


PORT OF WEIPA LONG-TERM SEAGRASS MONITORING PROGRAM: 2000 - 2020

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KEY FINDINGS

Seagrass Condition

Good

Likely causes of seagrass condition:

⬆ *Favourable seagrass resilience leading into the 2019/2020 wet season*

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

- Monitoring in 2020 found seagrasses in the port of Weipa were in good condition overall.
    - Most 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 one of the highest recorded in the 20-year monitoring program history.

- Seagrass cover across the broader port area (including Pine River Bay, Embley, Hey and Mission Rivers) was higher than any other survey since monitoring began in 2000.

- Light conditions were above the threshold for seagrass growth and survival throughout the year, with the exception of an expected period during the wet season.

- Favourable climate conditions for multiple years has led to greater seagrass cover across the port and the overall good condition of Weipa's seagrass in 2020.

- The healthy state of Weipa's seagrass in 2020 means they should be resilient to planned maintenance dredging activities in 2021 assuming that there are no major seagrass losses associated with the predicted La Nina weather conditions leading up to the 2021 maintenance dredging campaign.

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 within the IMA representing the range of different seagrass community types found in Weipa are assessed for changes in biomass, area and species composition. Changes to these metrics are then used to develop a seagrass condition index (see section 2.3). In 2020 all seagrasses within a broader area of the port were also remapped, as part of a three yearly update (last done in 2017).

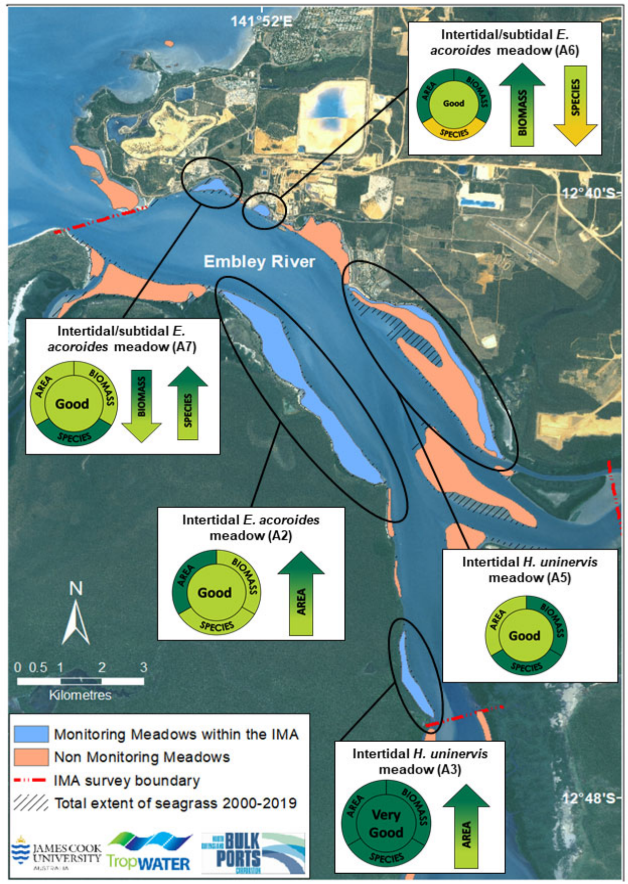

Figure 1. Seagrass meadow condition in the Port of Weipa 2020.

Seagrasses in the port of Weipa were in an overall good condition in 2020. Seagrasses maintained an extensive footprint within the IMA with total area above the twenty year long-term average (Figure 2). The area and biomass of the five core monitoring meadows was rated as good or very good compared with their long-term average (Figure 1). The species composition of meadows was maintained with the expected mix and dominance of foundation species. However, over the past four years the species composition of meadow A6, has had an increasing percentage of *Halodule uninervis* at the expense of the foundation species *Enhalus acoroides* which led to a decrease in condition score from good to satisfactory for species composition in 2020.

In 2020 the annual monitoring survey was expanded to include the broader port area (Pine River Bay, Embley, Hey and Mission Rivers) to provide an updated assessment of seagrass condition in a broader area of the Weipa port limits. Total area of seagrass mapped in the expanded survey was 5182 ± 137 ha, higher than the previous broad scale survey in 2017, and the highest recorded since monitoring began in 2000. In the broad scale survey there was a decline in the number of meadows with a continuous cover of seagrass relative to 2017, but still greater than any other year.

The healthy condition of Weipa seagrasses in 2020 was likely due to their high level of resilience leading up to the wet season, the prompt return of favourable light conditions following the wet season, 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 resilience meant they were in a good position to resist wet season pressures by utilising stored energy reserves, but critically there was no further reductions of light below their likely light requirements for the remainder of the year.

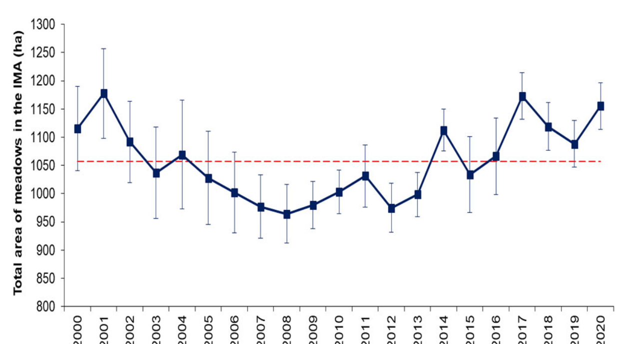

Figure 2. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2020. (error bars = "R" reliability estimate). Red dashed line indicates 20-year mean of total meadow area.

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 above the long-term average, however, in the critical times closer to the monitoring survey (1-3 months), daytime tidal exposure was at or below the long-term monthly averages. Annual rainfall was also below average.

The good condition of seagrass in 2020 means they are likely to be resilient to planned annual maintenance dredging during 2021, providing there are no major weather events that could lead to their decline prior to scheduled maintenance dredging. The onset of La Nina and associated rainfall events predicted for the 2020/2021 wet season may increase the time seagrass in Weipa are exposed to low light conditions compared with recent years.

The Weipa seagrass monitoring program 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).

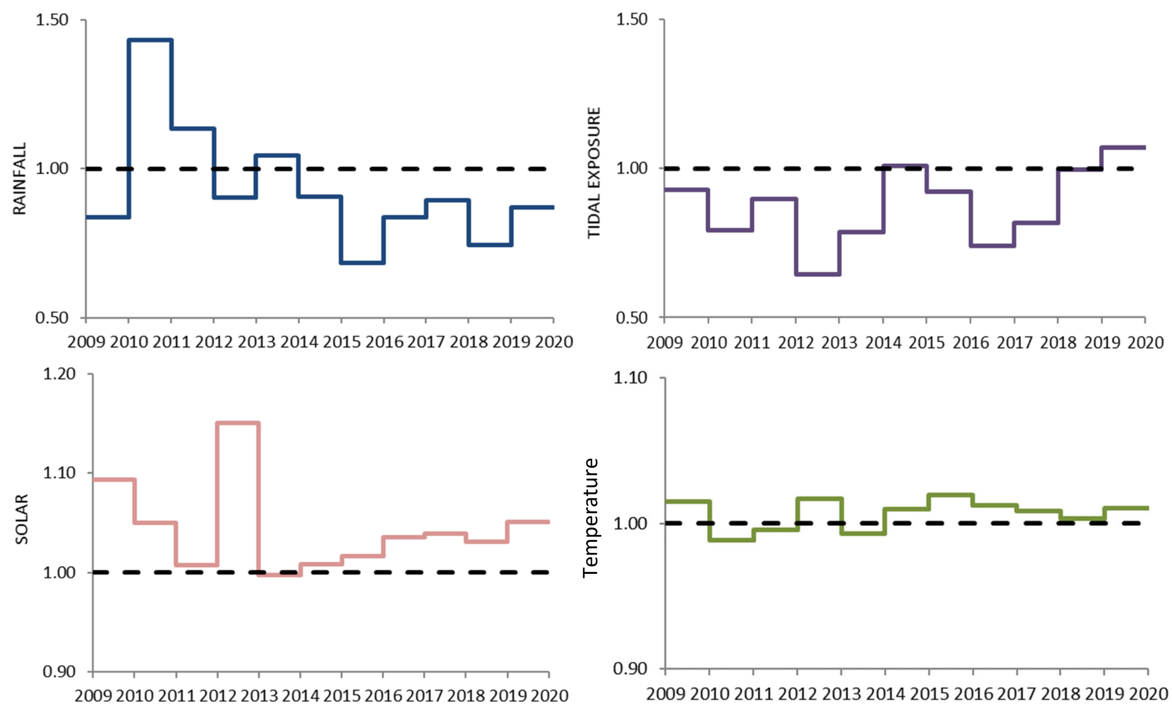

Figure 3. Recent climate trends in Weipa: Change in climate variables as a proportion of the long-term average. (See section 3.2 for detailed climate data).

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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 seagrass monitoring program in 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 has also provided significant advances in the science and knowledge of tropical seagrass and habitat ecology. This includes the development of tools, indicators and thresholds for the protection and management of seagrass, and an understanding of the drivers of seagrass change.

For more information on the program and reports from the other monitoring locations see https://www.tropwater.com

1.2 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 IMA represent the range of seagrass meadow communities identified in the greater Weipa region. Every three years (i.e., 2000, 2002, 2005, 2008, 2011, 2014, 2017, 2020) seagrass monitoring surveys are expanded to include a greater area of the Weipa port limits (i.e. Pine River Bay, Mission River, Embley River and Hey River), with a focus on mapping seagrass meadow distribution, meadow cover type and species composition in these areas (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 since September 2010 (Figure 14).

This report presents the results of the long-term seagrass monitoring assessments conducted in August 2020. The objectives were to:

1. Map seagrass distribution and determine biomass and meadow area in core monitoring meadows and across the broader port;
2. Assess changes in seagrass meadows with previous monitoring surveys;
3. Assess light and temperature conditions within seagrass meadows;
4. Incorporate the results into the Geographic Information System (GIS) database for the port of Weipa.

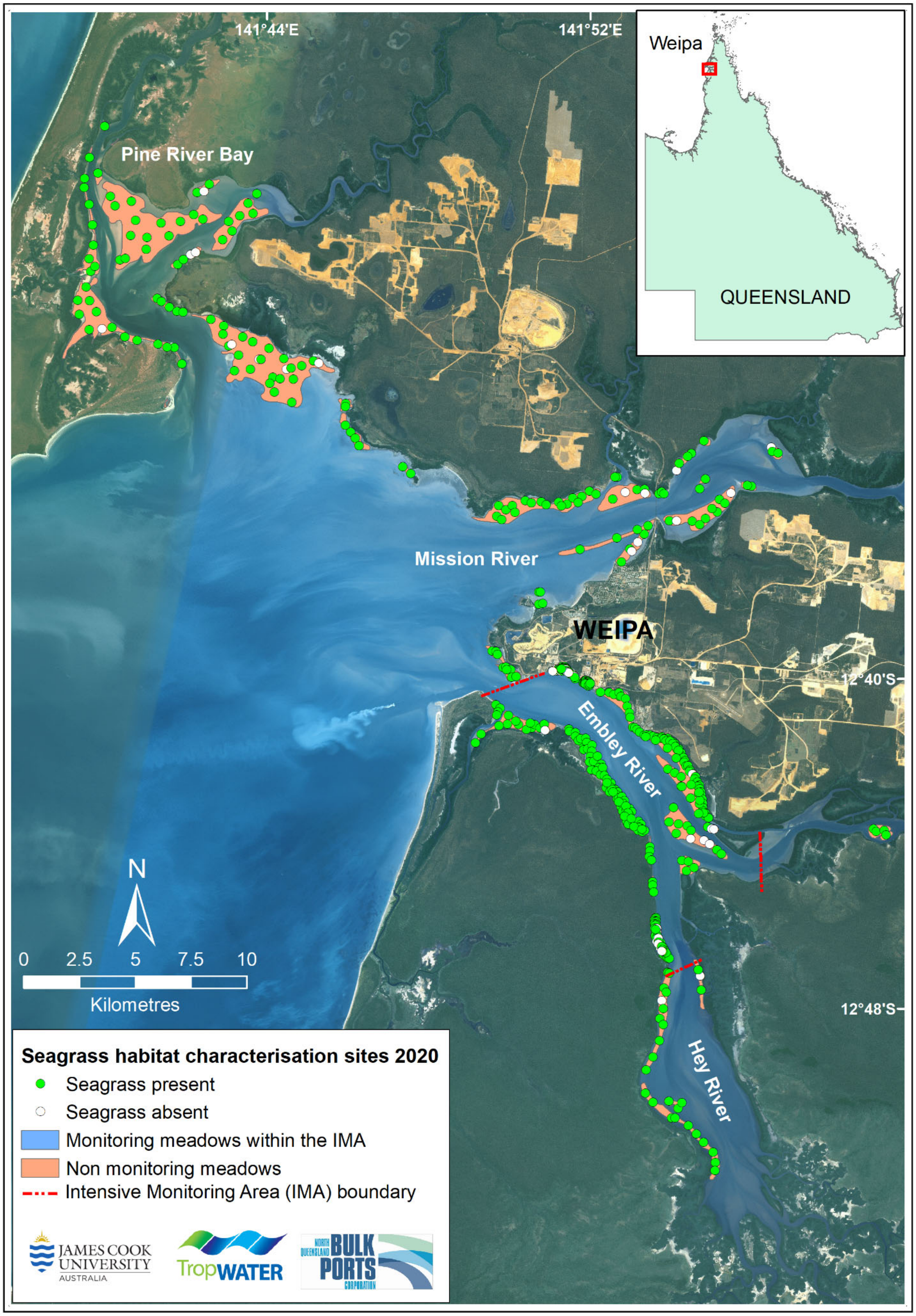


Figure 5. Location of 2020 seagrass survey sites and seagrass meadows in the Port of Weipa.

2 METHODS

2.1 Field Surveys

Annual monitoring of seagrass within the port of Weipa was conducted between August 29th – 31st 2020. Annual monitoring focuses on five core monitoring meadows within the Intensive Monitoring Area (IMA) (Figure 5 & 14) (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 surveys, 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 2020 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 across the broader port of Weipa. (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 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. Isolated *E. acoroides* plants occurring within the *Halodule* dominated meadows A3 and A5 are excluded from all biomass and species composition analyses in order to track the dynamics of the morphologically smaller *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 represent 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 10.8®. Three seagrass GIS layers were created to describe spatial features of the region: a site layer, seagrass meadow layer, and seagrass 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 and longitude, depth below mean sea level (dbMSL; metres) for subtidal sites.
  - Habitat information – sediment type; seagrass information including presence/absence, above-ground biomass (total and for each species) and biomass standard error (SE); percent cover of seagrass, algae, and open substrate; presence/absence of DFTs.
  - Sampling method and any relevant comments.

- *Meadow layer:* The meadow (polygon) layer provides summary information for all sites within each meadow, including:
  - Temporal details – survey date.
  - Habitat information – depth category (intertidal/subtidal), mean meadow biomass + standard error (SE), meadow area (hectares) + reliability estimate (R), number of sites within the meadow, seagrass species present, meadow density and community type, meadow landscape category (Figure 7).
  - Meadow identification number – a unique number assigned to each monitoring meadow to allow comparisons among surveys.
  - Sampling method and any relevant comments.

- *Interpolation 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.

Seagrass meadows were described using a standard nomenclature system. Seagrass community type is defined using the dominant species' percent contribution to mean meadow biomass (for all sites within a meadow) (Table 1). Community density is based on mean biomass and the dominant species within the meadow (Table 2).

Table 1. Seagrass meadow 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. Seagrass meadow density categories.

Density	Mean above ground-biomass (grams dry weight per metre square (g DW m^{-2}))				
	***H. uninervis* (narrow)**	***H. ovalis H. decipiens***	***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 constructed using seagrass presence/absence site data, field notes, GPS marked meadow boundaries, colour satellite imagery of the survey region (Source: Landsat 2017, courtesy ESRI; Google Earth), and aerial photographs taken during helicopter surveys.

Meadow area was determined using the calculate geometry function in ArcGIS®. Meadows were also assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 3). The mapping precision for seagrass meadows was ranged between 2 and 5 metres. 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 2020.

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 develop Weipa seagrass grades and scores.

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 are assessed at two intertidal sites in the A2 meadow (reducing to one following this survey), at one site in the subtidal/intertidal A7 meadow and one subtidal/intertidal site in meadow A6 (Figure 14), using custom built benthic data logging stations (Figure 9). 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.

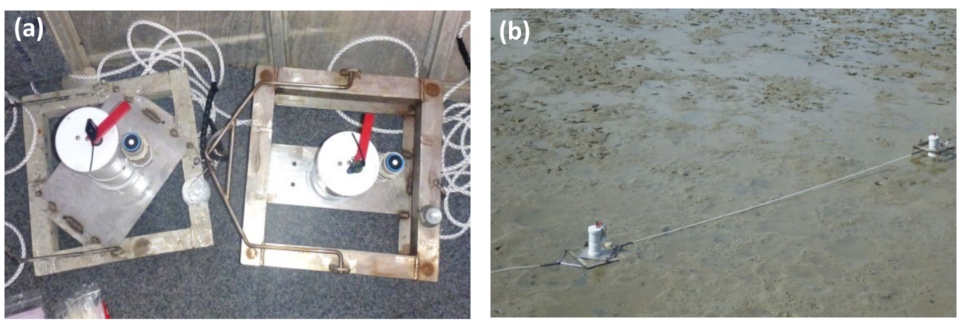


Figure 9. (a) Logging station consisting of a stainless steel frame with PAR loggers and temperature loggers attached, and wiper units (b) deployment of logging stations on the A2 meadow.

3 RESULTS

3.1 Seagrass in the Port of Weipa

A total of 433 sites were surveyed in 2020, including 327 in the Weipa IMA (Figure 5). Seagrass was present at 87% of sites, comprising of five species (Figure 10).

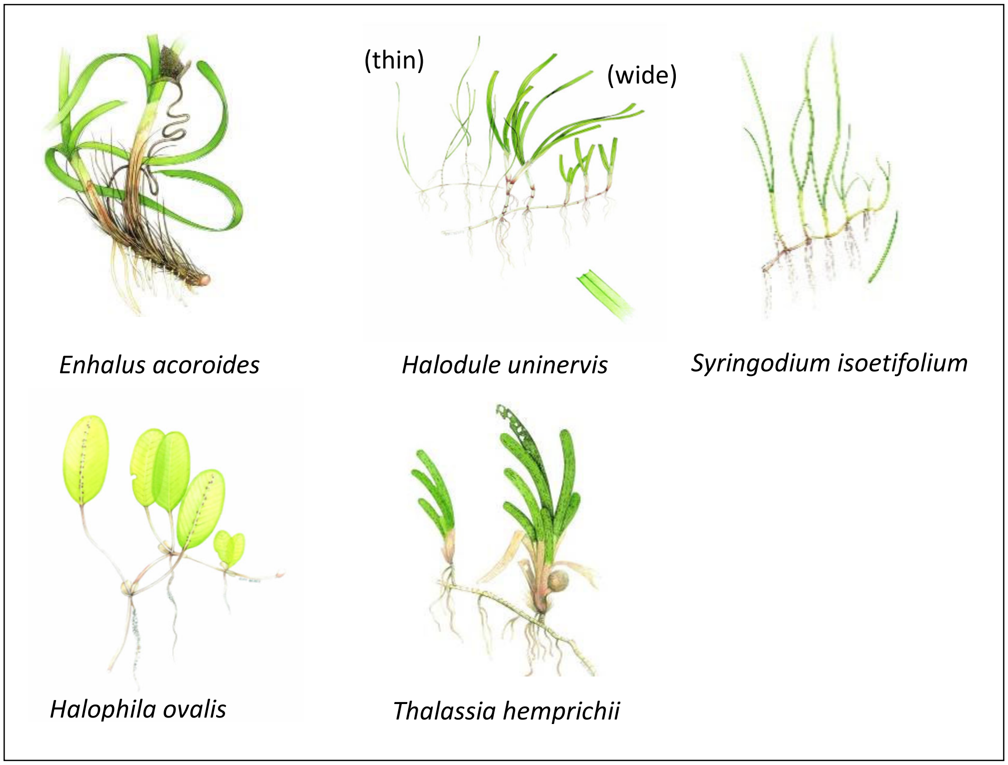


Figure 10. Seagrass species present in the Port of Weipa 2020.

3.1.1 Seagrass in the Intensive Monitoring Area

Sixteen seagrass meadows were mapped in 2020 within the IMA (Figure 14). The total seagrass meadow area was 1155 ± 41 ha, which is above the 20-year average of seagrass monitoring in Weipa (Figure 11). Area has been above the IMA long-term average for the last five years (Figure 11).

Enhalus acoroides dominated thirteen of the sixteen IMA meadows (Figure 14), all with light density cover. *H. uninervis* was the dominant species in the other three meadows, (Figure 14).

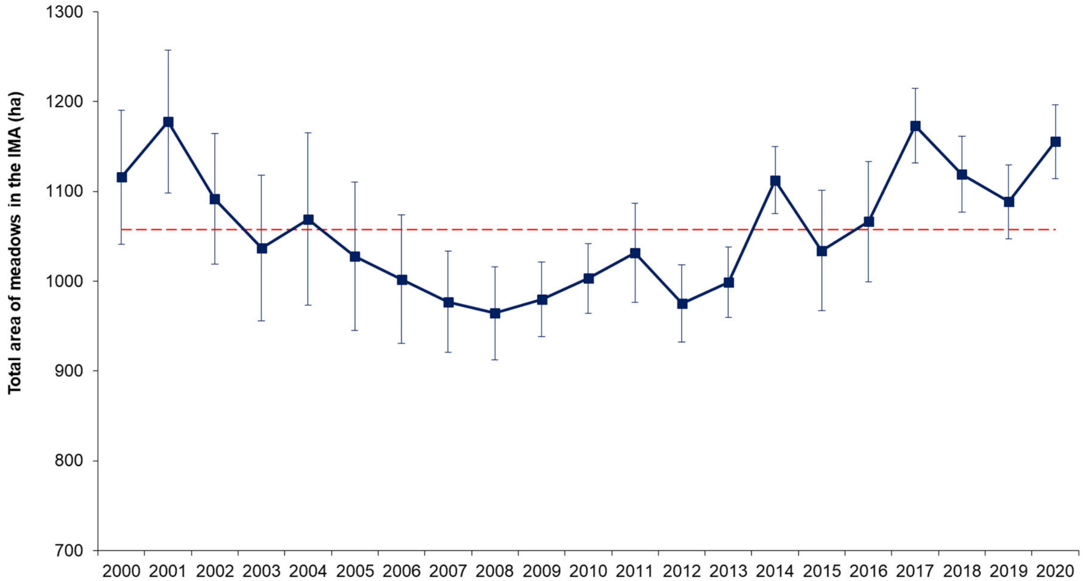
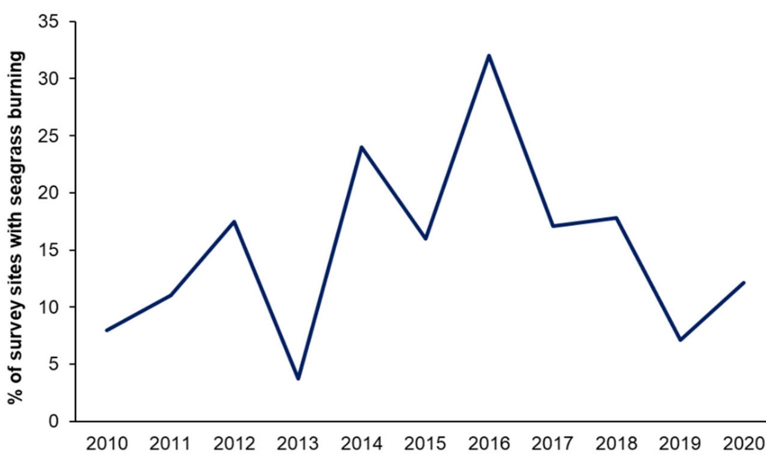


Figure 11. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2020 (error bars = "R" reliability estimate). Red dashed line indicates 20-year mean of total meadow area.

The condition known as burning (the browning and subsequent death of seagrass blades) was observed at 12% of survey sites within the IMA in 2020. This was a higher percentage than 2019 but still one of the lowest occurrence years to date (Figure 12).



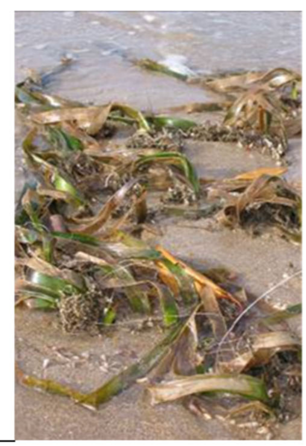


Figure 12. Percentage of sites within the IMA that have evidence of *Enhalus acoroides* burning in the Weipa IMA meadows.

Dugong feeding trails (Figure 13) are not commonly observed within the IMA. Dugong feeding trails have only been recorded in the two *H. uninervis* meadows (A3, A5) in three previous surveys; 2016, 2018, 2019. In 2020 dugong feeding trails were observed in the northern section of meadow A5 where there was dense *H. uninervis* present. Dugong feeding trails were common throughout the *H. uninervis* and *H. ovalis* meadows across the broader port area particularly in the *H. uninervis* meadows in Hey River and Pine River Bay.

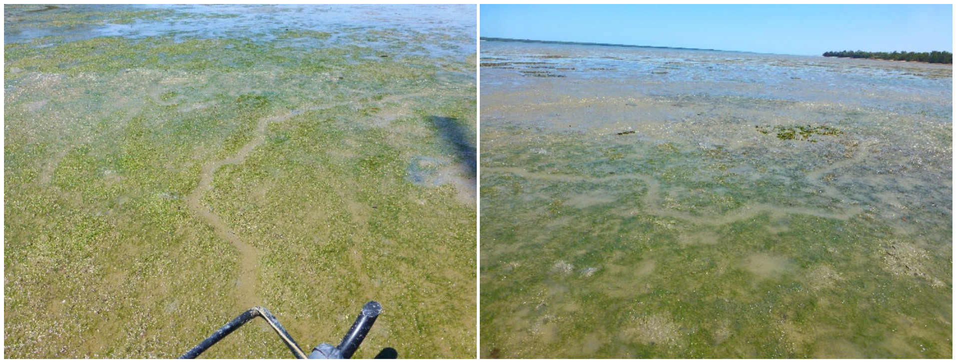


Figure 13. Examples of Dugong feeding trails in the A5 Weipa monitoring meadow captured in 2019.

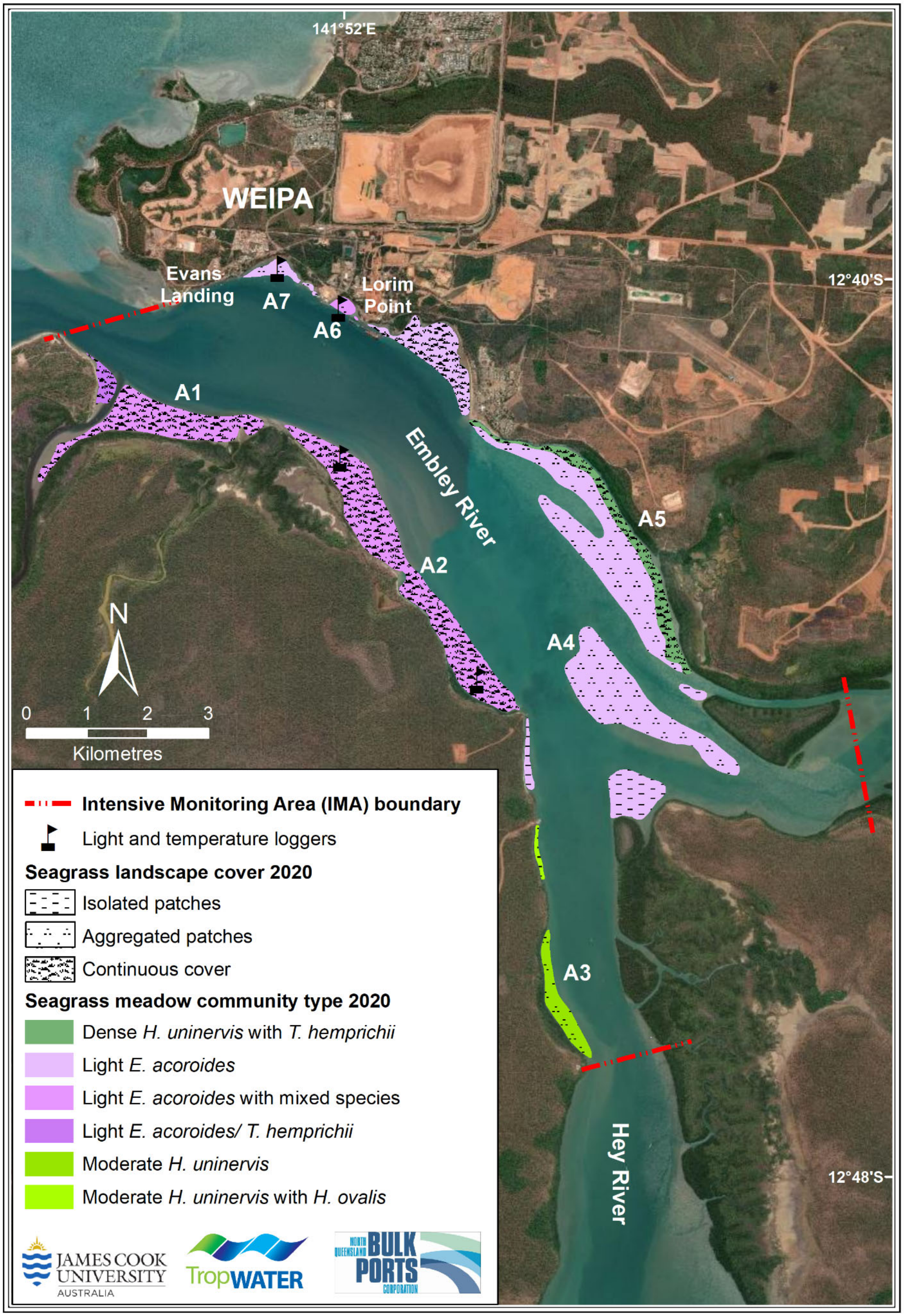


Figure 14. Meadow type and landscape cover for seagrass within the Intensive Monitoring Area 2020.

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 2020 (Table 4). All three seagrass condition indicators (seagrass biomass, area and species composition) were graded as satisfactory or better in all monitoring meadows (Table 4).The condition of seagrass in the core annual monitoring meadows has generally been stable over the last four years.

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

All *E. acoroides* dominated meadows had a light density of seagrass biomass. Meadow A2, on the western side of the Embley River had a continuous cover of seagrass, while the A6 and A7 meadows closer to port infrastructure consisted of aggregated patches of seagrass (Figure 14). *Enhalus acoroides* maintained its dominance of the species composition in all three meadows (Figures 16, 20). For the A6 meadow, there was an increase in less stable species causing the species composition score to decline in this meadow to satisfactory (Figure 20).

Meadow A2: Biomass and species composition for meadow A2 remained in a good condition for 2020, while the area of the meadow improved to very good condition (Table 4, Figure 16). Meadow area has been at or above the long-term average for the last eight years (Figure 16). Biomass was similar to the ten-year baseline average during this year's survey, and has maintained a good condition for the last nine years.

Meadow A6: Area and biomass were classed as being in very good condition in this meadow, while species composition was classed as being satisfactory. The downgrade to satisfactory condition was due to an increase in less stable species (*H. uninervis)* in the meadow and a decrease in stable *E. acoroides* to the lowest percentage recorded since monitoring began in 2001 (Table 4, Figure 19, Appendix 3). Seagrass area in A6 was very good in 2020 and has been above the baseline mean for four consecutive years. Seagrass biomass in the meadow increased in 2020 reaching the highest density recorded since 2013 (Figure 19).

Meadow A7:
The overall condition of this meadow was classed as good with all three seagrass condition indicators in good or very good condition (Table 4, Figure 20). Most of the seagrass biomass in this meadow occurred towards the middle of the meadow, with the western and eastern ends of the meadow low in density and very patchy (Figure 20).

3.1.2.2 Halodule uninervis dominated meadows (A3, A5)

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

Meadow A3:
Seagrass in the A3 meadow located in the Hey River was in very good condition in 2020. Seagrass biomass increased for the third consecutive year, and meadow area improved to very good from good (in 2019) (Figure 17). Species composition also maintained a very good condition consistent with 2019 (Figure 17).

Meadow A5:
Seagrass biomass in the A5 meadow, south of Napranum, was the highest recorded since monitoring began in 2000. This meadow has been in a good condition for the last two years (Table 4; Figure 18). Meadow area increased for the third consecutive year, reaching the baseline average for the first time since 2011 and species composition was considered very good. There was a decrease in the presence of the larger stable species *E. acoroides* and *T. hemprichii* in the in 2020 compared to 2019 (Figure 18; Appendix 3).

Table 4. Grades and scores for seagrass indicators for 2020 in the port of Weipa.

Meadow	Biomass	Area	Species Composition	Overall Meadow Score
A2	0.75	0.85	0.75	0.75
A3	0.87	0.90	0.99	0.89
A5	1.00	0.76	0.98	0.76
A6	0.89	0.91	0.62	0.75
A7	0.78	0.68	1.00	0.68
Overall Score for the Port of Weipa				**0.77**

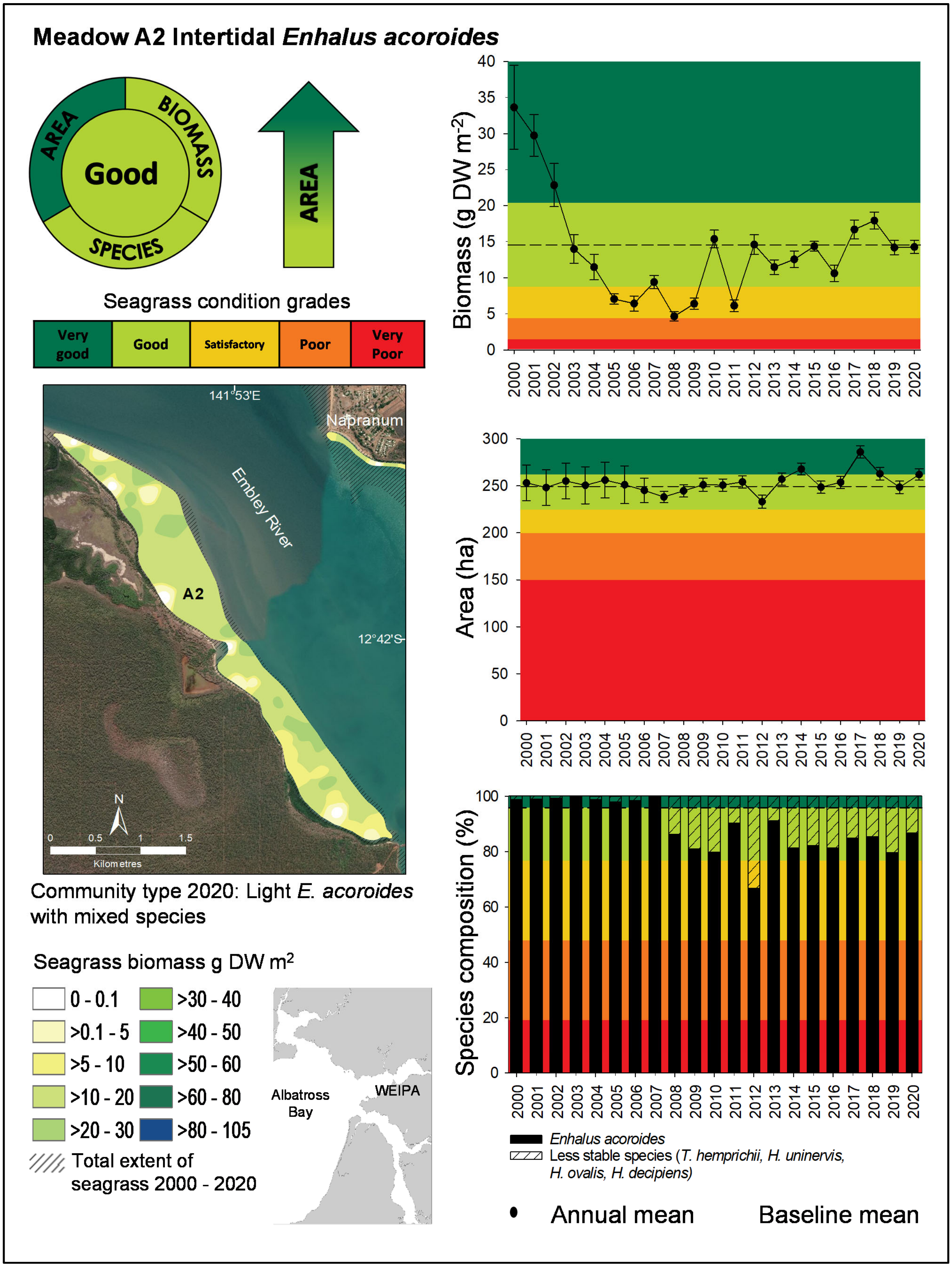


Figure 16. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A2 in Weipa; 2000 to 2020 (biomass error bars = SE; area error bars "R").

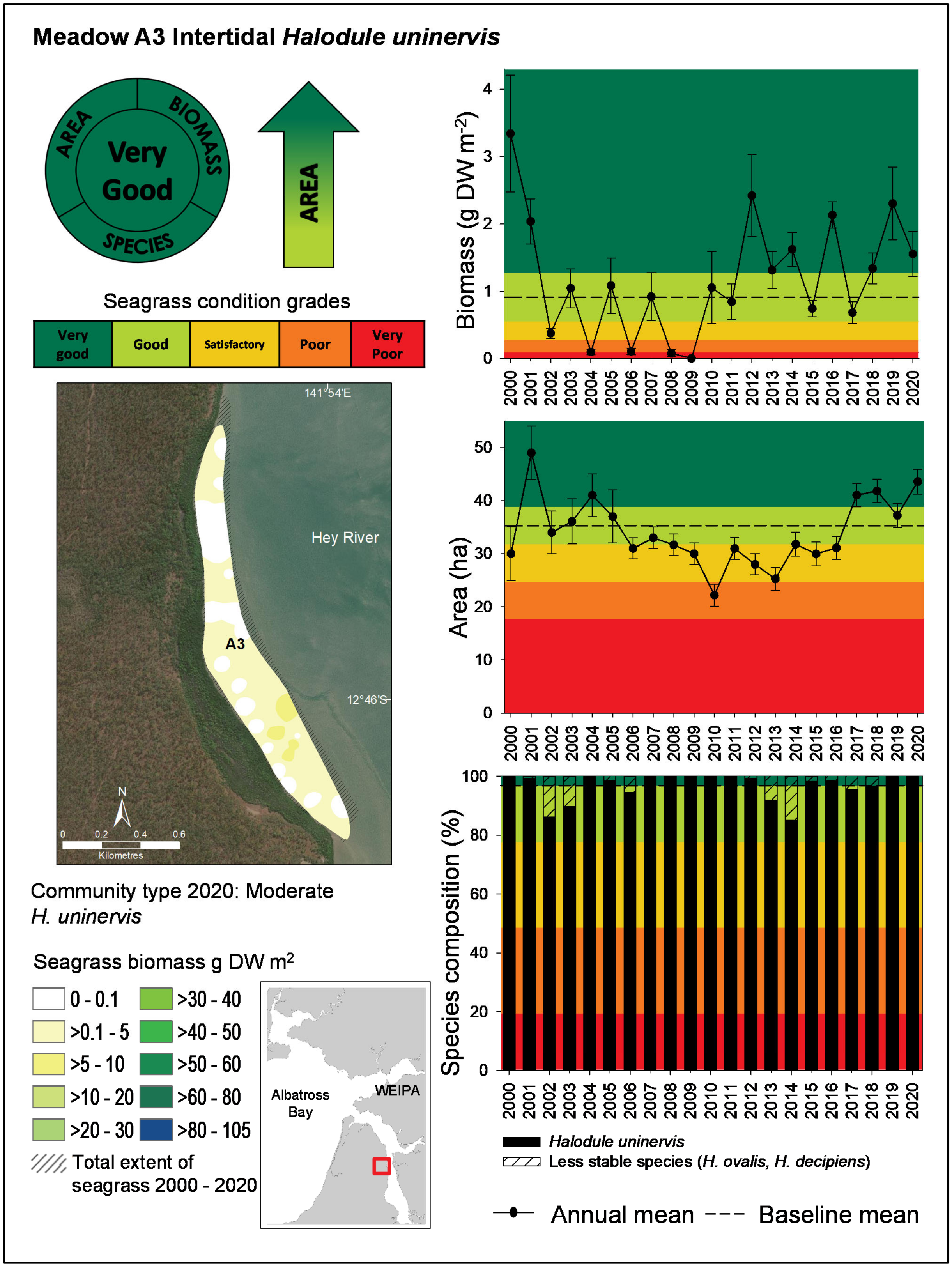


Figure 17. Changes in biomass, area and species composition for the *H. uninervis* dominated core monitoring meadow A3 in Weipa; 2000 to 2020 (biomass error bars = SE; area error bars "R").

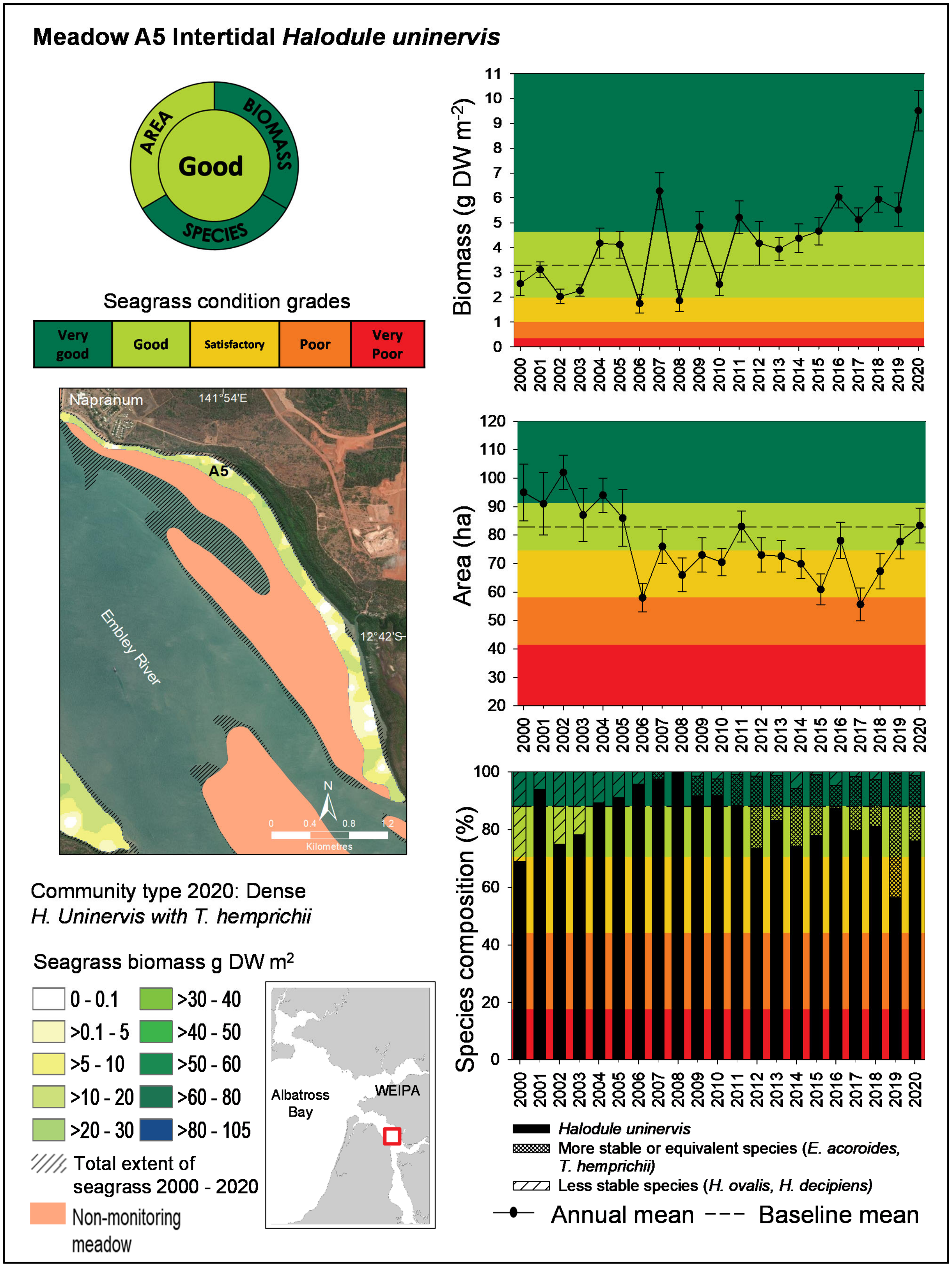


Figure 18. Changes in biomass, area and species composition for the *H. uninervis* dominated core monitoring meadow A5 in Weipa; 2000 to 2020 (biomass error bars = SE; area error bars “R”).

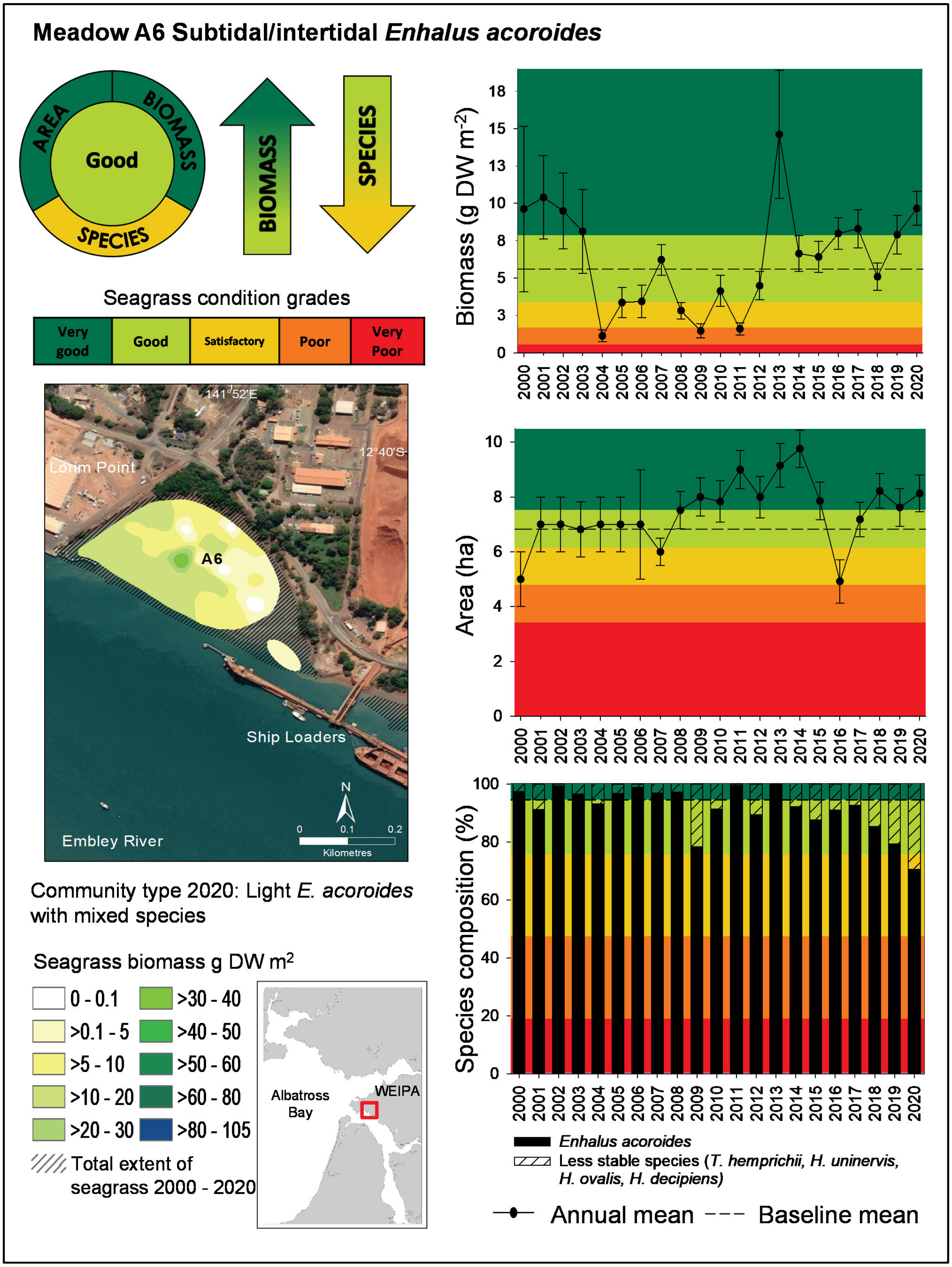


Figure 19. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A6 in Weipa; 2000 to 2020 (biomass error bars = SE; area error bars "R").

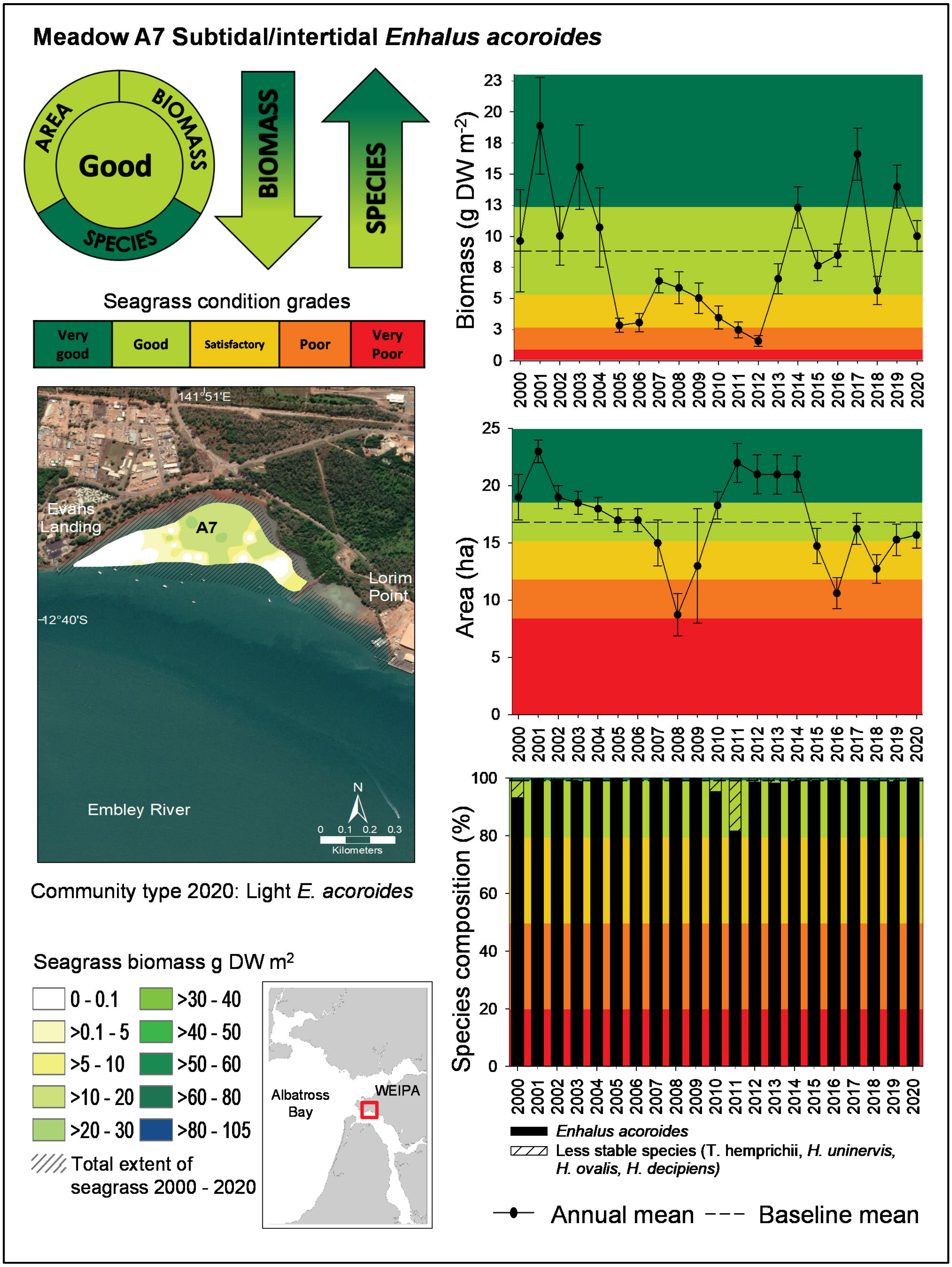


Figure 20. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A7 in Weipa; 2000 to 2020 (biomass error bars = SE; area error bars “R”).

3.1.3 Seagrass condition in the broader Port of Weipa

Seagrass distribution in the broader port area of Weipa in 2020 was the largest recorded since monitoring began in 2000 (5181.9 ± 136.6 ha) (Figure 22). Meadow landscape categories across the broader port consisted mainly of isolated to aggregated patches of seagrass (Figure 22). The total area of meadows with isolated patches was the greatest for any of the 3 yearly broader port surveys since 2000 (Figure 22)

Seagrass meadows covered 320 ± 14 ha in the Hey River an increase since 2017 (Figure 23). There was a large expansion of *H. uninervis* meadows on the south-western bank of Hey River. Seagrass extended nearly along the entire western bank of Hey River for the first time since 2005. Meadows in Hey River were classified as having a continuous cover or aggregated patches of seagrass indicating an improvement in condition since 2017 when meadows were mainly classified as isolated patches (Figure 23). Species composition of each of the Hey River meadows has remained relatively constant through the years.

The seagrass footprint in the Mission River has remained broadly similar across surveys (Figure 24). In 2020, the meadow in the middle of the river underwent a large westward extension of seagrass cover, but otherwise meadow area and composition has remained largely unchanged (Figure 24). Along the southern bank and upstream of the Mission River Bridge, seagrass meadows are made up of isolated patches of seagrass (*E. acoroides* and *H. ovalis*), and are dominated by large areas of unvegetated sediment (Figure 24). Seagrass in these meadows is very sparse and isolated small patches typically less than 1m diameter. The large meadow on the northern shore of the Mission River consisting of *T. hemprichii, E. acoroides* and *H. uninervis* had a continuous cover of seagrass in 2017 but decreased in cover to aggregated patches in 2020 (Figure 24).

In 2020 there were substantial meadows in Pine River Bay with seagrass covering an area of 2,638.5 ± 45 ha in twenty one meadows, similar to the previous survey in 2017 (Figure 25). Meadow area in Pine River Bay has remained similar over the years but the species composition and cover has varied. Large meadows inside the bay consisted of patchy *E. acoroides*, varying cover of *H. ovalis* across mud banks, with large areas of unvegetated mud (Figure 25). Meadows on the western shore of Pine River Bay continued to be dominated by *T. hemprichii* but the cover reduced from continuous cover in 2017 to aggregated patches in 2020 (Figure 25). At the mouth of the bay a meadow consisting of stable species such as *Syringodium isoetifolium* and *T. hemprichii* covered a large area similar to 2017, and had very high biomass (43.7 g DW m^{-2}) relative to other meadows throughout the port *(*Figure 21 & 25).

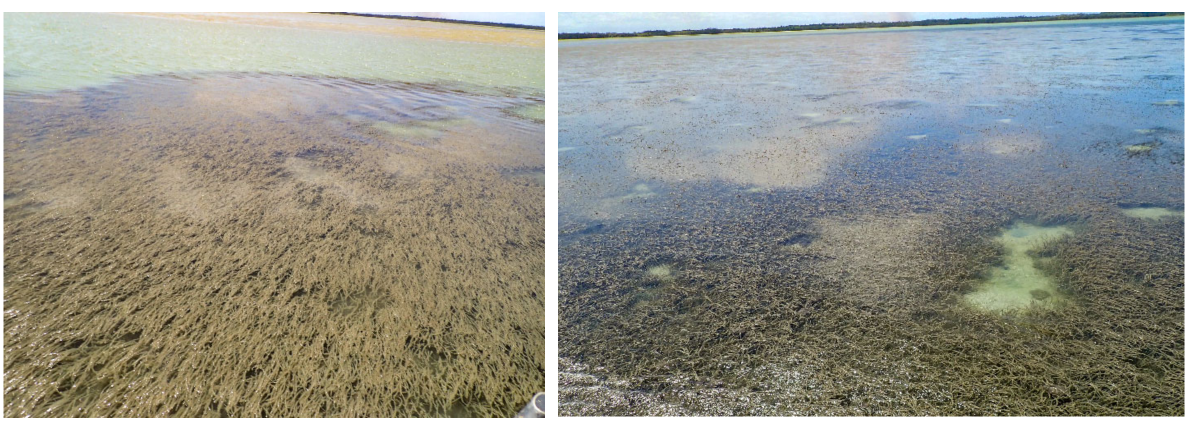


Figure 21. *Syringodium isoetifolium* and *T. hemprichii* meadows at the mouth of Pine River Bay; 2020.

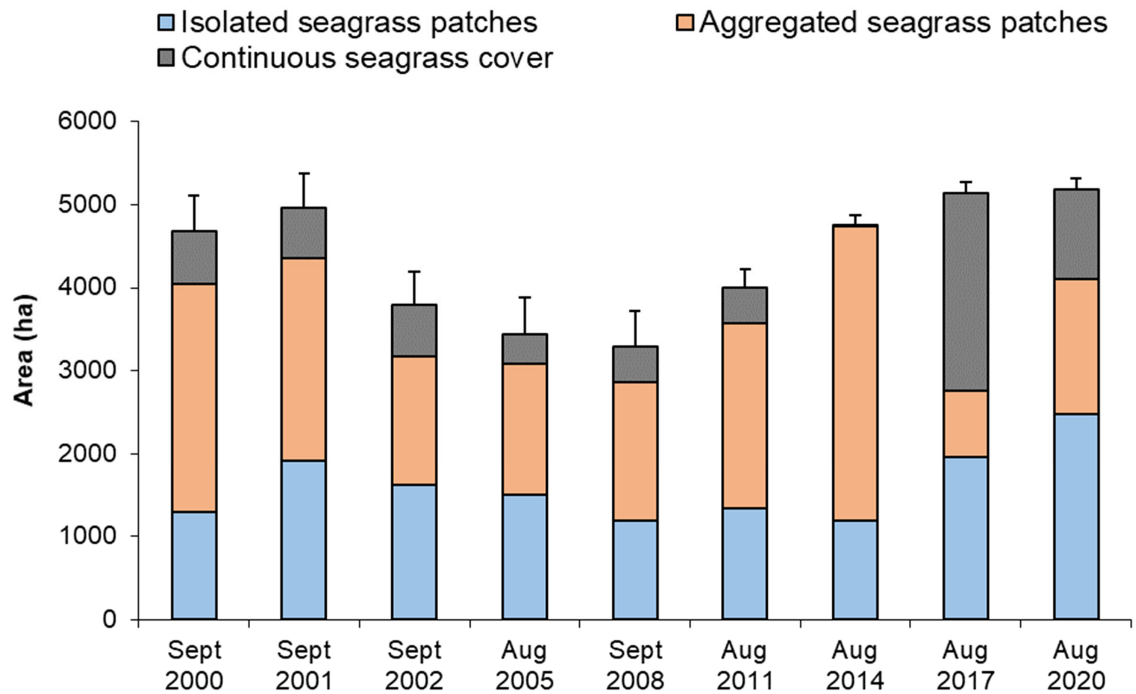


Figure 22. Total seagrass area (ha) and the landscape cover within the broader port of Weipa, 2000-2020. Error bars = "R" reliability estimates.

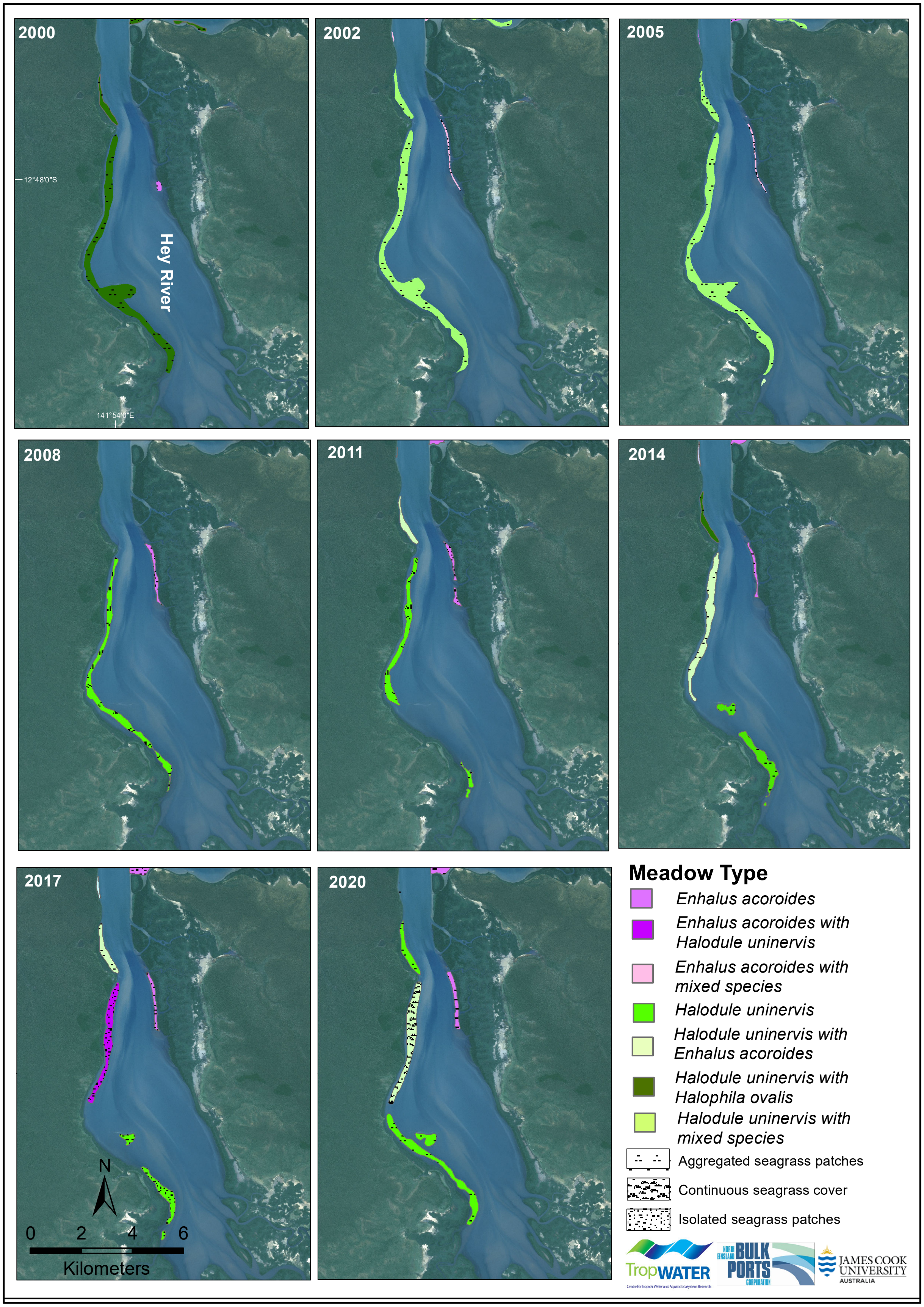


Figure 23. Seagrass meadow distribution, cover and species composition in Hey River in the broader port surveys between 2000 and 2020.

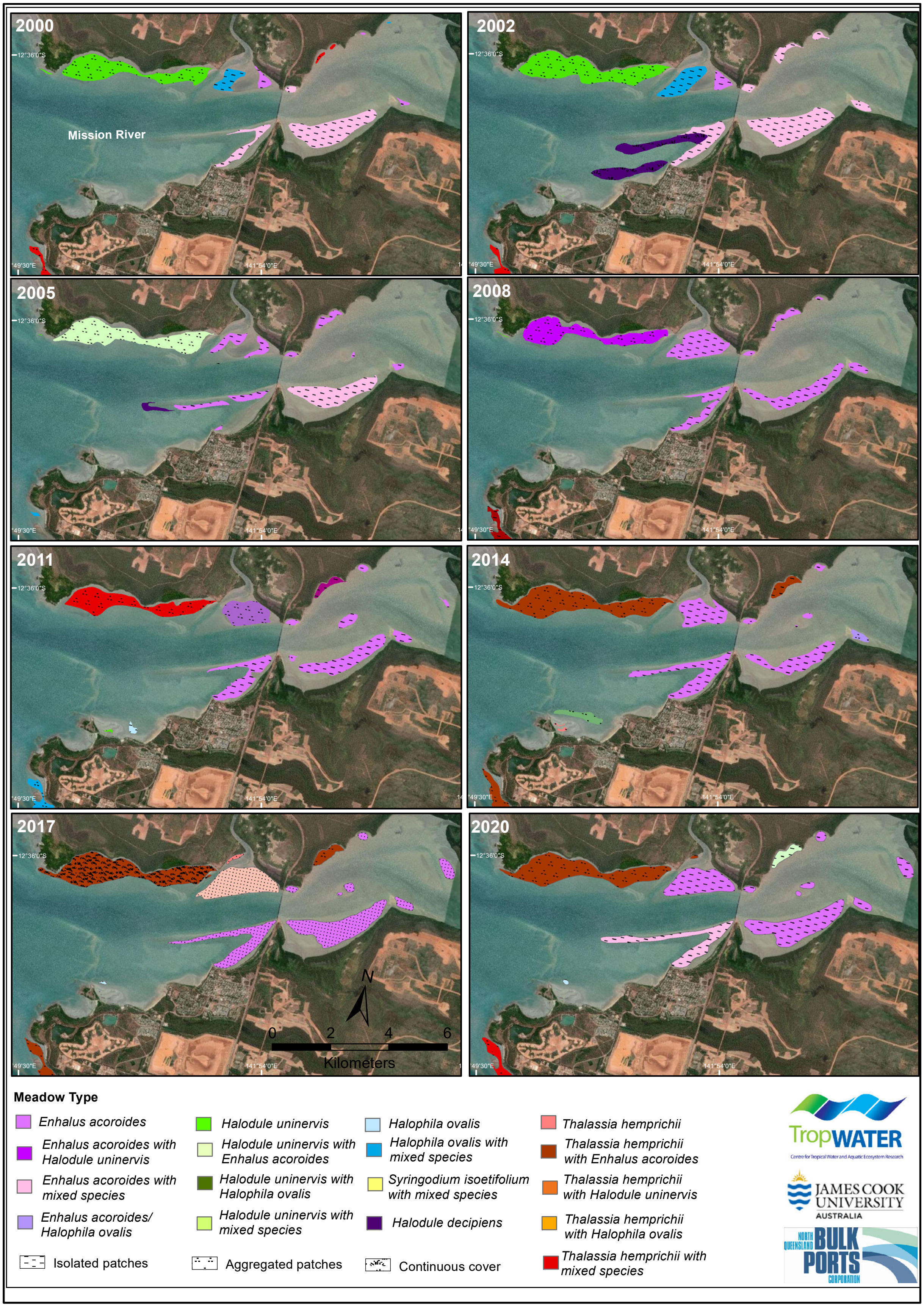


Figure 24. Seagrass meadow distribution, cover and species composition in Mission River in the broader port surveys between 2000 and 2020.

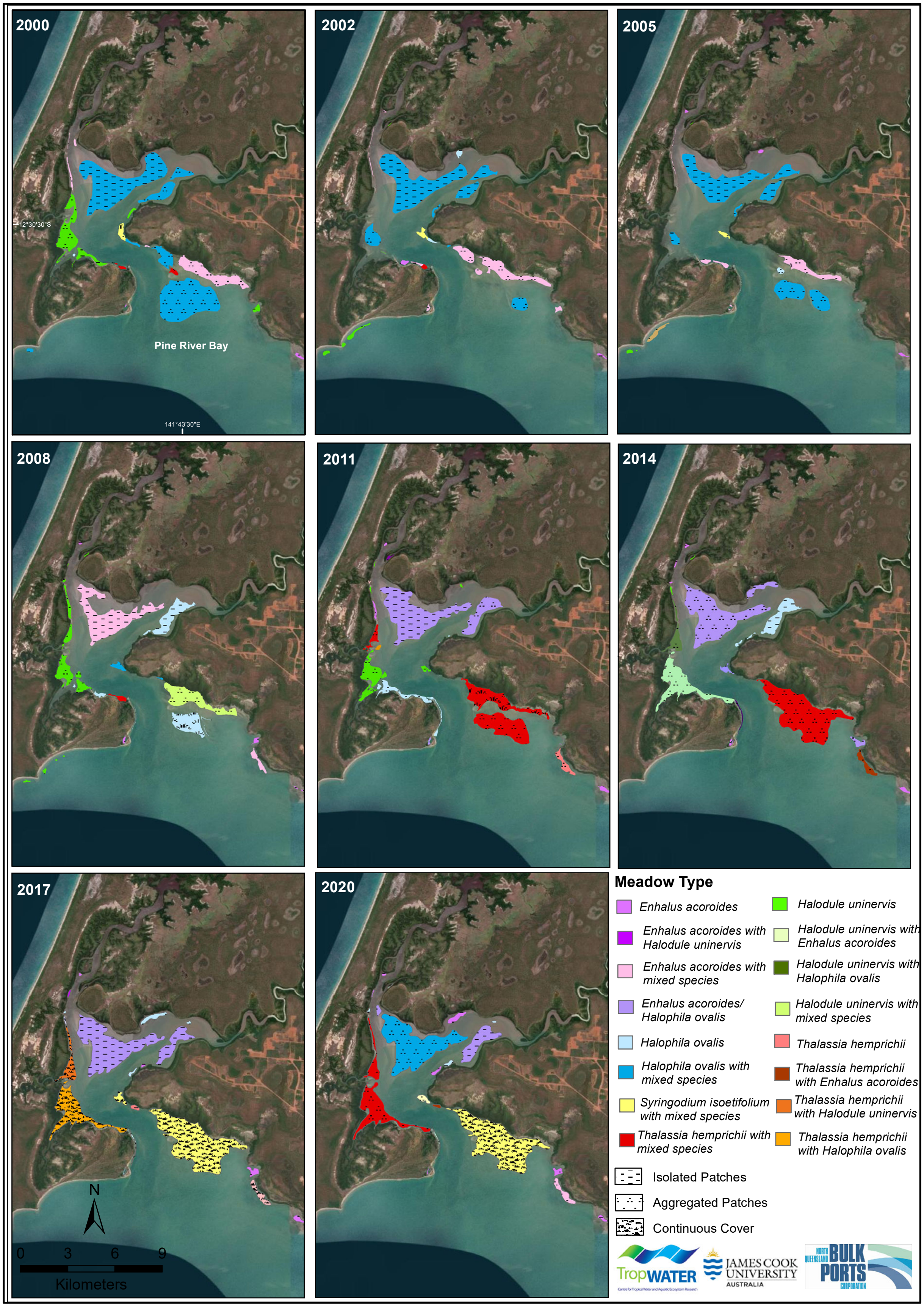


Figure 25. Seagrass meadow distribution, cover and species composition in Pine River Bay in the broader port surveys between 2000 and 2020

3.2 Weipa environmental data

3.2.1 Rainfall

Total annual rainfall in Weipa (2019/20) was 1668mm, the sixth consecutive year below the long-term average (Figure 26a). Rainfall followed similar wet season trends leading up to the annual survey, with above-average rainfall in January of 516mm (Figure 26b).

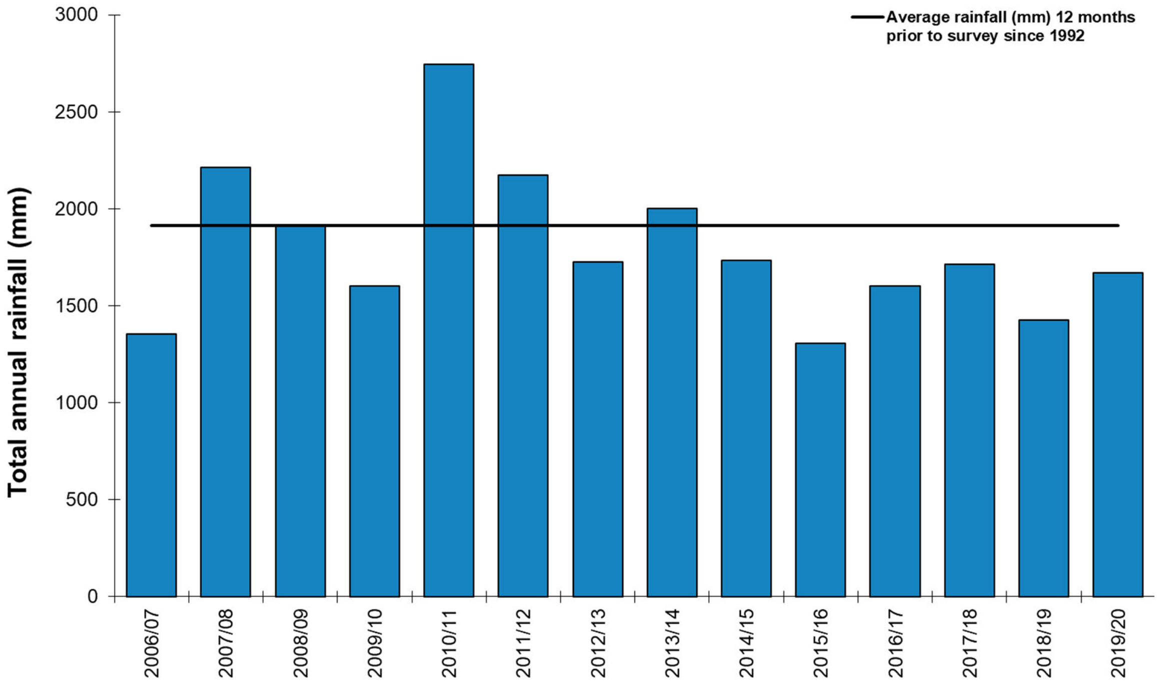


Figure 26a. Total annual rainfall recorded at Weipa Airport; 2006-2020. Data is twelve months prior to survey.

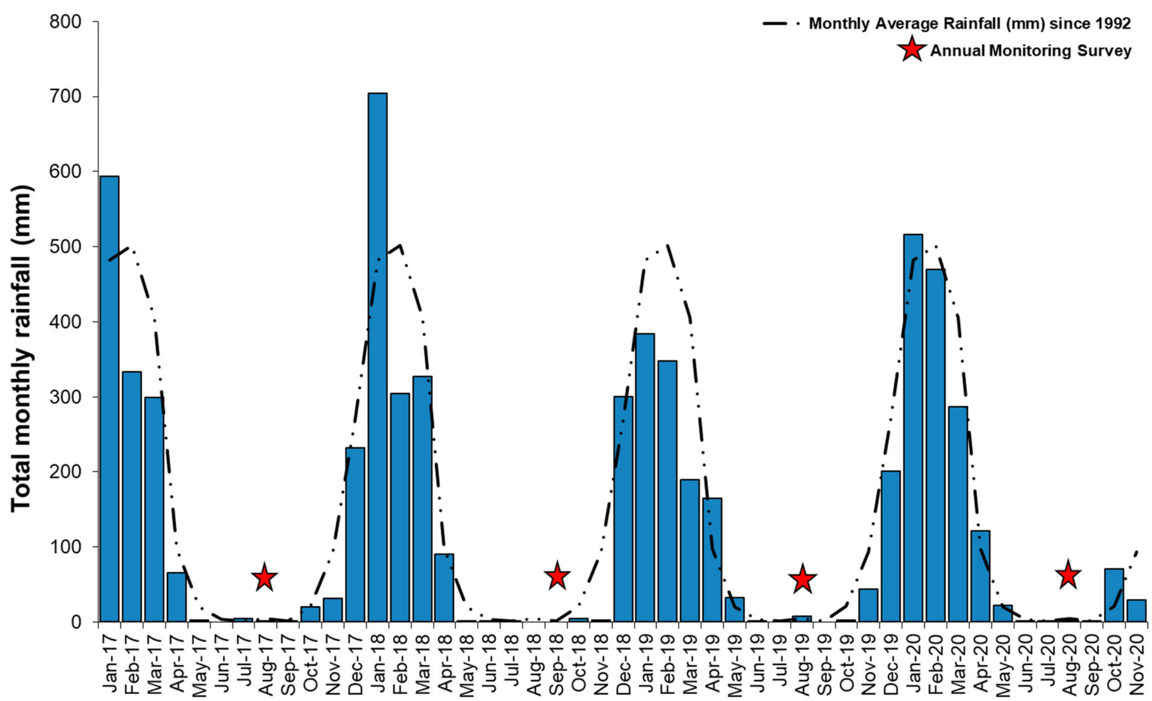


Figure 26b. Total monthly rainfall (mm); January 2017 – November 2020.

3.2.2 Daytime Tidal Exposure

The amount of tidal exposure to daytime air for intertidal meadows (418 hours) was above the long-term average for the first time in 5 years (Figure 27a). In the critical times closer to the monitoring survey (1-3 months) daytime tidal exposure was at or below the long-term monthly averages (Figure 27b). 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 27b).

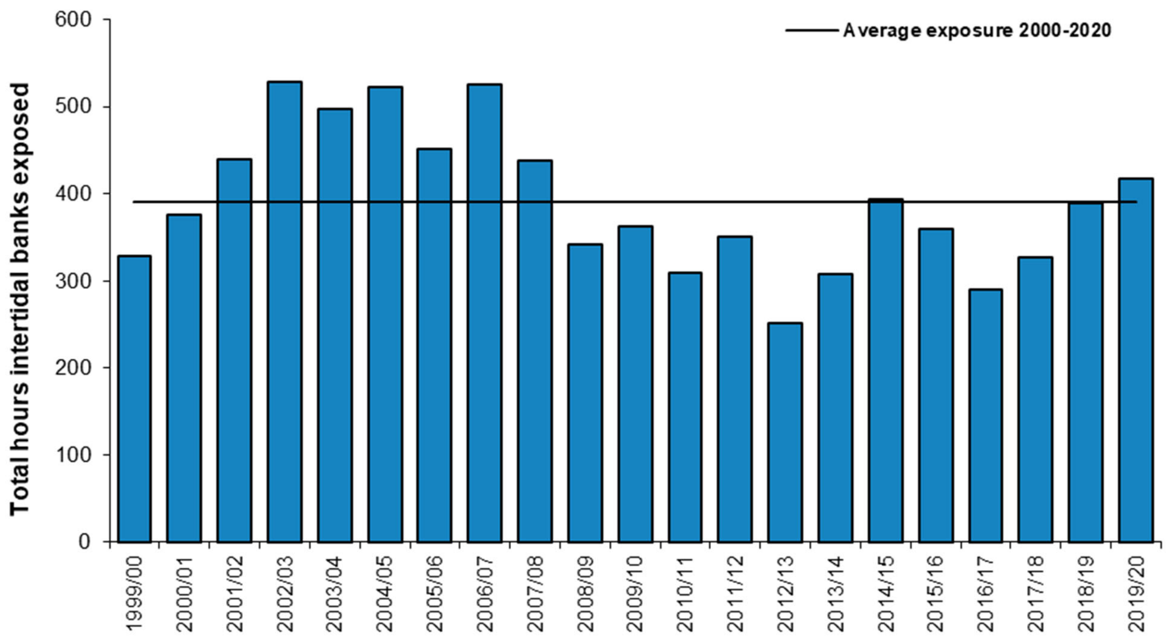


Figure 27a. Total daily tidal exposure to air 1999/00 -2019/20. Data is twelve months prior to survey.

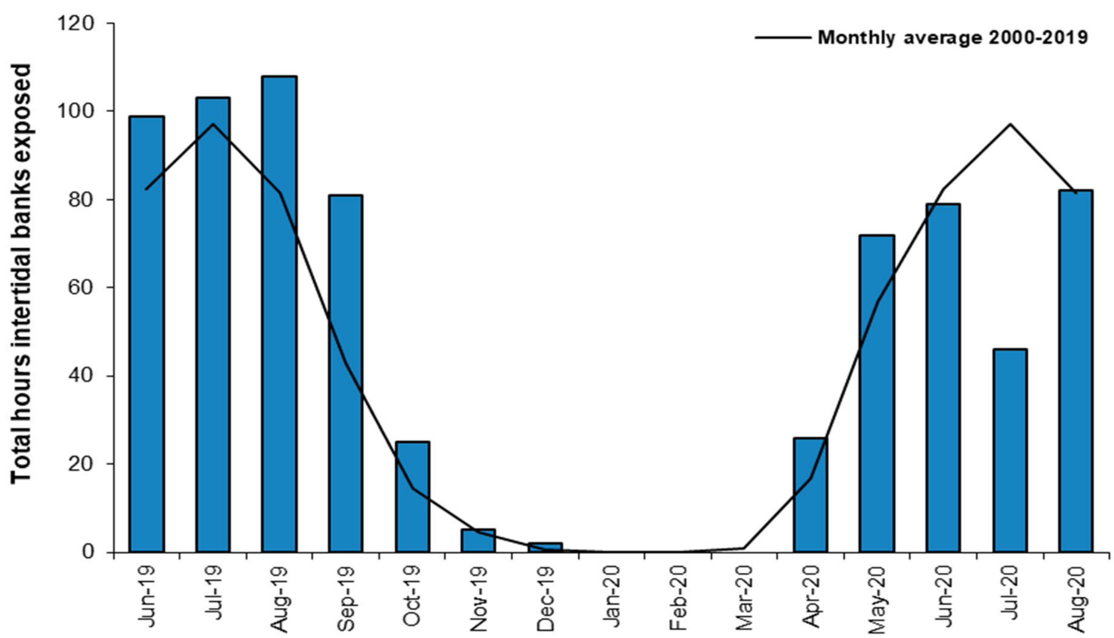


Figure 27b. Monthly total daytime tidal exposure to air (hours; ≤0.9m tidal height); June 2019 – August 2020.

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 27a).

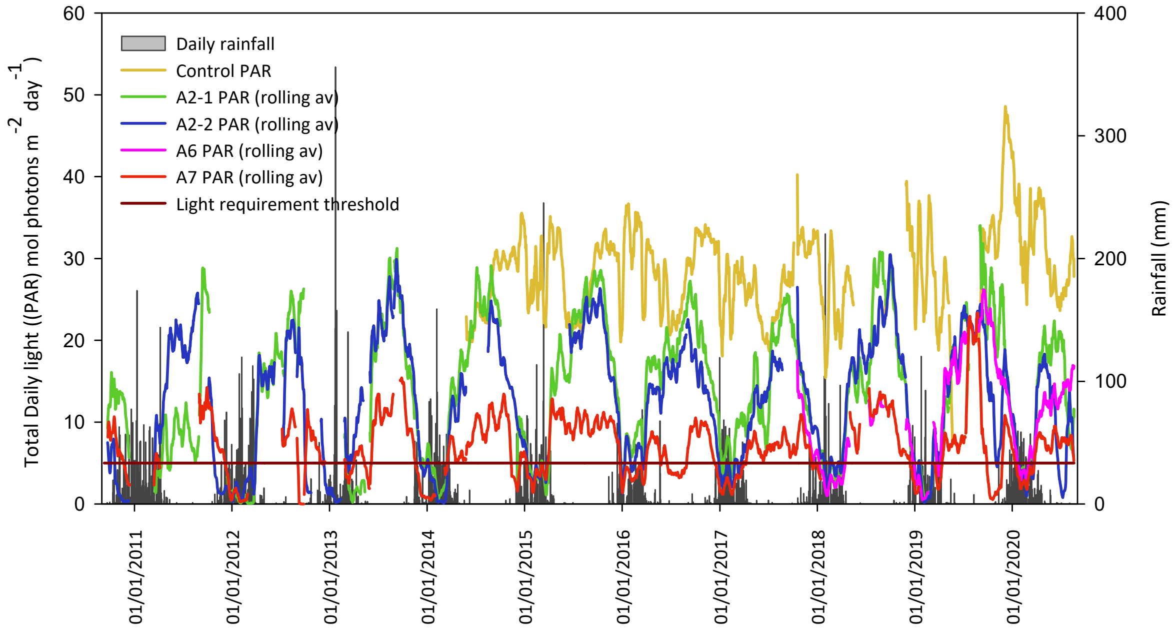
PAR was less in the deeper meadows (A6 and A7) than the shallower A2 meadow as would be expected due to greater light attenuation with depth of water and shorter periods of low tide exposure to air. In the twelve months prior to the seagrass survey PAR ranged from (see Figure 27);

- Control logger (above water): 1.81 to 52.71 mol m^{-2} day^{-1};
- A2 intertidal meadow: 0.03 to 61.33 mol m^{-2} day^{-1};
- A6 & A7 intertidal/subtidal meadow: 0.01 to 34.4 mol m^{-2} day^{-1}.

At the maximum end of the range, PAR at all sites was considerably higher compared to the previous survey year (see Rasheed et al. 2020). For example, in 2018/2019 maximum PAR in the A2 meadow was 39.17 mol m^{-2} day^{-1}, a 22 mol difference from 2019/2020. Below average rainfall and above average hours of tidal exposure are likely to have contributed to these higher values.

The longest ongoing integration period (14-day rolling average) that PAR fell below the acute threshold (5 mol m^{-2} day^{-1}) during 2020 was a six week period from mid-January through to early March (Figure 27b). This period coincides with the wet/high rainfall season in the region which was similar to the long term average in 2019/20.

a)



b)

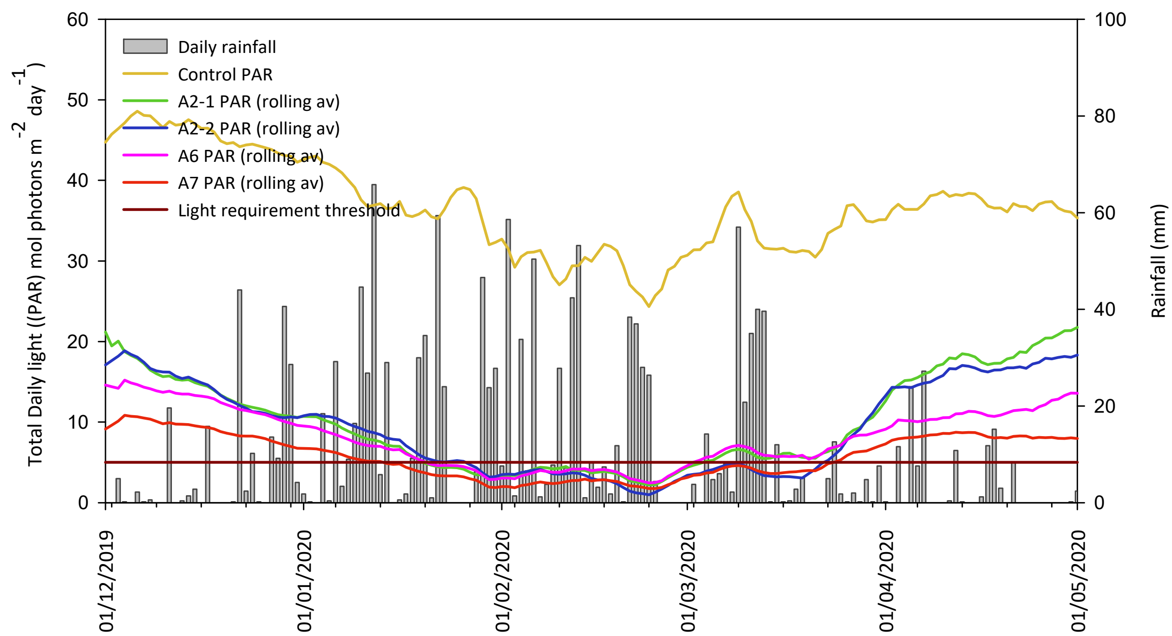


Figure 28 (a) Daily photosynthetically active radiation (PAR; mol photons m^{-2} day^{-1}) and total daily rainfall (mm) at Weipa; January 2011 – August 2020. (b) Period of low light over the 2019-2020 wet season.

4 DISCUSSION

Seagrasses in the Port of Weipa were in an overall good condition in 2020. An extensive footprint of seagrass was maintained in the port region (IMA) with area one of the highest recorded in the 20 year history of monitoring. Seagrass area across the broader port region including Hey River, Pine River Bay and Mission River was also the highest ever recorded. The presence of dugong feeding trails during the survey were further signs of a healthy and productive seagrass ecosystem in Weipa in 2020. The healthy condition of Weipa's seagrasses means they should be resilient to planned maintenance dredging activities in 2021 assuming that there are no major seagrass losses associated with the predicted La Nina weather conditions leading up to the 2021 maintenance dredging campaign.

Improvements in seagrass condition over the last three years can be attributed to below average rainfall and high light conditions that promote seagrass growth and expansion. Both seagrass area and biomass generally improve under low rainfall and river flow conditions, when turbidity is low, and benthic light levels provide seagrass with enough light for photosynthesis, facilitating favourable growing conditions (Collier et al. 2016). 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. While rainfall has been below average in recent years, light levels during the wet season can still remain below the threshold (5 mols^{-2} day^{-1}) required for healthy seagrass for extended periods, regardless of rainfall as in 2018/19 and 2019/20. *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). Based on the work we have done between 2015 and 2020 on *Enhalus acoroides* it appears 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 *E. acoroides* enters 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 is 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.

Some individual meadows in the Hey and Mission Rivers underwent significant expansion since the previous broad area survey in 2017. Meadows where there was an increase in area were dominated by *H. uninervis* or *T. hemprichii*. Both species can undergo rapid horizontal rhizome elongation under favourable conditions enabling rapid meadow growth and colonisation of new habitats (Marba & Duarte 1998). In contrast, meadows dominated by *E. acoroides,* which are some of the largest in the Port of Weipa, tend to be stable over time with only occasional increases or decreases in size. Small changes in area over time suggests that *E. acoroides* horizontal rhizome expansion occurs slowly or less frequently. While *E. acoroides* above-ground biomass can increase quickly, rhizome extension is less well understood and may be prohibitive to rapid meadow expansion (Marba & Duarte 1998). Sexual reproduction has been observed in *E. acoroides* in Weipa in past surveys but was not observed at the time of the 2020 survey (Rasheed et al. 2019). Sexual reproduction may provide an alternative life history strategy for meadow recovery and expansion, however, our understanding of *E. acoroides* life history strategies is generally lacking. Future research in this area is likely to lead to more informed management of these meadows in the event of seagrass loss.

Large seagrass area, high biomass and prevalence of persistent species (*E. acoroides, T. hemprichii*) suggest Weipa seagrass meadows will be resilient to the upcoming La Nina wet season. La Nina weather conditions are predicted to bring high rainfall and severe storms and cyclones over the 2020/2021 wet season. High rainfall and flooding can result in the loss of seagrass; there were severe seagrass losses throughout North Queensland after the last period of extended La Nina conditions (2009-2011) (York et al. 2016; McKenna et al. 2015). While the severity of rainfall will dictate if there will be substantial impacts to seagrass, the excellent seagrass condition in Weipa leading into the wet season provides a good basis for resilience to seagrass losses.

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). In 2019, Karumba seagrasses were in their poorest condition in the 26 years they have been monitored, following extended flooding of the local rivers and a persistent turbid flood plume over the seagrass meadows. Seagrass condition in Karumba in 2020 had improved to a satisfactory condition, with the return of more benign conditions (Scott et al 2021). Similar to Weipa, the seagrasses around Thursday Island have remained in relatively good condition over recent years. Weipa, however, stands out in the region as an area of significant seagrass expansion over the last three years, indicative of an overall healthy port marine environment.

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		BIOMASS ↑	Decrease below threshold from previous year		BIOMASS ↓

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 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.

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).

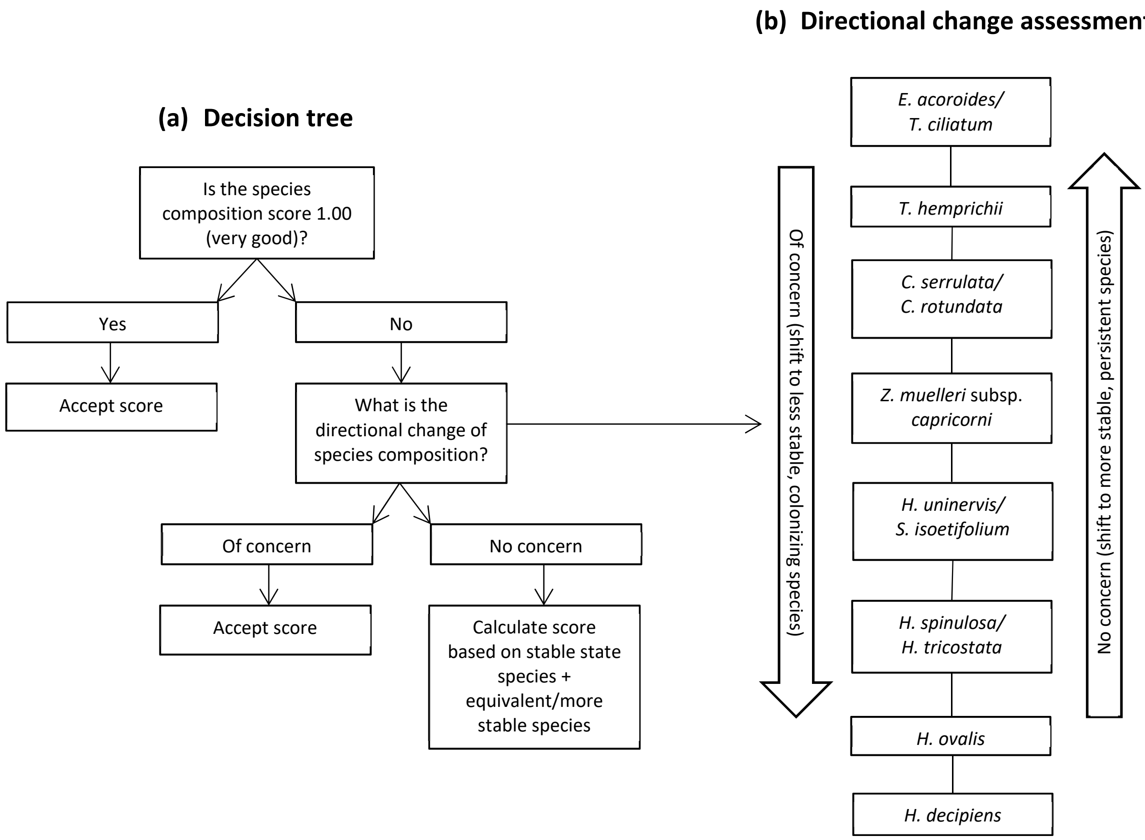


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in the Port of Weipa.

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 ($B_{satisfactory}$):

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

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

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

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

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

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

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

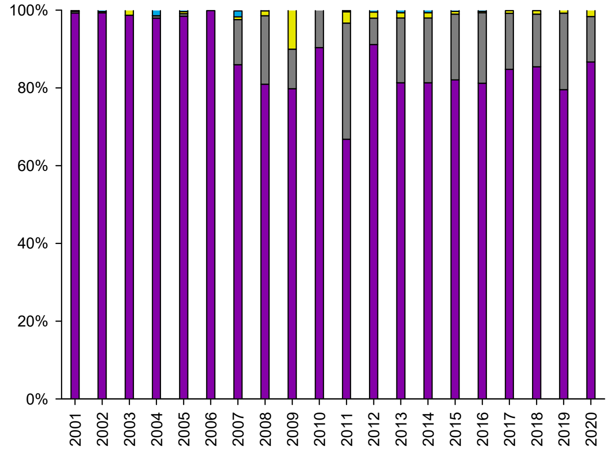
5. Determine the biomass score for 2016 ($Score_{2016}$) by scaling B_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

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

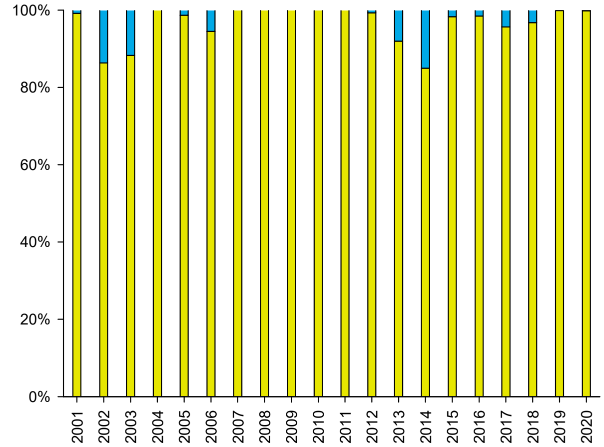
Where $LB_{satisfactory}$ is the defined lower bound (LB) score threshold for the satisfactory grade, i.e. 0.50 units.

Appendix 3. Detailed species composition; 2000 – 2020

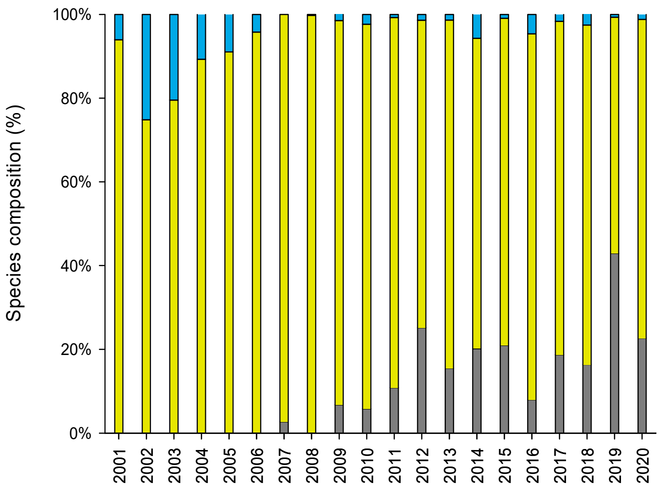
Meadow A2



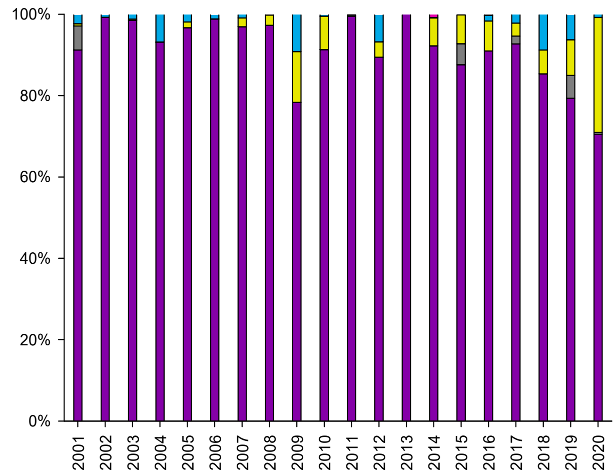
Meadow A3



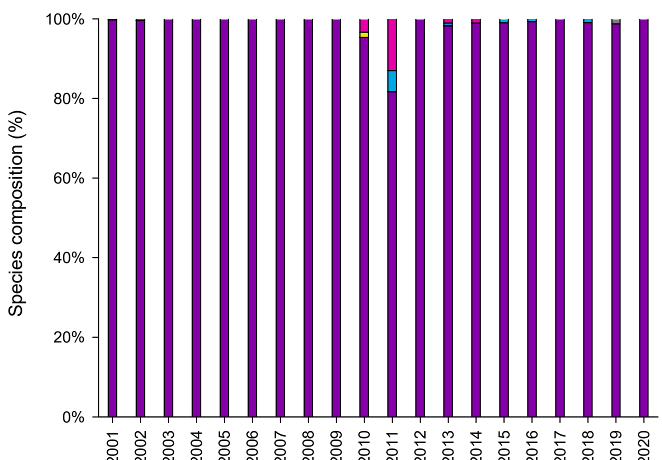
Meadow A5



Meadow A6



Meadow A7



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 – 2020.

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**	**Aug-20**
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)	14.19 ± 0.98 (62)	14.27 ± 0.89 (64)
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)	2.30 ± 0.54 (45)	1.55 ± 0.33 (42)
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)	5.52 ± 0.67 (60)	9.51 ± 0.81 (58)
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)	7.91 ± 1.30 (40)	9.67 ± 1.1 (33)
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)	10.01 ± 1.25 (41)

Appendix 4. Meadow above-ground biomass and area

Total meadow area + R (ha) for each core monitoring meadow within the Port of Weipa, 2000 – 2020.

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**	**Aug- 20**
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	261.85± 6.49
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	45.57 ± 2.37
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	83.33 ± 6.14
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	8.13 ± 0.67
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	15.69 ± 1.12
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**	**412.58 ± 16.79**

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