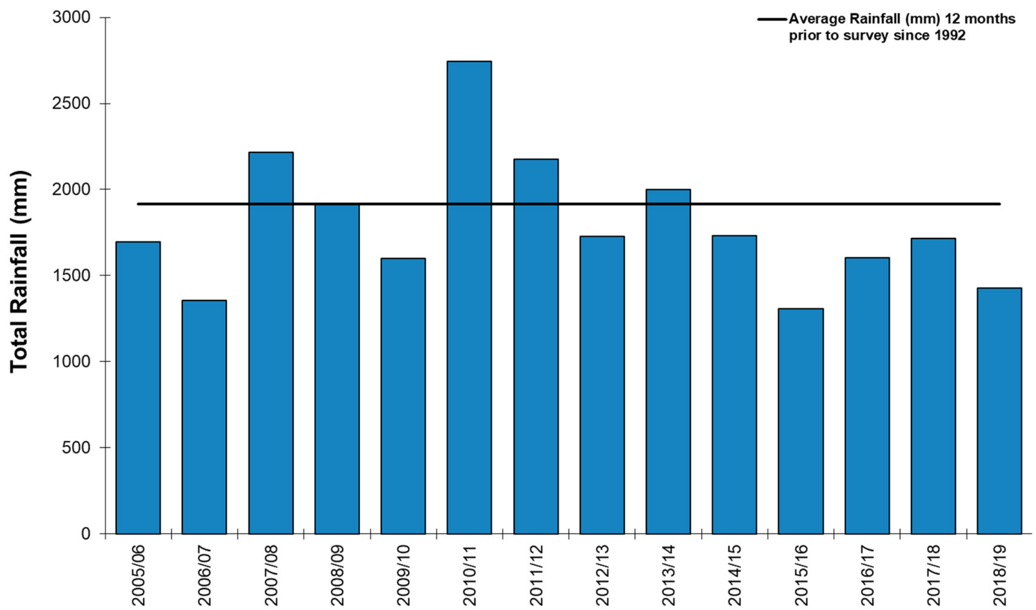


Figure 22a. Total annual rainfall recorded at Weipa Airport; 2005-2019. Data is twelve months prior to survey.

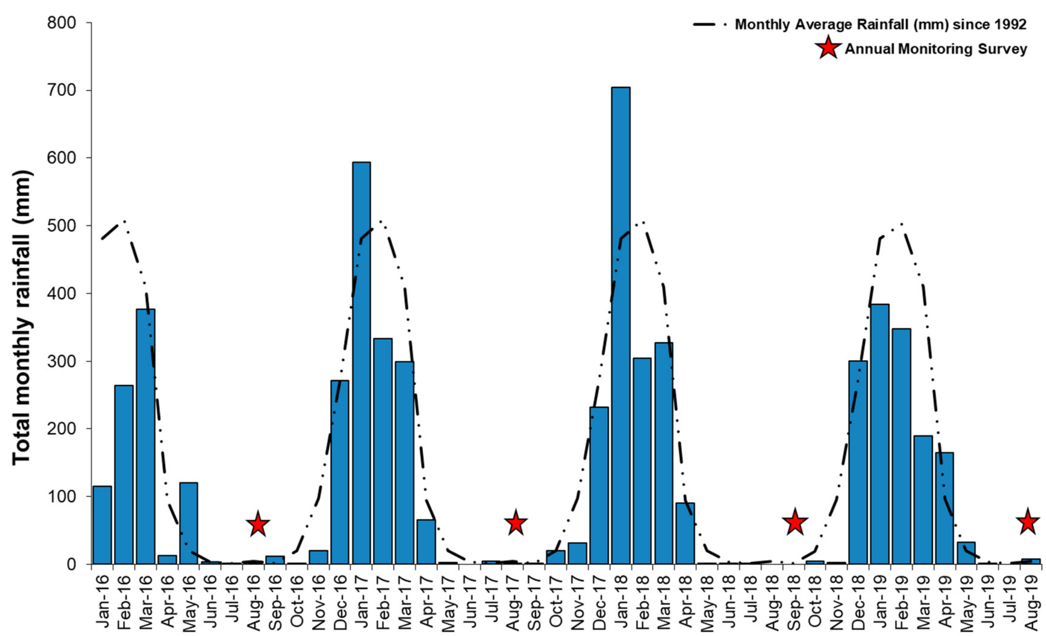


Figure 22b. Total monthly rainfall (mm); January 2016 – August 2019.

3.2.2 Daytime Tidal Exposure

The amount of tidal exposure to daytime air for intertidal meadows in the twelve months prior to survey (389 hours) was equal to long-term average (Figure 23a). Intertidal seagrass meadows generally have a greater amount of daytime exposure during the winter/dry season months and minimal to no exposure during the summer/wet season months (Figure 23b). In the months leading up to the 2019 survey, above average exposure hours were seen in Weipa (Figure 23b).

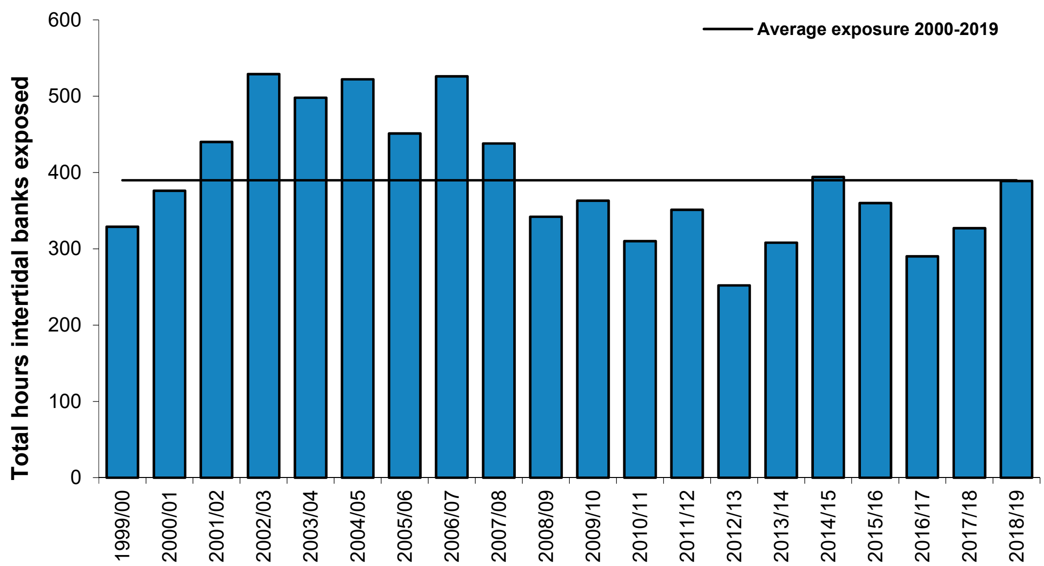


Figure 23a. Total daily tidal exposure to air 1999/00 -2018/19. Data is twelve months prior to survey.

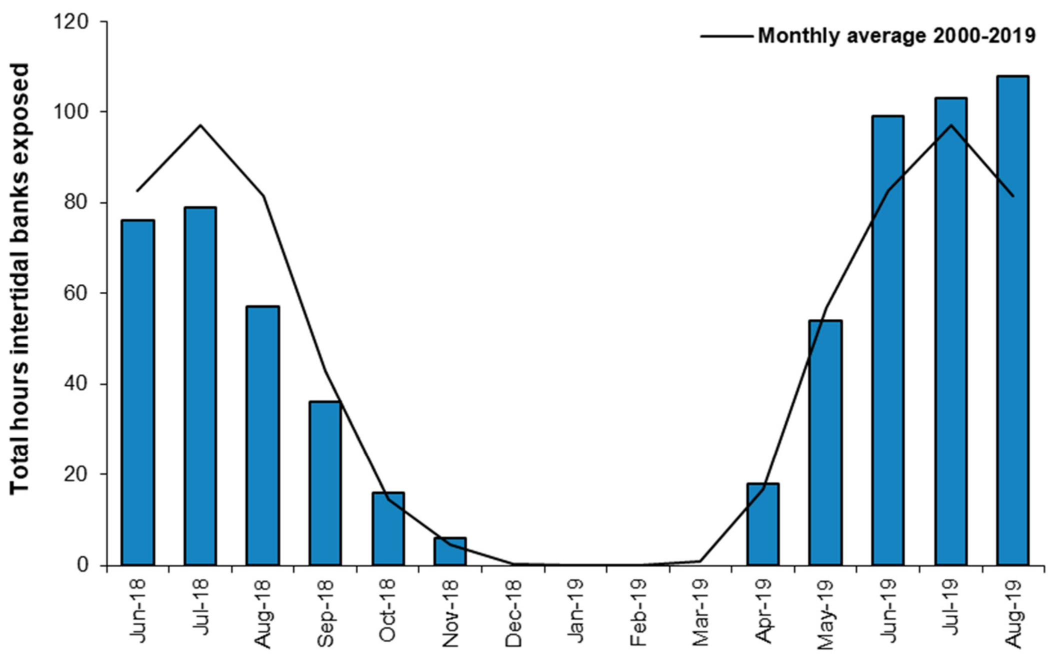


Figure 23b. Monthly total daytime tidal exposure to air (hours; ≤0.9m tidal height); June 2018 – August 2019.

3.2.4 Benthic Daily Photosynthetically Active Radiation (PAR (light))

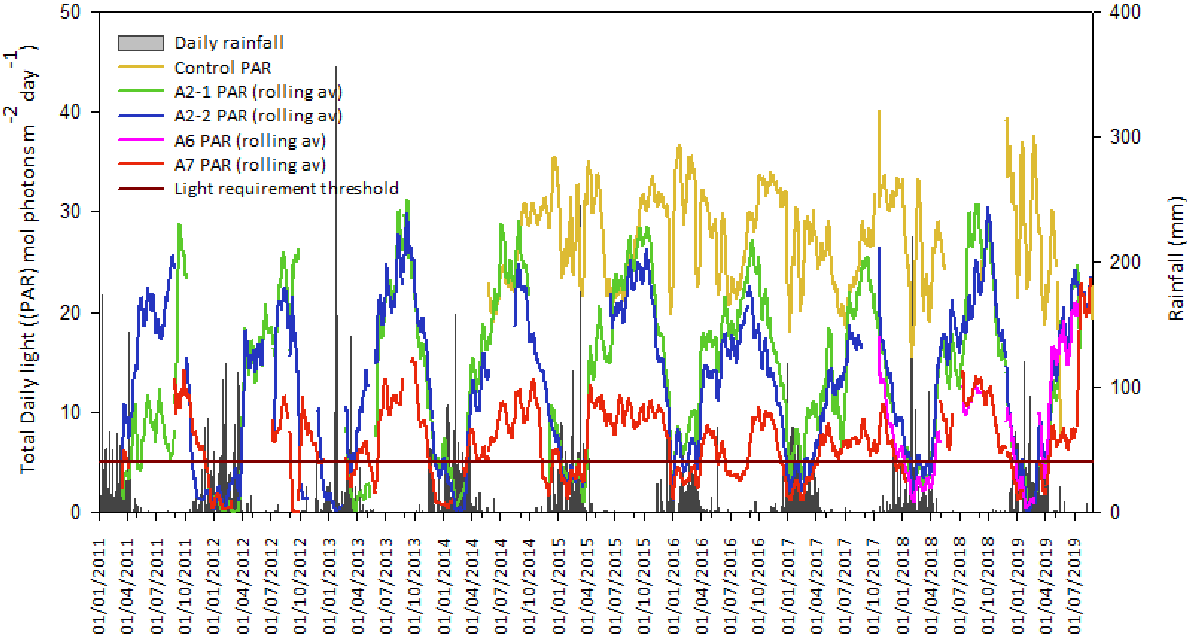
Total daily PAR is measured at two locations in the shallow intertidal meadow on the south-western bank of the Embley River (A2), and in the deeper meadows between Evans Landing and Lorim Point (meadows A6 and A7) (Figure 14). The A6 logging station was established in 2017 and preliminary data from that site indicated the placement of the loggers was not in a suitable place for meaningful light recordings. The logging station was relocated to a more appropriate position in September 2018; as such, data for A6 does not incorporate the full time series presented below (Figure 24 a).

PAR was less in the deeper meadows (A6 & A7) than the shallower A2 meadow as would be expected due to greater light attenuation with depth of water and shorter periods of low tide exposure to air. In the twelve months prior to the seagrass survey PAR ranged from (see Figure 24);

- Control logger (above water): 1.66 to 42.54 mol m^{-2} day^{-1};
- A2 intertidal meadow: 0.01 to 39.17 mol m^{-2} day^{-1};
- A6 & A7 intertidal/subtidal meadow: 0.01 to 29.31 mol m^{-2} day^{-1}.

While no specific light requirement growth thresholds for *E. acoroides* have been developed, it is likely that both *E. acoroides* and *H. uninervis* require at least 5 mol m^{-2} day^{-1} over an integration time of 14 days (Collier et al. 2016) to maintain effective growth as an acute management trigger. For the long-term maintenance of seagrass, they may need as much as ~10-13 mol m^{-2} day^{-1} (Collier et al. 2016). As part of this ,monitoring program we have been investigating *E. acoroides* light requirements with the goal of developing improved thresholds (see 3.3). The longest ongoing integration period (14-day rolling average) that PAR fell below the acute threshold suggested in Collier et al (2016) (5 mol m^{-2} day^{-1}) during 2019 was an extended period which occurred from late December 2018 through to the beginning of April in 2019 (Figure 24 b) and lasted 48 consecutive days in the A2 meadow at its peak. This period coincides with the wet season/high rainfall in the region and encompasses two tropical cyclones as previously mentioned. Both of these events caused a significant increase in wave height over this time span, increasing from the normal 1-2 meters to 5-6 meters, resulting in increased water turbidity and combined with lower incident light due to high cloud cover is the likely cause to this drop in light levels.

a)



b)

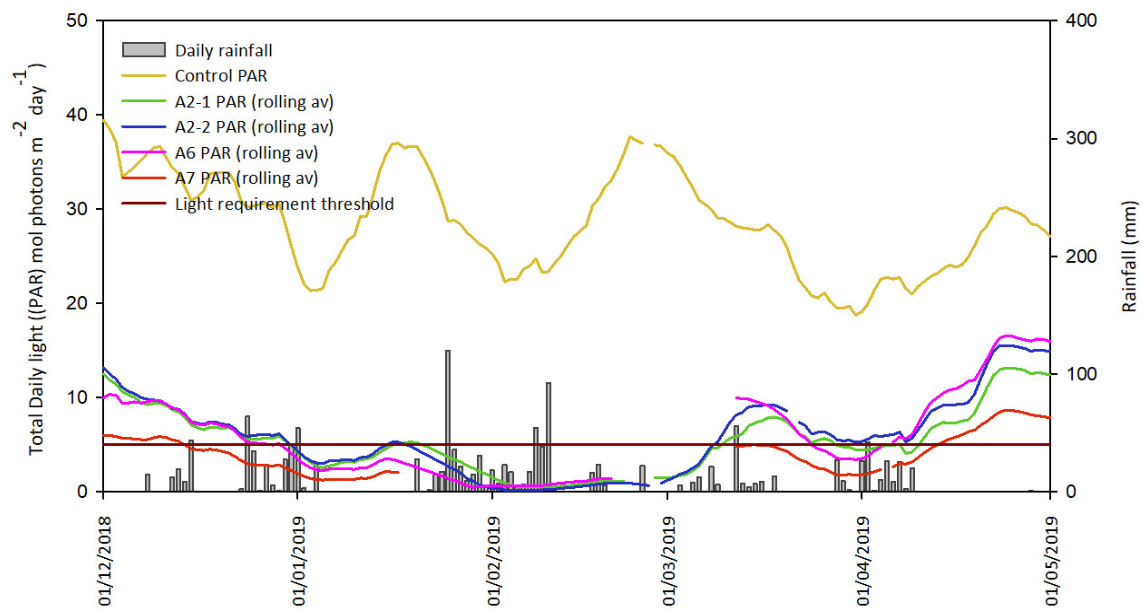


Figure 24 (a) Daily photosynthetically active radiation (PAR; mol photons m-2 day-1) and total daily rainfall (mm) at Weipa; January 2011 – August 2019, at Meadow A2 northern (A2-1) and southern (A2-2), Meadow A7, control logger and preliminary data from Meadow A6. (b) Period of low light over the 2018-2019 wet season.

3.3 Light (PAR), temperature and intertidal seagrass change

Quarterly seagrass assessments in Meadow A2 were incorporated into the established PAR and temperature program in 2015 to track the persistent species *E. acoroides* in relation to light levels. In 2019, quarterly assessments were conducted in May and August. Seagrass biomass ranged from 30.98 ± 1.29 g DW m^{-2} in May to 14.23 ± 0.86 g DW m^{-2} in August (Figure 25). Since quarterly biomass monitoring has been established, there have been some variations in biomass annually; however, there seems to be little impact from periods of natural wet season low light levels on *E. acoroides* in the intertidal A2 meadow over longer time scales. PAR on the intertidal A2 meadow has followed 'typical' patterns of high and low light levels during dry and wet seasons, and tidal exposure (Figure 26). As mentioned above, during each wet season PAR reaches very low levels and fell below 5 mol m^{-2} day^{-1} (light threshold) between December 2018 and April 2019 in the A2 meadow. However, *E. acoroides* in intertidal meadows appears to have a good capacity to resist these wet season low light periods, with biomass being maintained at similar pre-wet season levels following these low light events (Figure 25). It is likely this is due to the large energy stores accumulated in the below ground structures of this species and we recommend future studies investigate these further (see section 4).

In early 2018, we transitioned the temperature data loggers from Thermodata® iBTag submersible loggers to widely used Bluetooth HOBO® data loggers. The HOBO® loggers did not perform well Weipa, often being destroyed by animals causing water inundation and resulting in data loss. We re-deployed iBTag temperature loggers in September 2018, and have been collecting complete data sets since the iBTag's were re-deployed. The result of this was the gap in temperature data seen in Figure 26. For the temperature data available in the twelve months prior to the survey, the overall temperatures at the seagrass meadows in 2019 remained similar to the previous three years (Figure 25). Mean and maximum daily water temperature at the site was less variable than in previous years

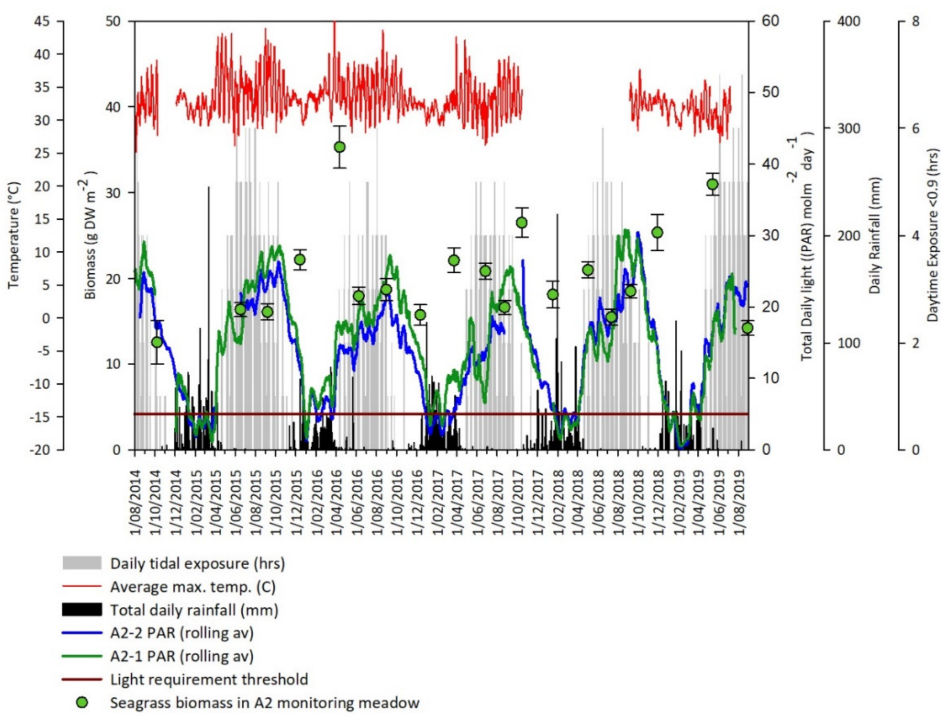


Figure 25. Total daily light (14 day rolling average (PAR; mol photons m^{-2} day^{-1})), seagrass biomass (g dw m^{-2}), maximum sea temperature within the seagrass canopy (◦C), total daily rainfall (mm) and total daily hours intertidal banks are exposed to air (hrs) in Weipa August 2014 – August 2019 in the A2 intertidal monitoring meadow. B) Period of low light over the 2018-2019 wet season.

4 DISCUSSION

Seagrasses in the Port of Weipa were in an overall good condition in 2019. They maintained an extensive footprint in the region closest to the port (IMA) with total area one of the highest recorded during the 20 year monitoring program history. The species composition of meadows was maintained with the expected mix and dominance of foundation species, and area and biomass of all meadows were rated in good to very good condition against their 10-year baseline history. Seagrasses in Weipa were able to maintain their condition despite extended impacts from multiple cyclones during the wet season that resulted in low light reaching the meadows and high levels of siltation in the shipping channels and berth areas of the port. The presence of dugong feeding trails and flowering/fruiting of seagrass recorded during the survey were further signs of a healthy and productive seagrass ecosystem in 2019.

Weipa's seagrass meadows were resilient to the pressures associated with long-lasting, extreme weather events during the 2018-2019 wet season, and the resulting increased annual maintenance dredging during 2019. Between December 2018 and April 2019 the region was impacted by Tropical Cyclone (TC) Penny and TC Trevor, and high rainfall associated with ex TC Oma. These events led to abnormally large waves and seas that resulted in resuspension of sediments that accumulated into navigation and shipping channels of the port as well as resulting in an extended period of low light over the seagrass meadows. The regions seagrass meadows received substantially less than the 5 mol m^{-2} day^{-1} light (PAR) that *H. uninervis* is likely to require for positive growth (Collier et al. 2016) for approximately three months during this time.

Previous experience from the monitoring program has shown that generally seagrasses have been able to persist in Weipa following various weather events and natural periods of low light throughout the wet season. *Enhalus acoroides* is a persistent species that has a large storage of carbohydrate energy reserves in below ground structures that can sustain the plant (Kilminster et al. 2015). While seemingly being able to withstand extended periods of low light during the wet season, losses of *E. acoroides* occurred in 2015 and 2016 between Evans Landing and Lorim Point (McKenna & Rasheed 2019b), when there were additional uncharacteristic localised reductions in light during the dry season. These losses show that the species can be vulnerable particularly when there are multiple occurrences of sustained low light within a year. It is likely that *E. acoroides* is relying on the generally good light conditions that typically occur in the dry season to recover their energy reserves and resilience each year. In 2019 while low light occurred for a longer period of time than previous wet seasons (Figure 26), high light conditions above the seagrass light threshold occurred for the remainder of the year, and importantly throughout the growing season, unlike the localised events in 2015/2016.

Based on the work we have done between 2015 and 2019 on *Enhalus acoroides* it is obvious that this species is utilising stored carbohydrates in their below ground structures to tie them over during the regular wet season low light periods. Based on the most recent results it appears that providing they enter the wet season in good condition, they can withstand upwards of three months of light below a threshold that would be required to support net gain in energy from photosynthesis without any long term detrimental effects to their above ground biomass. Due to this, management of this species using traditional light threshold values, such as those recommended in Collier et al. (2016), may not be particularly effective on their own. Critical to understanding how resilient the species will be to light impacts is understanding the status of carbohydrate reserves in the rhizomes and whether the plant is drawing down on these. We would encourage further work on examining these carbohydrate reserves as a way of assisting future resilience assessments for this species.

What appears to be more critical for *Enhalus acoroides* in Weipa is to ensure that there are not additional periods of low light outside of the regular wet season impact. When these have been recorded previously in the program the species declines (Rasheed & McKenna 2019b). Previous annual maintenance dredging events in Weipa have been relatively short and light is maintained at sufficient levels for seagrass growth when they occur. The wet season of 2018/2019 resulted in exceptional siltation of the channels, berth pockets and apron areas of the port with more than 2,400,000m^3 of sediment above design depth required to be removed. As part of the response to the larger volumes and expanded timeframes required for the 2019 dredging, NQBP implemented a reactive water quality monitoring program for the dredging operation with real time data available to ensure light requirements for seagrass were met throughout the dredging. The planning and operation of the dredging campaign successfully maintained adequate light for seagrasses well above light thresholds for the entire dredging program between the 4th June and 13th July 2019, and as the results of this seagrass report show, seagrasses were maintained in a healthy and resilient condition following the dredging program

Other environmental conditions that can effect seagrass growth were also generally favourable in the twelve months prior to the survey and likely contributed to the sustained good condition of seagrass in the Weipa area. Tidal exposure was below average, reducing air exposure stress including "burning" of seagrass leaves that has been observed previously during the monitoring program and led to seagrass declines (Unsworth et al. 2012). While there were some burnt leaves observed in 2019, the incidence was the lowest recorded in six years.

Similar seagrass monitoring to the Port of Weipa is conducted to the north in the Torres Strait (Wells et al. 2019) and further south in the Gulf of Carpentaria around Karumba (Shepherd et al. 2020). Seagrass condition in Weipa in 2019 was better than Thursday Island where seagrasses had declined from good to satisfactory condition since 2018 (Wells et al. 2019). Seagrasses to the south in Karumba, were in there poorest condition in the 26 years they have been monitored, following extended flooding of the local rivers lead to a persistent turbid flood plume over the seagrass meadows. Along the eastern coast of Queensland, there is still a general trend of recovery in seagrass meadows since large scale losses of seagrasses occurred in the years leading up to 2011, associated with extended La Niña climate conditions and severe storms.

5 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 (2000-2009). This baseline was set based on results of the Gladstone Harbour 2014 pilot report card (Bryant et al. 2014). The 2002-2009 period incorporates a range of conditions present in the Port of Weipa, including El Niño and La Niña periods, and multiple extreme rainfall and river flow events. The 10-year long-term baseline 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 Figure A1).

Meadow Classification

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

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

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

Threshold Definition

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

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

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

Grade and Score Calculations

A score system (0–1) and score range was applied to each grade to allow numerical comparisons of seagrass condition among meadows, and for the Port of Weipa region (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 Port of Weipa 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 *H. uninervis* 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 the Port of Weipa, 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).

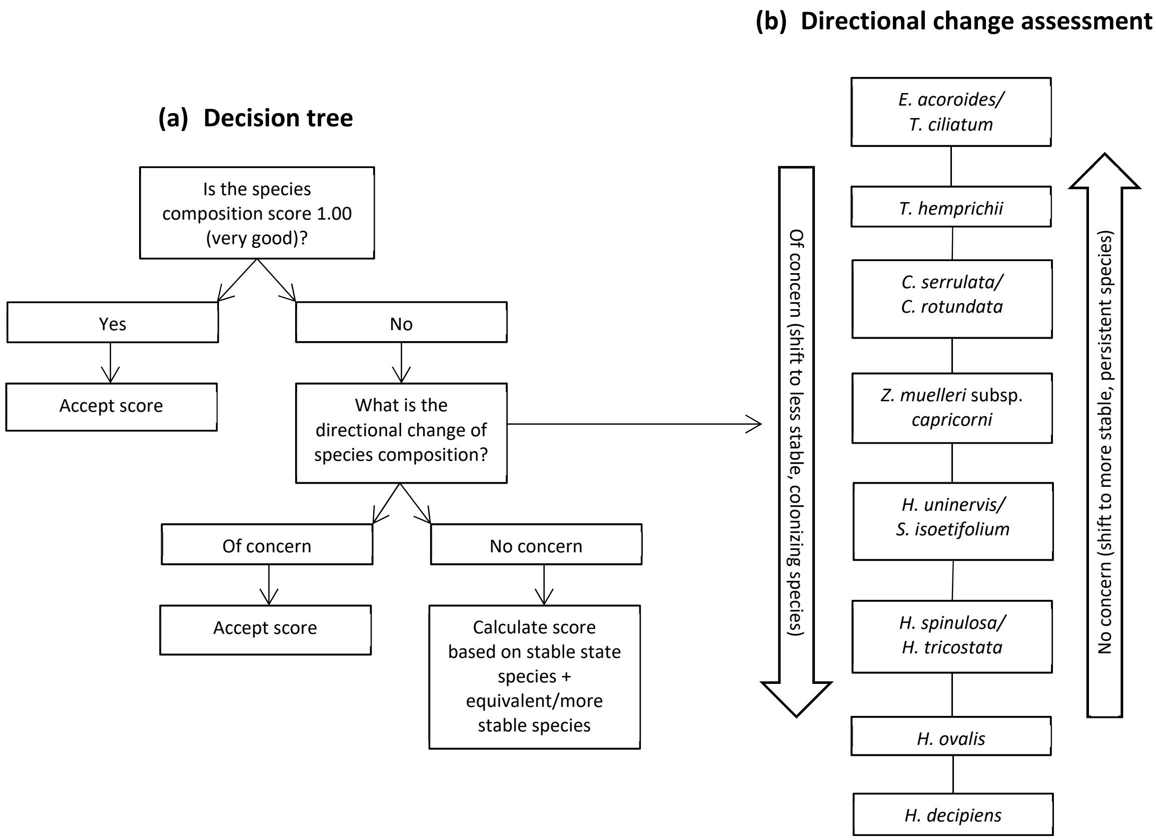


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in the Port of Weipa.

Score Aggregation

A review in 2017 of how meadow scores were aggregated from the three indicators (biomass, area and species composition) led to a slight modification from previous years' annual report. 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.

Both seagrass meadow area and biomass are fundamental to describing the condition of a seagrass meadow. A poor condition of either one, regardless of the other, describes a poor seagrass meadow state. Importantly they can and do vary independently of one another. Averaging the indicator scores is not appropriate as in some circumstances the area of a meadow can reduce dramatically to a small remnant, but biomass within the meadow is maintained at a high level. Clearly such a seagrass meadow is in poor condition, but if you were to take an average of the indicators it would come out satisfactory or better. The reverse is true as well, under some circumstances the spatial footprint of a meadow is maintained but the biomass of seagrass within is reduced dramatically, sometimes by an order of magnitude. Again, taking an average of the two would lead to a satisfactory or better score which does not reflect the true state of the meadow. As both of these characteristics are so fundamental as to the condition of a seagrass meadow, the decision was to have the overall meadow score be the lowest of the indicators rather than an average. This method allowed the most conservative estimate of meadow condition to be made (Bryant et al. 2014b).

Seagrass species composition is an important modifier of seagrass meadow state. A change in species to more colonising forms can be a key indicator of disturbance and a meadow in recovery from pressures. As not all seagrass species provide the same services a change in species composition can lead to a change in the function and services a meadow provides. Originally, the species composition indicator was considered in the same way as biomass and area, if it was the lowest score, it would inform the overall meadow score. However, while seagrass species is an important modifier it is not as fundamental as the actual presence of seagrass (regardless of species). While the composition may have changed there is still seagrass present to perform at least some of the roles expected of the meadow such a food for dugong and turtle for example. The old approach led to some unintended consequences with some meadows receiving a "0" score despite having good area and biomass simply because the climax species for that meadows base condition had not returned after losses had occurred. So while it is an important modifier, species composition should not be the sole determinant of the overall meadow score (even when it is the lowest score). As such the method for rolling up the 3 indicator scores was modified so that in the circumstances where species composition is the lowest of the 3 indicators, it contributes 50% of the score, with the other 50% coming from the lower of the 2 fundamental indicators (biomass and area). This maintains the original design philosophy but provides a 50% reduction in weighting that species composition could effectively contribute.

The change in weighting approach for species composition was tested across all previous years and meadows in the Port of Weipa as well the other seagrass monitoring locations where we use this scoring methodology (Cairns, Townsville, Abbot Point, Mackay, Hay Point, Mourilyan Harbour, Torres Strait, Gladstone and Karumba). A range of different weightings were examined, but the 50% weighting consistently provided the best outcomes. The change resulted in sensible outcomes for meadows where species composition was poor and resulted in overall meadow condition scores that remained credible with minimal impact to the majority of meadow scores across Weipa (and the other locations), where generally meadow condition has been appropriately described. Changes only impacted the relatively uncommon circumstance where species composition was the lowest of the 3 indicators. The reduction in weighting should not allow a meadow with very poor species composition to achieve a rating of good, due to the reasons outlined above, and the 50% weighting provided enough power to species composition to ensure this was the achieved compared with other weightings that were tested.

Overall Port of Weipa 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

An example of calculating a meadow score for biomass in satisfactory condition in 2016.

1. Determine the grade for the 2016 (current) biomass value (i.e. satisfactory).

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

$$B_{diff} = B_{2016} - B_{satisfactory}$$

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_{2016} takes up:

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

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:

$$Score_{2016} = LB_{satisfactory} + (B_{prop} \times SR_{satisfactory})$$

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

Appendix 3. Detailed species composition; 2000 – 2018.

Appendix 4. Meadow above-ground biomass and area

Mean above-ground seagrass biomass (g DW m^{-2}) ± standard error and number of biomass sampling sites (in brackets) for each core monitoring meadow within the Port of Weipa, 2000 – 2019.

Monitoring Meadow	Mean Biomass ± SE (g DW m^{-2}) (no. of sites)																			
	Sep-00	Sep-01	Sep-02	Sep-03	Aug-04	Aug-05	Aug-06	Sep-07	Sep-08	Sep-09	Sep-10	Aug-11	Aug-12	Sep-13	Aug-14	Sept-15	Aug-16	Aug-17	Sept-18	Sept-19
A2 Intertidal *Enhalus* dominated	33.63 ± 5.82 (17)	29.73 ± 2.88 (51)	22.84 ± 2.99 (50)	13.99 ± 1.96 (54)	11.47 ± 1.77 (51)	7.04 ± 0.72 (51)	6.43 ± 1.03 (54)	9.40 ± 0.90 (46)	4.65 ± 0.63 (48)	6.39 ± 0.77 (70)	15.36 ± 1.23 (52)	6.13 ± 0.82 (51)	14.60 ± 1.36 (65)	11.47 ± 1.01 (76)	12.55 ± 1.15 (81)	14.37 ± 0.66 (91)	10.62 ± 1.13 (66)	16.70 ±1.28 (72)	17.92 ± 1.18 (68)	14.12 ± 0.99 (62)
A3 Intertidal *Halodule* dominated	3.34 ± 0.87 (11)	2.04 ± 0.33 (26)	0.38 ± 0.07 (30)	1.04 ± 0.29 (26)	0.10 ± 0.04 (26)	1.08 ± 0.41 (25)	0.11 ± 0.05 (31)	0.92 ± 0.36 (31)	0.08 ± 0.05 (28)	0.0002 ± 0.0001 (31)	1.05 ± 0.53 (26)	0.84 ± 0.26 (44)	2.42 ± 0.61 (34)	1.31 ± 0.28 (69)	1.62 ± 0.25 (71)	0.74 ± 0.12 (77)	2.13 + 0.19 (42)	0.68 ± 0.16 (71)	1.34 ± 0.23 (56)	1.87 ± 0.36 (45)
A5 Intertidal *Halodule* dominated	2.55 ± 0.49 (9)	3.11 ± 0.31 (51)	2.03 ± 0.29 (51)	2.26 ± 0.23 (49)	4.18 ± 0.61 (50)	4.11 ± 0.54 (50)	1.75 ± 0.38 (57)	6.27 ± 0.74 (48)	1.87 ± 0.45 (48)	4.83 ± 0.61 (76)	2.52 ± 0.46 (62)	5.21 ± 0.66 (78)	4.17 ± 0.88 (60)	3.94 ± 0.47 (70)	4.38 ± 0.57 (67)	4.66 ± 0.55 (67)	6.03 + 0.44 (95)	5.12 ± 0.47 (69)	5.94 ± 0.51 (91)	5.21 ± 0.58 (60)
A6 Intertidal/ subtidal *Enhalus* dominated	9.63 ± 5.52 (9)	10.4 ± 2.79 (26)	9.5 ± 2.54 (25)	8.13 ± 2.90 (25)	1.14 ± 0.40 (26)	3.37 ± 1.00 (26)	3.45 ± 1.09 (26)	6.22 ± 1.01 (31)	2.83 ± 0.55 (25)	1.47 ± 0.47 (29)	4.14 ± 1.04 (25)	1.61 ± 0.41 (49)	4.49 ± 0.94 (28)	14.61 ± 4.29 (32)	6.64 ± 1.19 (32)	6.43 ± 1.03 (32)	7.99 + 1.05 (19)	8.30 ± 1.26 (32)	5.1 ± 0.91 (33)	7.8 ± 1.27 (40)
A7 Intertidal/ subtidal *Enhalus* dominated	9.63 ± 4.12 (14)	18.89 ± 3.88 (30)	10.03 ± 2.34 (33)	15.57 ± 3.39 (31)	10.71 ± 3.19 (24)	2.84 ± 0.58 (30)	3.06 ± 0.73 (33)	6.41 ± 0.97 (33)	5.85 ± 1.28 (21)	5.03 ± 1.22 (24)	3.46 ± 0.92 (21)	2.47 ± 0.65 (35)	1.58 ± 0.42 (36)	6.58 ± 1.20 (45)	12.31 ± 1.65 (39)	7.64 ± 1.20 (34)	8.48 + 0.91 (28)	16.61 ± 2.08 (30)	5.63 ± 1.13 (28)	12.99 ± 1.82 (38)

Appendix 4. Meadow above-ground biomass and area

Total meadow area + R (ha) for each core monitoring meadow within the Port of Weipa, 2000 – 2019.

Monitoring Meadow	**Total meadow area + R (ha)**																			
	Sep-00	**Sep-01**	**Sep-02**	**Sep-03**	**Aug-04**	**Aug-05**	**Aug-06**	**Sep-07**	**Sep-08**	**Sep-09**	**Sep-10**	**Aug-11**	**Aug-12**	**Sep-13**	**Aug-14**	**Sep-15**	**Aug-16**	**Aug-17**	**Sept-18**	**Sept-19**
A2 Intertidal *Enhalus* dominated	253.0± 19.0	248.0± 19.0	255.0± 19.0	250.4± 19.7	256.0± 19.0	251.0± 20.0	245.0± 13.0	238.0± 6.0	244.5± 6.6	251.0± 7.0	250.7± 6.5	254.0± 6.5	233.0± 7.0	256.9± 6.6	267.7± 6.5	248.3± 6.5	253.59 ± 6.56	285.82 ± 6.51	262.63 ± 6.62	248.32 ± 6.61
A3 Intertidal *Halodule* dominated	30.0± 5.0	49.0± 5.0	34.0± 4.0	36.1± 4.3	41.0± 4.0	37.0± 5.0	31.0± 2.0	33.0± 2.0	31.7± 2.0	30.0± 2.1	22.2± 2.1	31.0± 2.1	28.0± 2.0	25.3± 2.2	31.8± 2.3	30.0± 2.2	31.11 ± 2.2	41.04 ± 2.22	41.82 ± 2.22	37.21 ± 2.22
A5 Intertidal *Halodule* dominated	95.0± 10.0	91.0± 11.0	102.0± 6.0	87.0± 9.3	94.0± 6.0	86.0± 10.0	58.0± 5.0	76.0± 6.0	66.0± 6.0	73.0± 6.0	70.5± 4.7	83.0± 5.5	73.0± 6.0	72.6± 5.5	69.9± 5.3	60.9± 10.8	78.06 ± 6.34	55.63 ± 5.82	67.26 ± 6.19	77.67 ± 6.03
A6 Intertidal/ subtidal *Enhalus* dominated	5.0± 1.0	7.0± 1.0	7.0± 1.0	6.8± 1.0	7.0± 1.0	7.0± 1.0	7.0± 2.0	6.0± 0.5	7.5± 0.7	8.0± 0.7	7.8± 0.8	9.0± 0.7	8.0± 3.0	9.2± 1.6	9.8± 1.4	7.9± 1.4	4.92 ± 3.34	7.19 ± 2.61	8.22 ± 2.61	7.62 ± 0.68
A7 Intertidal/ subtidal *Enhalus* dominated	19.0± 2.0	23.0± 1.0	19.0± 1.0	18.5± 1.0	18.0± 1.0	17.0± 1.0	17.0± 1.0	15.0± 2.0	8.7± 1.9	13.0± 5.0	18.3± 1.2	22.0± 3.4	21.0± 7.0	21.0± 3.5	21.0± 6.4	14.7± 6.0	10.62 ± 5.53	16.23 ± 5.56	12.74 ± 1.26	15.28 ± 1.37
Total	**402.0± 37.0**	**418.0± 37.0**	**417.0± 31.0**	**398.8± 35.3**	**416.0± 31.0**	**398.0± 37.0**	**358.0± 23.0**	**368.0± 16.5**	**358.4± 17.0**	**375.0± 20.8**	**369.4± 15.3**	**399.0± 18.2**	**363.0± 25.0**	**384.9± 19.4**	**400.1± 21.8**	**361.8± 27.0**	**378.31 ± 23.97**	**405.91 ± 22.72**	**392.67 ± 16.92**	**386.09 ± 25.00**

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