PORT OF WEIPA LONG-TERM SEAGRASS MONITORING PROGRAM: 2000 - 2017

Sozou, AM & Rasheed MA

Report No 18/02

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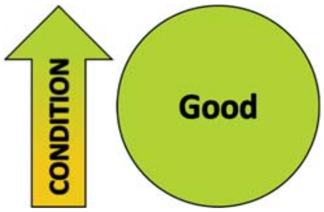
KEY FINDINGS

Seagrass Condition



Likely causes of seagrass condition:

⬆ *Favourable climate conditions for seagrass growth*

⬆ *Improved light conditions in meadows between Evans Landing and Humbug Terminal*

- In 2017 the broader Weipa port limits were surveyed to provide an update on overall seagrass distribution and condition. Total area of seagrass (5,140 ha) was the largest recorded since monitoring began in 2000 and coverage of seagrass within meadows was also higher than all previous port limits surveys.

- Seagrasses in the Port of Weipa were overall in a good condition in 2017.
    - Biomass and species composition for the five core monitoring meadows were in a good or very good condition.
    - Area of seagrass inside the intensive monitoring area (IMA) was the highest recorded since 2001.
    - Only one monitoring meadow had a poor overall score, meadow A5 south of Napranum, due to a reduction in area.

- The seagrass meadows between Evans Landing and Lorim Point (Meadows A6 & A7) had recovered from localised declines recorded leading up to 2016, and both were classified as being in good condition in 2017. It appears the reasons behind the declines were related to acute or short term reductions in light rather than any chronic ongoing pressure.

- The light environment remained favourable for seagrasses, with light recorded in meadow A7 improving from 2016.

- The key climax seagrass species *Enhalus acoroides* appears well adapted to cope with periods of extremely low light for several weeks and up to 2 months that occur during wet season flood and rainfall events.

- Seagrass condition in 2017 suggests they were likely to remain resilient to planned maintenance dredging activities during 2018

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. This year (2017) included remapping the broader port limits.

Seagrasses in the Port of Weipa were overall in a good condition with biomass and species composition in a good or very good condition (Figure 1). Area was found to be in a good or very good condition, with the exception of meadow A5 which had a poor area score (Figure 1).

Total area of seagrass in the IMA was the highest that had been recorded since 2001 (Figure 2). In addition the climax high biomass species *Enhalus acoroides* dominated eleven out of fifteen meadows.

Meadows A6 and A7 (between Evans Landing and Lorim Point) had recovered from the declines that were observed in 2015 and 2016. Additional interim monitoring of these meadows conducted in May and June 2017 showed improvements in seagrass had started to occur. During the annual monitoring in August 2017 seagrass condition had further improved with both of these meadows scoring a good condition for 2017. Light levels at the monitoring station within this region (meadow A7) had returned to a more normal range in 2017 and was once again consistent with trends observed at the other light monitoring stations in the port. These results suggest that the causes for the localised declines in these meadows were likely to be due to an acute or short term event rather than a chronic longer term pressure.

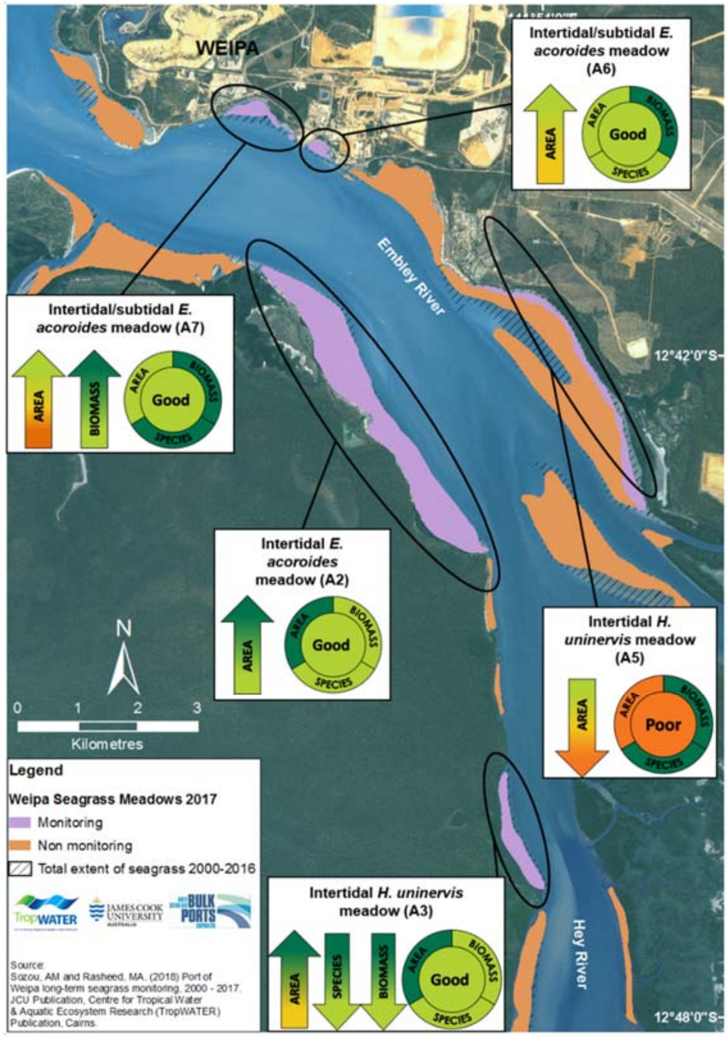


Figure 1. Seagrass meadow condition in the Port of Weipa 2017.

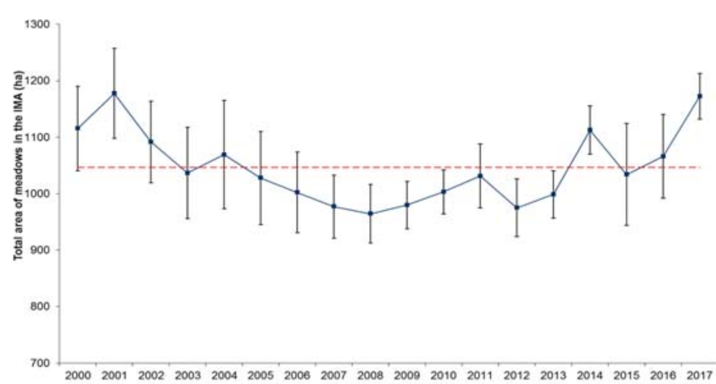


Figure 2. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2017. (error bars = "R" reliability estimate). Red dashed line indicates 18-year mean of total meadow area.

In 2017, the broader port limits in Weipa (Embley and Mission Rivers and Pine River Bay) were surveyed to provide an updated assessment of seagrass condition with the entire port limits region. Total area of seagrass mapped within the port limits was 5139.8 ± 143.8 ha, the largest seagrass distribution recorded since monitoring began in 2000. With the expanded area there was also an increase in meadows that contained a continuous seagrass coverage compared with previous whole of port assessments.

In general, climate conditions in Weipa were favourable for seagrass growth in the twelve months prior to the survey with below average tidal exposure (likely minimising air exposure stress including "burning" of seagrass leaves) and below average rainfall. This, combined with favourable light (Photosynthetically Active Radiation (PAR)) at monitoring stations inside the IMA was likely to have contributed to the good condition of seagrass in the region.

The key climax seagrass species *Enhalus acoroides* appears well adapted to cope with typical wet-season reductions in light. Quarterly assessments of seagrass change at light (PAR) monitoring sites suggest that *Enhalus acoroides* copes with several weeks and up to 2 months of extremely low light levels during high rainfall and river flow events, with seagrass biomass remaining relatively stable. This suggests that natural periods of low light are not low enough or sustained long enough to considerably degrade *E. acoroides,* a species that has a large storage of carbohydrate energy reserves in below ground structures. However, the losses of *E. acoroides* that occurred in 2015 and 2016 when there were additional localised reductions in light show that the species can be vulnerable, particularly when there are multiple occurrences of sustained low light within a year.

In 2017 recovery of meadows between Evans Landing and Lorim Point combined with the good condition of seagrasses (high biomass/large area) suggests that they were likely to remain resilient to planned annual maintenance dredging during 2018. The Weipa seagrass monitoring program forms part of a broader Queensland program that examines condition of 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 www.jcu.edu.au/portseagrasqld).

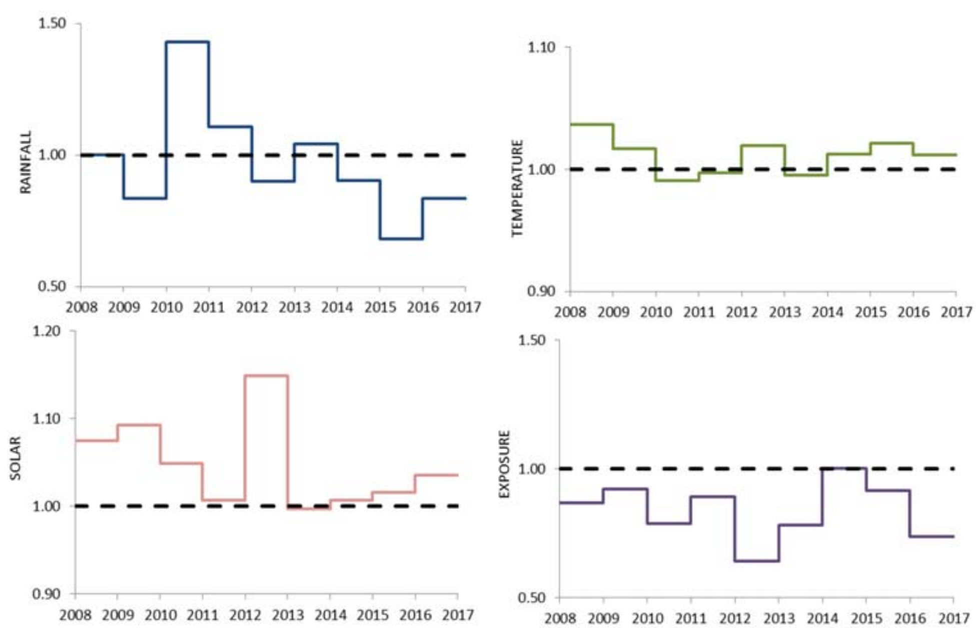


Figure 3. Recent climate trends in Weipa: Change in climate variables as a proportion of the long-term average. (See section 3.2 for detailed climate data).

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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. 2011). 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. While each location is funded separately, a common methodology and rationale is used providing a network of seagrass monitoring locations throughout Queensland (Figure 4).

Figure 4. Location of Queensland Port seagrass assessment sites.

A strategic long-term assessment and monitoring program for seagrasses provides port managers and regulators with the key information to ensure effective management of seagrass resources. It is useful information for planning and implementing port development and maintenance programs so they have a minimal impact on seagrass. The program also provides an ongoing assessment of many of the most threatened seagrass communities in the state.

The program not only delivers key information for the management of port activities to minimise impacts on seagrasses, but has also resulted in significant advances in the science and knowledge of tropical seagrass ecology. It has been instrumental in developing tools, indicators and thresholds for the protection and management of seagrass habitats and an understanding of the drivers of tropical seagrass change. It provides local information for individual ports as well as feeding into regional assessments of the status of seagrasses. For more information on the program and reports from the other monitoring locations see www.jcu.edu.au/portseagrassqld

1.2 Weipa Seagrass Monitoring Program

North Queensland Bulk Ports (NQBP) Corporation is responsible for managing and monitoring Weipa's port environment. NQBP has recognised that seagrasses form a key ecological habitat in the Weipa region and commissioned TropWATER to establish a long-term seagrass monitoring program for Weipa's port in 2000 (Roelofs et al. 2001; 2003; 2005). The goals of the program are to minimise impacts of port activities on seagrass habitats and to periodically assess the health of Weipa's port environment. 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) on seagrass meadows. In 2017 the annual maintenance dredge campaign commenced on May 17th and was completed in 23 days, with 297,301m^3 of dredge material relocated to the approved spoil ground. 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.

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). Each August/September all seagrass meadows within the IMA are surveyed and mapped. Five core monitoring meadows within the IMA are also assessed for biomass and seagrass species composition. These meadows 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).

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 (Figure 27). New to the monitoring program in 2015 was the expansion of the established PAR and temperature program to incorporate quarterly seagrass assessments at permanent transects sites alongside the logging stations in Meadow A2 (Figure 29). 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 once sufficient data has been gathered.

This report presents the results of the long-term seagrass monitoring assessments conducted in August 2017. The objectives were to:

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

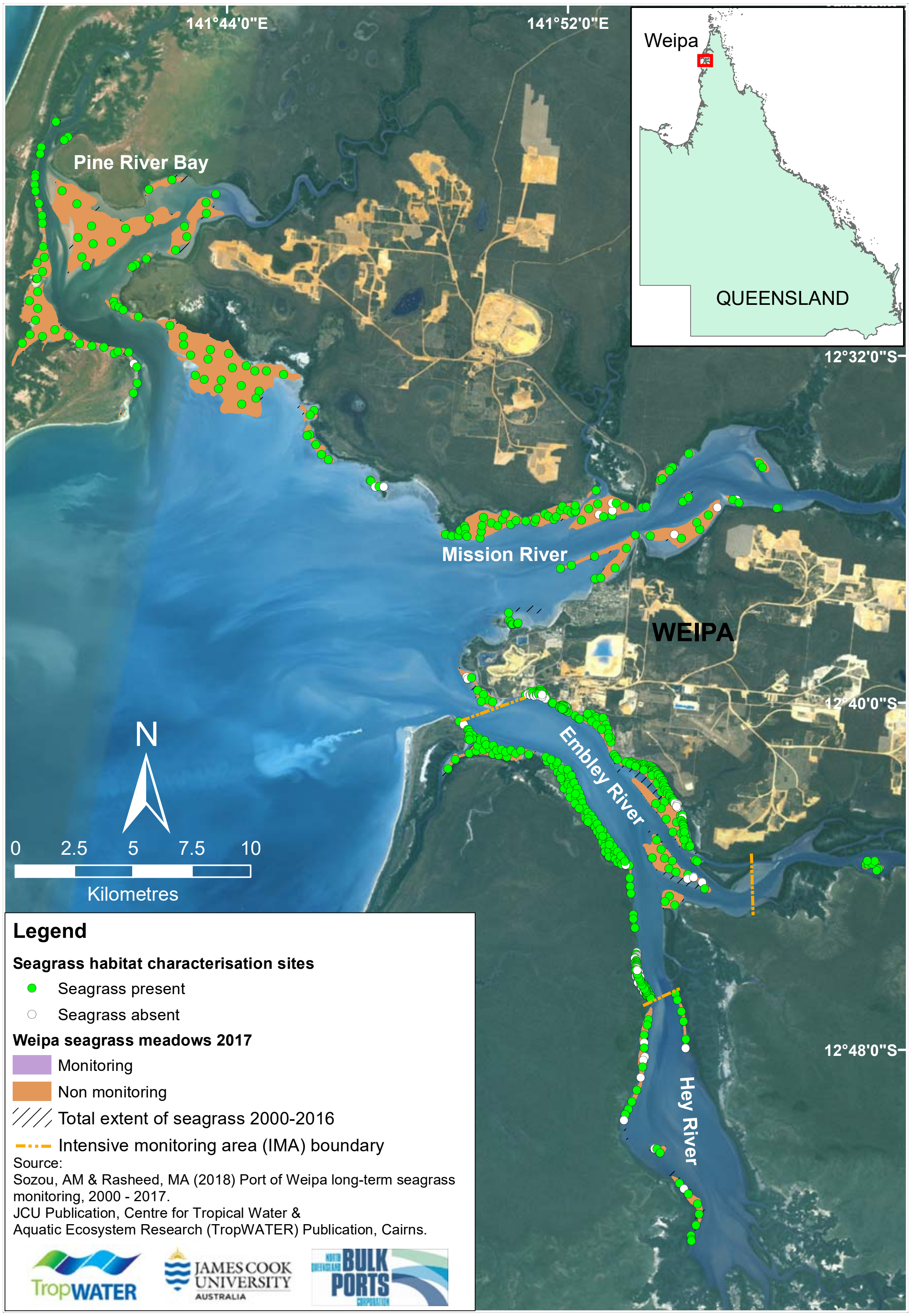

Figure 5. Location of 2017 seagrass survey sites and seagrass meadows in the Port of Weipa.

2 METHODS

2.1 Annual monitoring within the Intensive Monitoring Area and broader Weipa port limits

Annual seagrass monitoring and assessment of seagrass in the broader port limits within the Port of Weipa was conducted August 20th – 24th 2017. Annual monitoring over the past 17 years has focused on five core monitoring meadows selected from baseline surveys within the Intensive Monitoring Area (IMA) (Figure 5) (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.

Three levels of sampling were used in the August 2017 survey:

1. Assess and map seagrass distribution, species composition and biomass in the five core monitoring meadows (A2, A3, A5, A6, and A7; Figure 13);
2. Map seagrass distribution and species composition in non-core monitoring meadows within the IMA (Figure 5);
3. Map seagrass distribution and species composition in the broader port limits of Weipa (Figure 5).

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 were recorded including seagrass species composition, above-ground biomass, seagrass and algal percent cover, sediment type, time, position fixes (GPS; ±5m), and depth below mean sea level (dbMSL) for subtidal meadows. 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 CCTV 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*/*Halophila* 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*/*Halophila* 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 estimates 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 are 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 estimates.

2.2 Habitat mapping and Geographic Information System

Spatial data from the 2017 survey were entered into the Port of Weipa Geographic Information System (GIS). Three seagrass GIS layers were created in ArcGIS® - site information, seagrass meadow characteristics and seagrass landscape category.

- ***Site information***- data containing seagrass percent cover and above-ground biomass (for each species), depth below mean sea level (dbMSL), sediment type, latitude and longitude, sampling method and comments.
- ***Seagrass meadow characteristics***- area data for seagrass meadows with summary information on meadow characteristics. Seagrass meadows were assigned a meadow identification number which was used to compare individual meadows among annual monitoring surveys. Seagrass community types were determined according to species composition from nomenclature developed for seagrass meadows of Queensland (Table 1). Abundance categories (light, moderate, dense) were assigned to community types according to the above-ground biomass of the dominant species (Table 2).
- ***Seagrass landscape category***- area data showing the seagrass landscape category determined for each meadow (Figure 7).

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

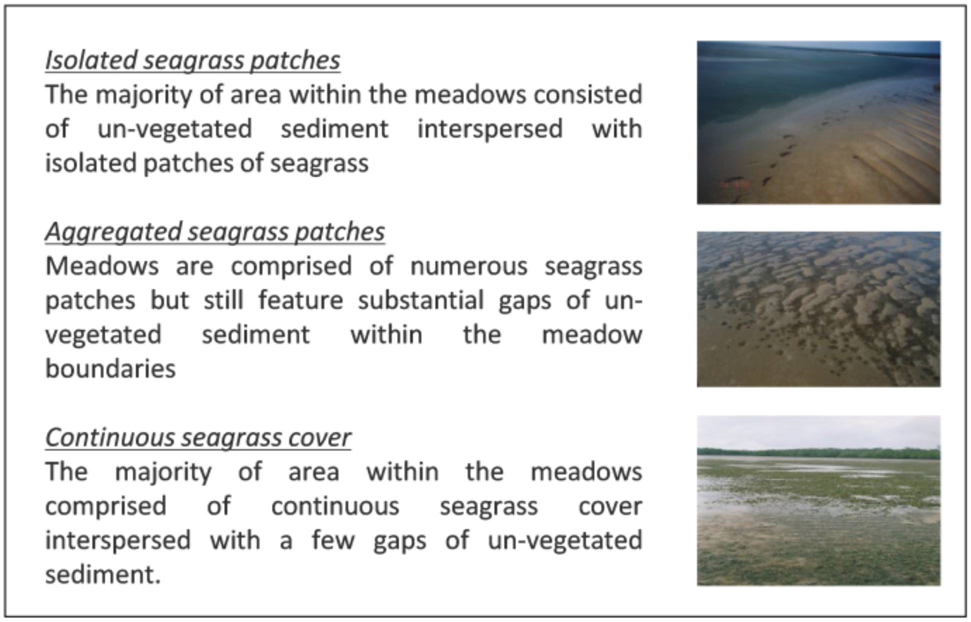

Figure 7. Landscape categories for seagrass meadows in Queensland

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.

Each seagrass meadow was assigned a mapping precision estimate (±m) based on the mapping method used for that meadow (Table 3). Mapping precision estimates ranged from 5m for intertidal seagrass meadows to 10 - 50m for intertidal to subtidal meadows. The mapping precision estimate was used to calculate a range of meadow area for each meadow, and was expressed as a meadow reliability estimate (R) in hectares. The reliability estimate for subtidal habitat is based on the distance between sites with and without seagrass when determining the habitat boundary. Additional sources of mapping error associated with digitising imagery and with GPS fixes for survey sites were embedded within the meadow reliability estimates.

Table 3. Mapping precision and methods for seagrass meadows in the Port of Weipa 2017.

Mapping precision	Mapping method
5m	Meadow boundaries mapped in detail by GPS from helicopter; Intertidal meadows completely exposed or visible at low tide; Relatively high density of mapping and survey sites; Recent satellite imagery aided in mapping.
20-50m	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.

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 the Port of Weipa was scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). The flow chart in Figure 8 summarises the methods used to calculate seagrass condition. See Appendix 1 for full details of score calculation.

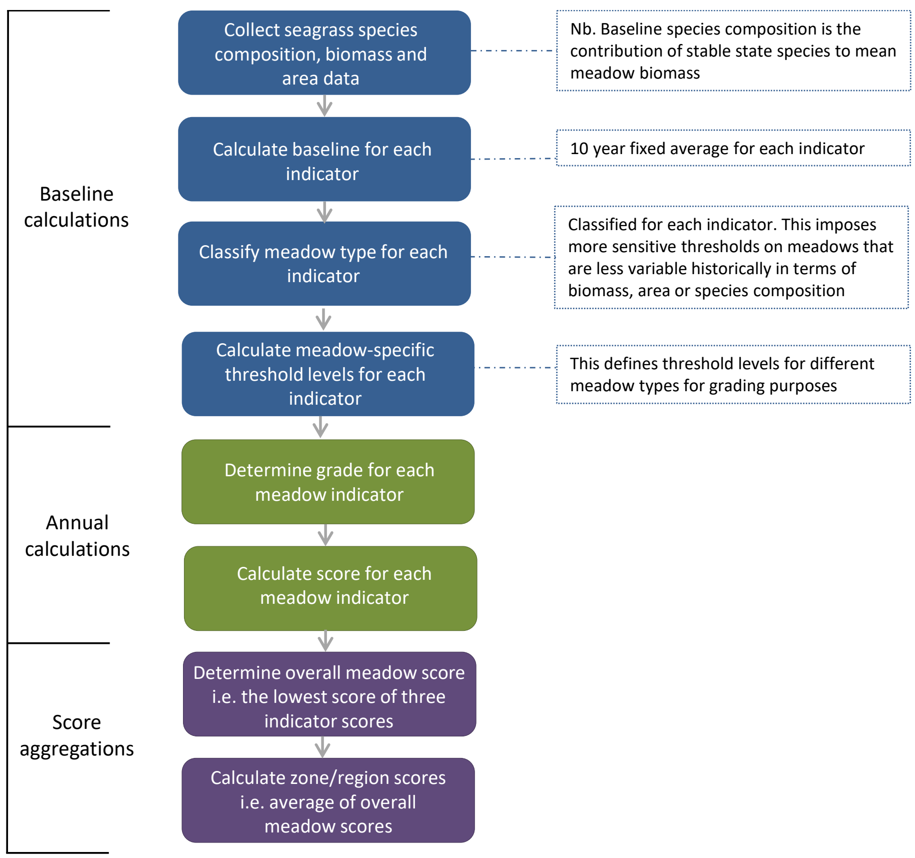

Figure 8. Flow chart to assess seagrass monitoring meadow condition.

2.4 Environmental data

Irradiance (Photosynthetically Active Radiation (PAR) mol photons m^{-2} day^{-1}) conditions within the seagrass meadows at Weipa have been assessed at a northern and southern site with the intertidal A2 meadow and at one site in the subtidal/intertidal A7 meadow (Figure 12) since September 2010 using custom built benthic data logging stations (Figure 9). An additional site was set up in 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 System, Dataflow Systems Pty. Ltd., New Zealand) 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.

Other general environmental data was obtained from the Australian Bureau of Meteorology (www.bom.gov.au) and the Department of Environment and Heritage Protection (www.ehp.qld.gov.au).

PAR loggers in cradles

Deployed PAR loggers in cradles on intertidal seagrass meadow

Figure 9. Logging station consisting of a stainless steel frame, PAR loggers, electronic wiper unit and temperature loggers.

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, 2 sites at the northern end of the meadow (A2-1a and A2-1b) and 1 at the south end (A2-2). For further information see McKenna et al. (2017).

The key information collected for seagrass at the quarterly assessment sites was:

- 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 species in the Port of Weipa

A total of 612 seagrass habitat characterization sites were surveyed in the IMA and extended port limits as part of the 2017 baseline survey, with seagrass present in 90% of sites (Figure 5). Six species of seagrass (from two families) were identified (Table 4).

Table 4. Seagrass species present in the Port of Weipa 2017.

CYMODOCEACEAE Taylor		***Halodule uninervis*** (narrow & wide leaf morphology) (Forsk.) Aschers • Narrow leaf blades 0.25-5mm wide • Trident leaf tip ending in three points • 1 central longitudinal vein which does not usually split into two at the tip • Usually pale ivory rhizome, with clean black leaf scars along the stem
		***Syringodium isoetofolium*** (Ascherson) Dandy • Easily distinctive seagrass • Tube-like leaves containing air cavities with a smooth pointed tip • Variable leaf length, from 5 cm to over 50 cm long
HYDROCHARITACEAE Jussieu		***Enhalus acoroides*** *(L.f.)* Royle • Very distinctive seagrass • Very long, ribbon-like leaves (30-150cm long, 1.25 - 1.75cm wide) • Thick leaves with many parallel veins • Very thick rhizome (at least 1cm) with black, fibrous bristles
		***Halophila ovalis*** (Br.) D.J. Hook. • Small oval shaped leaves (0.5 - 2cm long) • 8 or more cross-veins on leaf • No hairs on leaf surface • Dugong preferred food
		***Halophila decipiens*** Ostenfeld • Small oval leaf blade 1-2.5cm long • 6-8 cross veins • Leaf hairs on both sides • Found at intertidal and sub tidal depths
		***Thalassia hemprichii (Ehrenb.) Aschers. in Petermann*** • Long, ribbon-like leaves 10-40cm long • 10-17 longitudinal leaf veins • Short black bars of tannin cells on leaf blade • Leaf sheaths 3-7cm long • Thick rhizome (up to 5mm) with conspicuous scars between shoots

3.1.1 Seagrass in the Intensive Monitoring Area

Fourteen seagrass meadows were mapped in 2017 within the Intensive Monitoring Area (IMA) (Figure 12). The total combined seagrass meadow area was 1172.8 ± 40.0 ha, the second highest area that has been recorded in the 18 years of monitoring in Weipa and highest since 2001 (Figure 10). Area has been increasing in the IMA since 2015 (Figure 10).

Enhalus acoroides dominated eleven out of the fifteen meadows within the IMA (Figure 12), all with light density cover. *Halodule uninervis* was the dominant species in two meadows, monitoring meadow A5 and IMA meadow A3, consisting of continuous cover and aggregated patches respectively (Figure 12). *Thalassia hemprichii* was the dominant species in two of the IMA meadows, meadow A1 in the Embley River and a small meadow on the western bank of the Hey River (Figure 12).

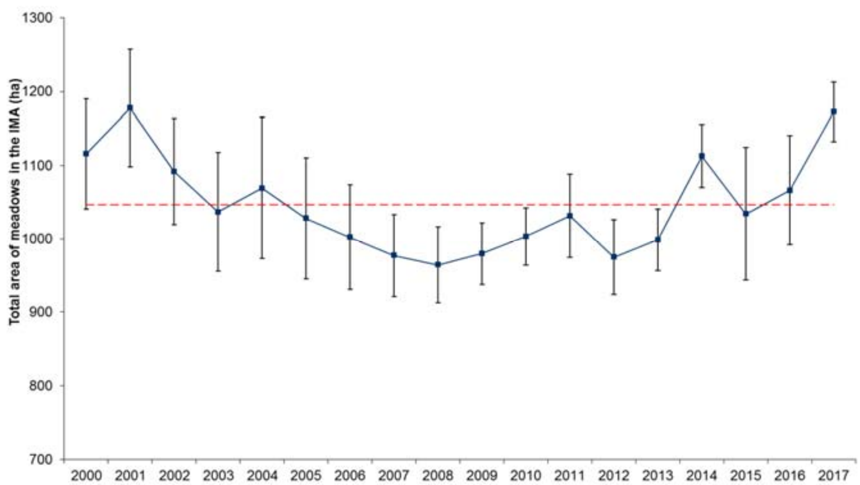

Figure 10. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2017 (error bars = "R" reliability estimate). Red dashed line indicates 18-year mean of total meadow area.

The condition known as burning, i.e. the browning and subsequent death of seagrass blades (Figure 11a), was observed at 17% of sites across all meadows within the IMA in 2017; a decrease from 2016. 2013 had the lowest occurrence of burning observed since first formally recorded in 2010 (Figure 11a).

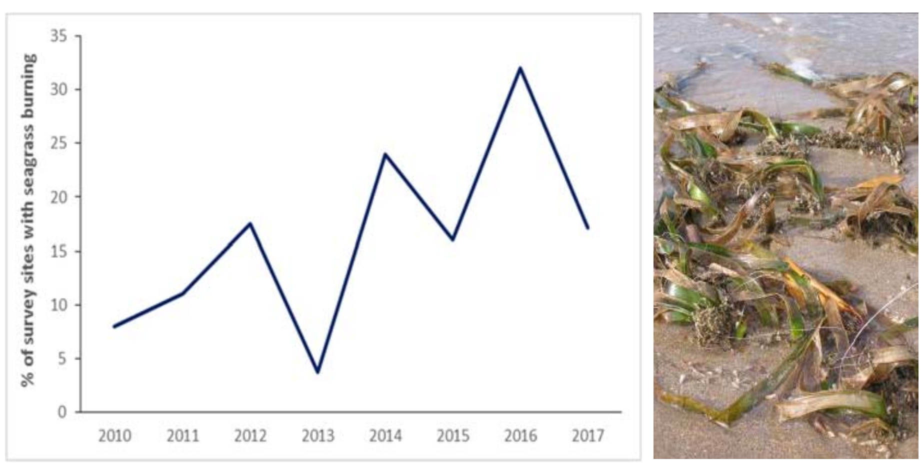

Figure 11a. Percentage of sites within the IMA that have evidence of *Enhalus acoroides* burning in the Weipa IMA meadows.

Dugong feeding trails are not commonly observed within the IMA having only been recorded here in one previous survey in 2016 where they were present in 3 meadows (A3, A5 and the large meadow between Lorim Point and Napranum; Figure 11b). No dugong feeding trails were recorded in the IMA in 2017 however they were recorded outside of the IMA in the Mission River and Pine River Bay, where dugong feeding has more commonly been found over the course of the monitoring program.

Figure 11b. Examples of Dugong feeding trails in the A5 Weipa monitoring meadow in 2016.

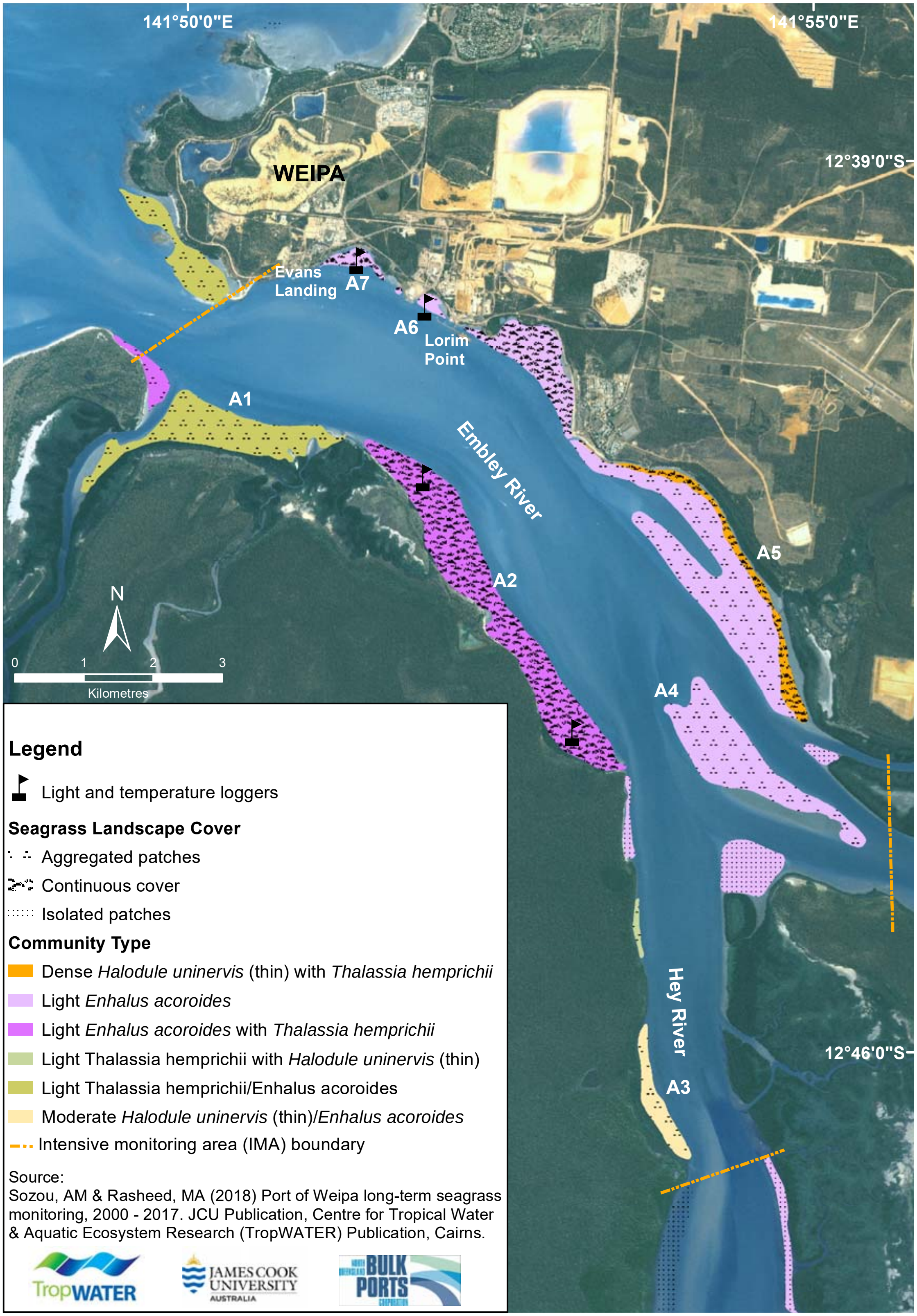

Figure 12. Meadow type and landscape cover for seagrass within the Intensive Monitoring Area 2017.

3.1.2 Seagrass condition in the core annual monitoring meadows

The overall condition of seagrass monitoring meadows in Weipa was classed as good (Table 5). This is an improvement in condition from the previous monitoring year (2016) which classed seagrass condition as satisfactory. For all monitoring meadows, seagrass biomass, area and species composition was in a good or very good condition, with the exception of monitoring meadow A5 where area was classed in a poor condition (Figure 15). The improvement of area across four out of the five monitoring meadows led to the increase in overall condition score of seagrass (Table 5).

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

All *E. acoroides* dominated meadows had a light seagrass cover that was continuous for meadows A2 and A7, and consisted of aggregated patches for meadow A6. *E. acoroides* formed an increased proportion of the seagrass species compared with 2016 for all three meadows (Figure 13; Figure 16; Figure 17).

Meadow A2:

Biomass and species composition for meadow A2 remained in a good condition for 2017, with the area increasing to a very good condition in comparison to 2016 (Figure 13). Meadow area was the highest recorded since monitoring began with 285.8 ± 6.5 ha. Biomass has varied spatially through time, with denser patches of seagrass occurring towards the northern end of the meadow, similar to 2016 (Figure 18).

Meadow A6:

Biomass was classed to be in a very good condition, with area and species composition classed as being in a good condition (Table 5). A decline in seagrass area for meadow A6 (along with neighbouring meadow A7) was noted in 2015 and 2016. The 2017 survey found a 46% increase in area of meadow A6, with this recovery leading to condition increasing from satisfactory to good (Figure 16).

Meadow A7:

There was a substantial recovery in area of this meadow from declines that occurred in 2015 and 2016. This lead to the overall meadow score improving from poor to good (Table 5; Figure 17). Biomass (16.6 ± 2.1 g DW m^{-2}) also improved from good to very good, and species composition remained in a good condition.

Additional interim monitoring of Meadows A6 & A7- May and June 2017

Additional monitoring was conducted in May and June 2017 for meadows A6 and A7 in response to the declines recorded for these meadows in 2015 and 2016. Biomass of meadows A6 and A7 in May 2017 was 5.72 ± 1.21 g DW m^{-2} and 10.31 ± 1.43 g DW m^{-2} respectively. Area was 4.3 ± 2.6 ha for meadow A6 and 6.6 ± 1.4 ha for meadow A7 (Figure 19). In June 2017, considerable increases in biomass and area were recorded for both meadows, and in August 2017 (annual monitoring see above) both of these meadows further recovered in area to be in a good condition.

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

Both *Halodule uninervis* dominated monitoring meadows consisted of aggregated patches, with a moderate or dense biomass coverage. Both meadows included at least two other species of seagrass, including *E. acoroides, Thalassia hemprichii, H. uninervis* and *Halophila ovalis.* Meadow A3 was classed in a good condition, with meadow A5 classed in a poor condition due to a reduction in area in 2017 (Figure 14; 15; Table 5).

Meadow A3:

The overall condition of meadow A3 increased from a satisfactory in 2016 to good condition in 2017 (Figure 14, Table 5). Improved condition was due to an increase in area from 31.1 ± 2.2 ha in 2016 to 41.0 ± 2.2 ha in 2017 (Figure 14). Biomass (0.68 ± 0.16 g DW m^{-2}) and species composition of the meadow remained in a good condition in 2017 (Table 5).

Meadow A5:
Declines in area of meadow A5, principally at the southern end of the meadow where seagrass has generally been the patchiest in previous surveys, resulted in this meadow being classified as in poor condition (Figure 15, Table 5). Despite the declines in area, biomass and species composition remained in a very good condition (Figure 15).

Table 5. Grades and scores for seagrass indicators (biomass, area and species composition) for 2017 in the Port of Weipa.

Meadow	Biomass	Area	Species Composition	Overall Meadow Score
A2	0.79	1.00	0.73	0.73
A3	0.69	0.87	0.84	0.69
A5	0.88	0.46	0.98	0.46
A6	0.86	0.80	0.83	0.80
A7	0.91	0.71	1.00	0.71
Overall Score for the Port of Weipa				**0.68**

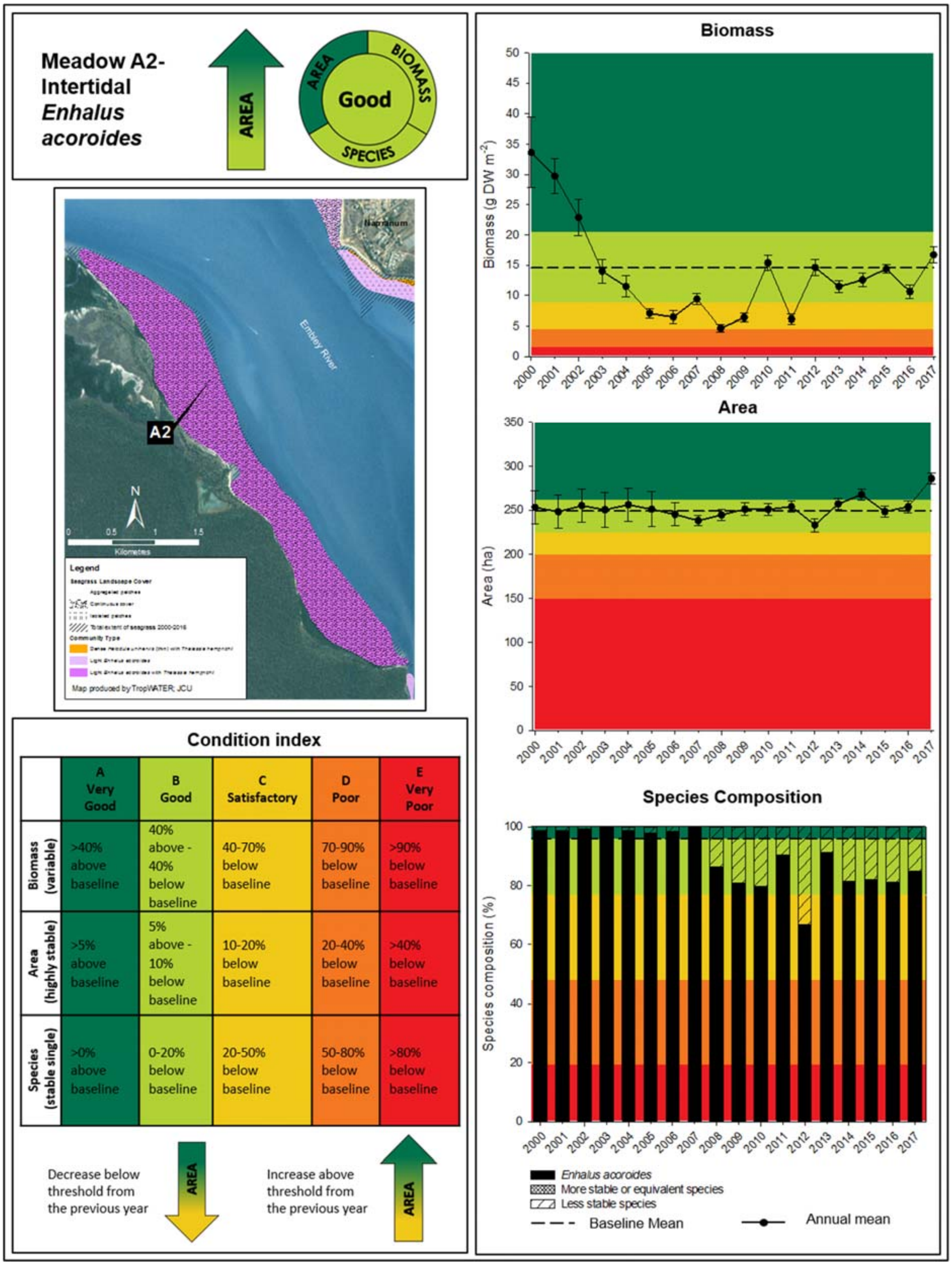

Figure 13. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A2 in Weipa from 2000 to 2017 (biomass error bars = SE; area error bars "R").

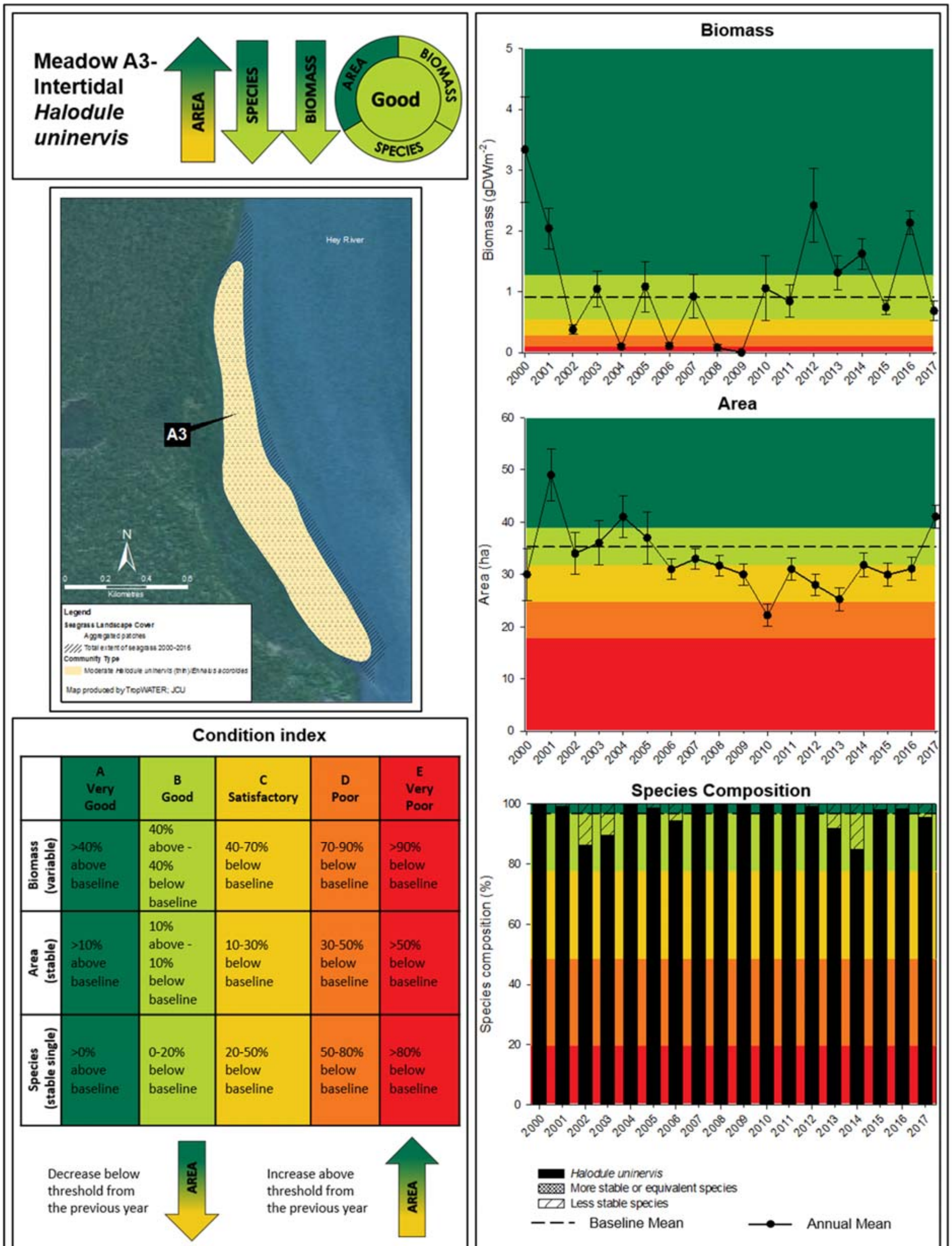

Figure 14. Changes in biomass, area and species composition for the *H. uninervis* dominated core monitoring meadow A3 in Weipa from 2000 to 2017 (biomass error bars = SE; area error bars "R").

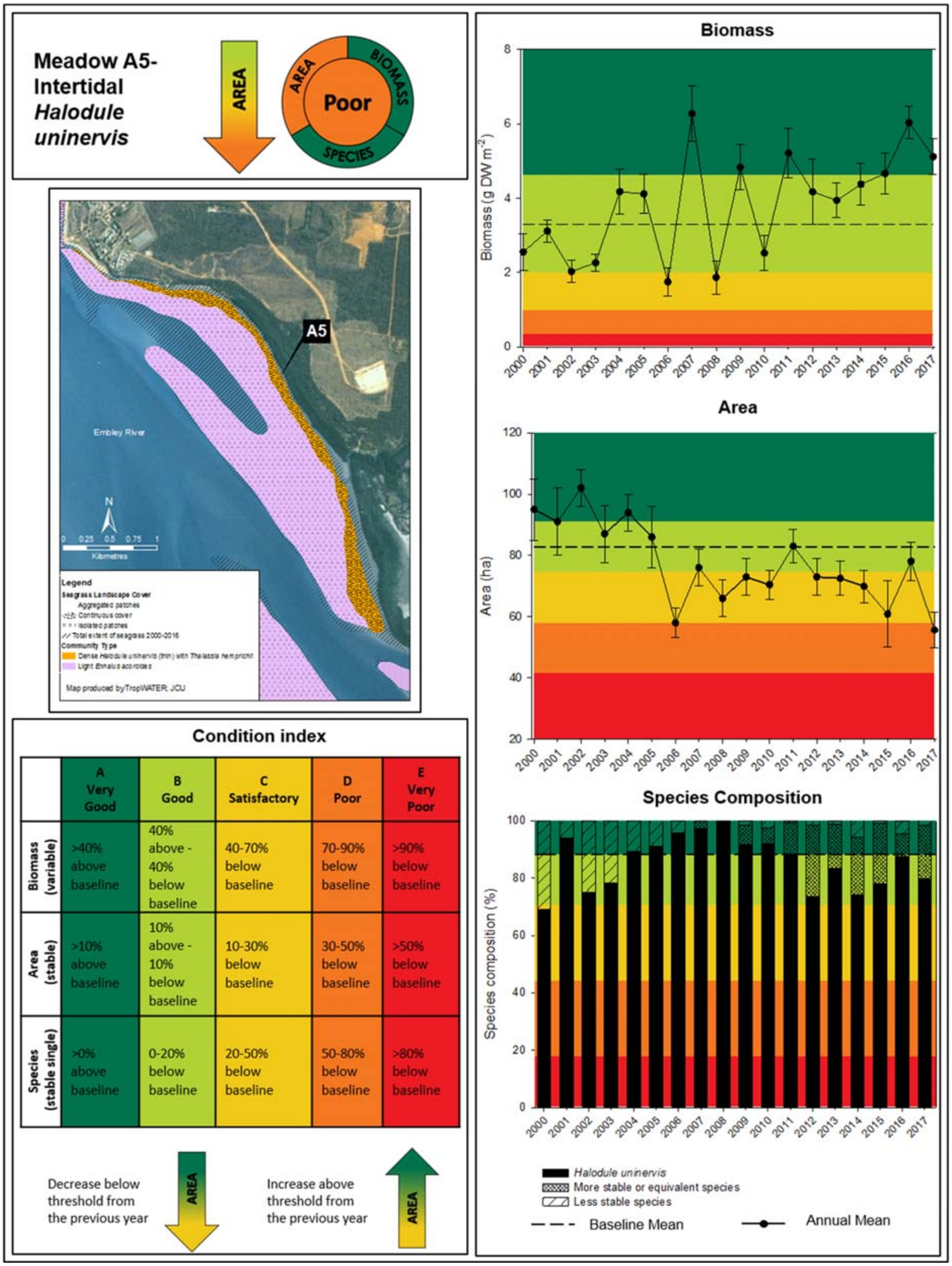

Figure 15. Changes in biomass, area and species composition for the *H. uninervis* dominated core monitoring meadow A5 in Weipa from 2000 to 2016 (biomass error bars = SE; area error bars "R").

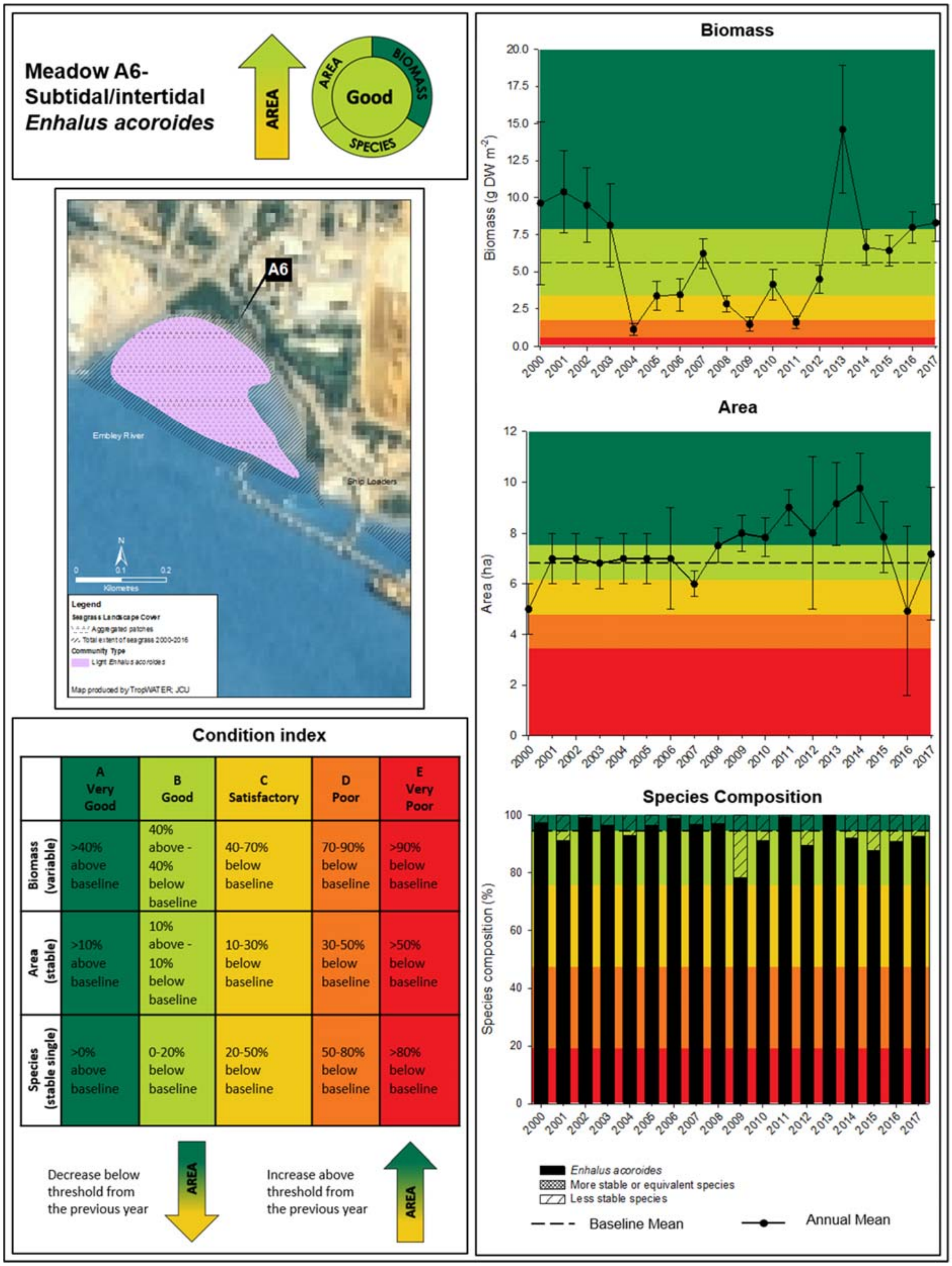

Figure 16. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A6 in Weipa from 2000 to 2017 (biomass error bars = SE; area error bars "R").

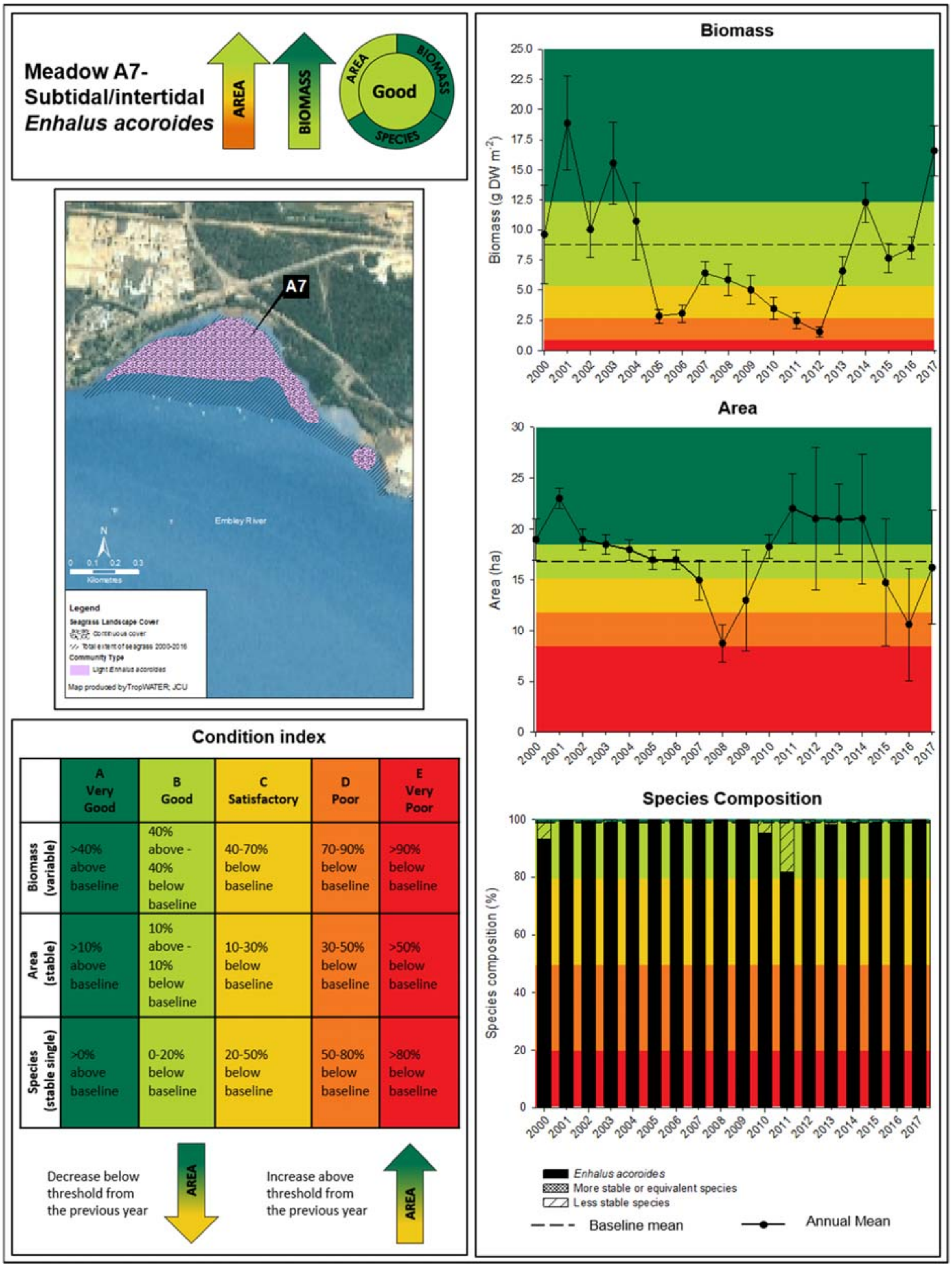

Figure 17. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A7 in Weipa from 2000 to 2017 (biomass error bars = SE; area error bars "R").

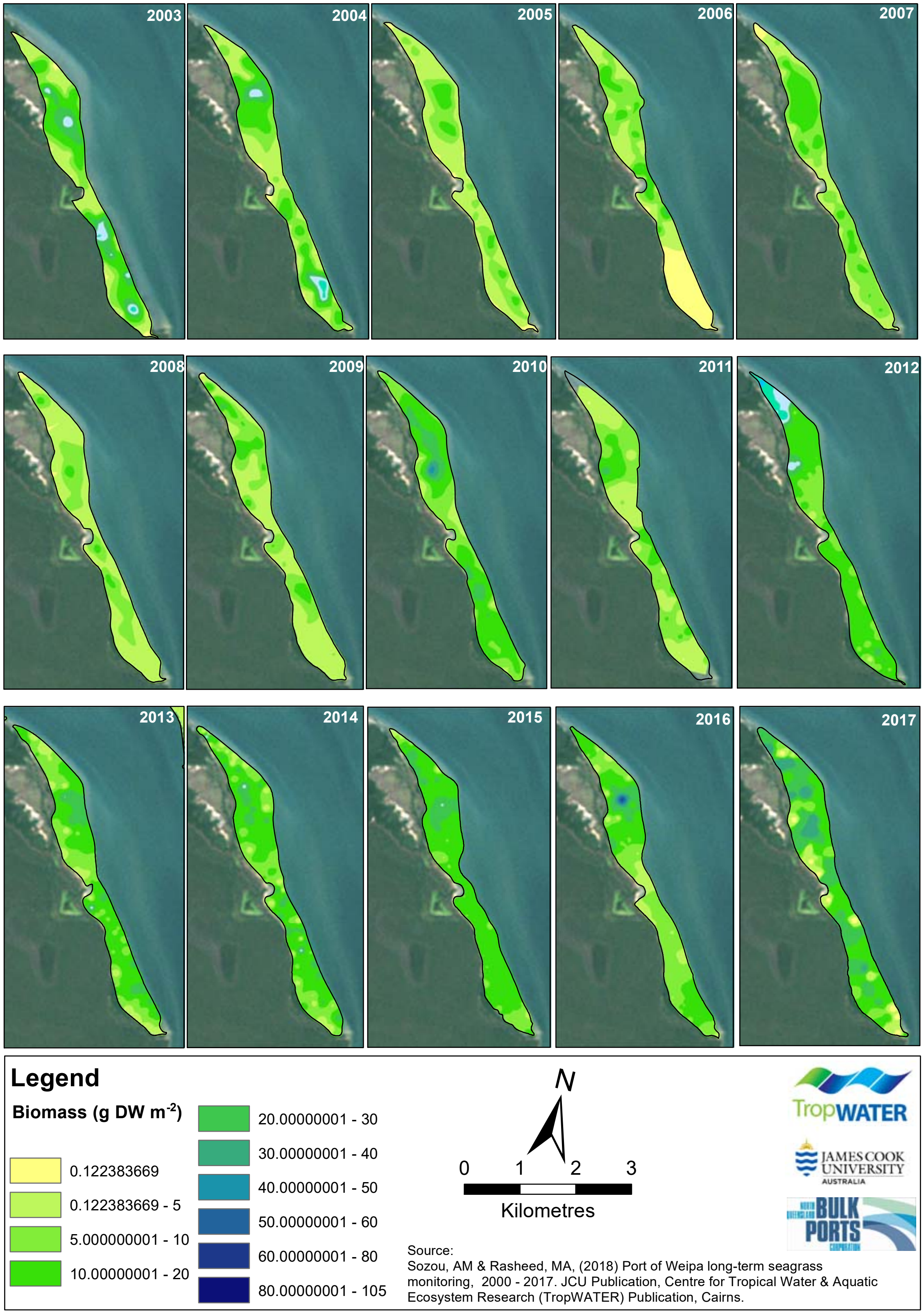

Figure 18. Seagrass biomass changes in the A2 monitoring meadow, 2003-2017.

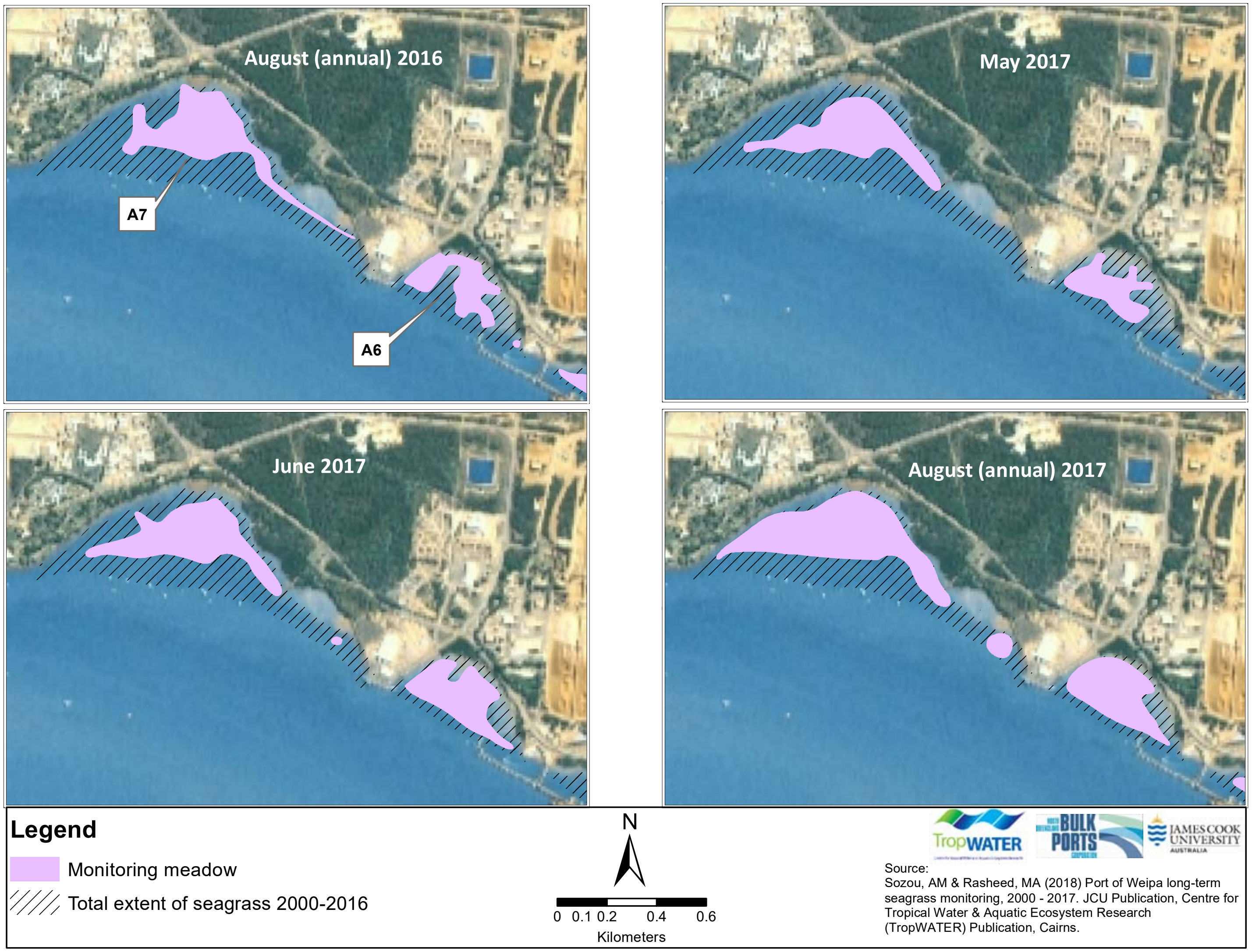

Figure 19. Seagrass distribution of meadow A6 and A7 in May and June 2017 (additional monitoring) and August 2017 and 2017 (annual survey).

3.1.3 Seagrass condition in the broader Port of Weipa

In 2017, seagrass distribution and community type within the entire port limits were mapped to enable a comparison with previous whole of port mapping conducted in 2000-2002, 2005, 2008, 2011 and 2014 (Figure 5) and to ensure trends in the monitoring meadows continued to reflect changes in the greater port limits region. In 2017 monitoring found the largest seagrass distribution recorded since monitoring began in 2000 (5139.8 ± 143.8 ha). Combined with this, there was a substantial increase in the number of meadows that were classed as having a continuous seagrass cover as opposed to aggregated or isolated patches. In 2017 this resulted in continuous cover meadows being the dominant landscape category in the port for the first time (2381.3 ± 60.3 ha) (Figure 20).

Location of seagrass meadows in the Hey River remained similar to previous surveys (Figure 21). While similar species were found in the Hey River meadows in 2017, there was an increase in the proportion of meadow biomass contributed by *Enhalus acoroides* for some, leading to them to switch in dominance from *Halodule uninervis* to *Enhalus acoroides*.

Seagrass in the Mission River has remained broadly similar to previous surveys. Along the southern shore and upstream of the Mission River Bridge, seagrass meadows are made up of very isolated patches of seagrass (*E. acoroides* and *H. ovalis*) and are in fact dominated by large areas of unvegetated sediment (Figure 22). Seagrass coverage is more substantial on the northern banks of the river downstream of the bridge where the most substantial meadow in Mission River is located, consisting of a continuous cover of *Thalassia hemprichii, Enhalus acoroides* and *Halodule uninervis* (Figure 22).

In 2017 there were substantial meadows in Pine River Bay with seagrass covering an area of 2,650.9 ± 52 ha in 17 meadows. This was a 7% increase in area since Pine river Bay seagrasses were last mapped in 2014 (Figure 23). The large highly patchy *E. acoroides* meadow on the large bank in the middle of the bay has changed little over the years and continues to be dominated by very isolated patches of *E. acoroides* and *Halophila ovalis* (Figure 23). The largest recent changes have occurred to meadows located at the mouth of the Bay where there have been substantial increases in seagrass area as well as increases in meadow biomass, decreases in the level of meadow patchiness and an increase in larger growing species such as *Syringodium isoetofolium* and *Thalassia hemprichii* particularly on the western side of the Bay *(*Figure 23).

Dugong feeding trails were observed in the broader Port of Weipa towards the top of the Pine River Bay, and the large *E. acoroides* with *H. ovalis* meadow at the mouth of the Mission River.

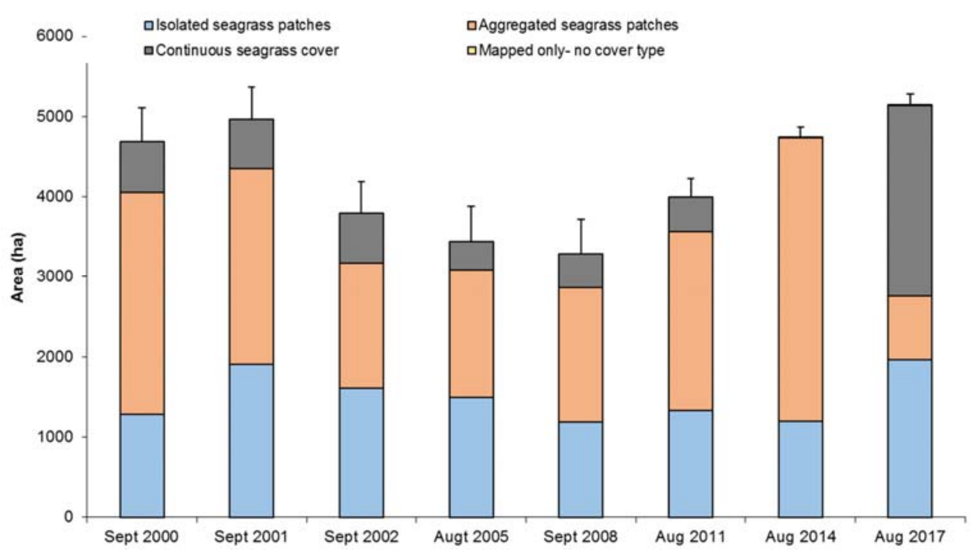

Figure 20. Total seagrass area (hectares) and the landscape cover within the Weipa port limits, 2000-2017. Error bars = "R" reliability estimate.

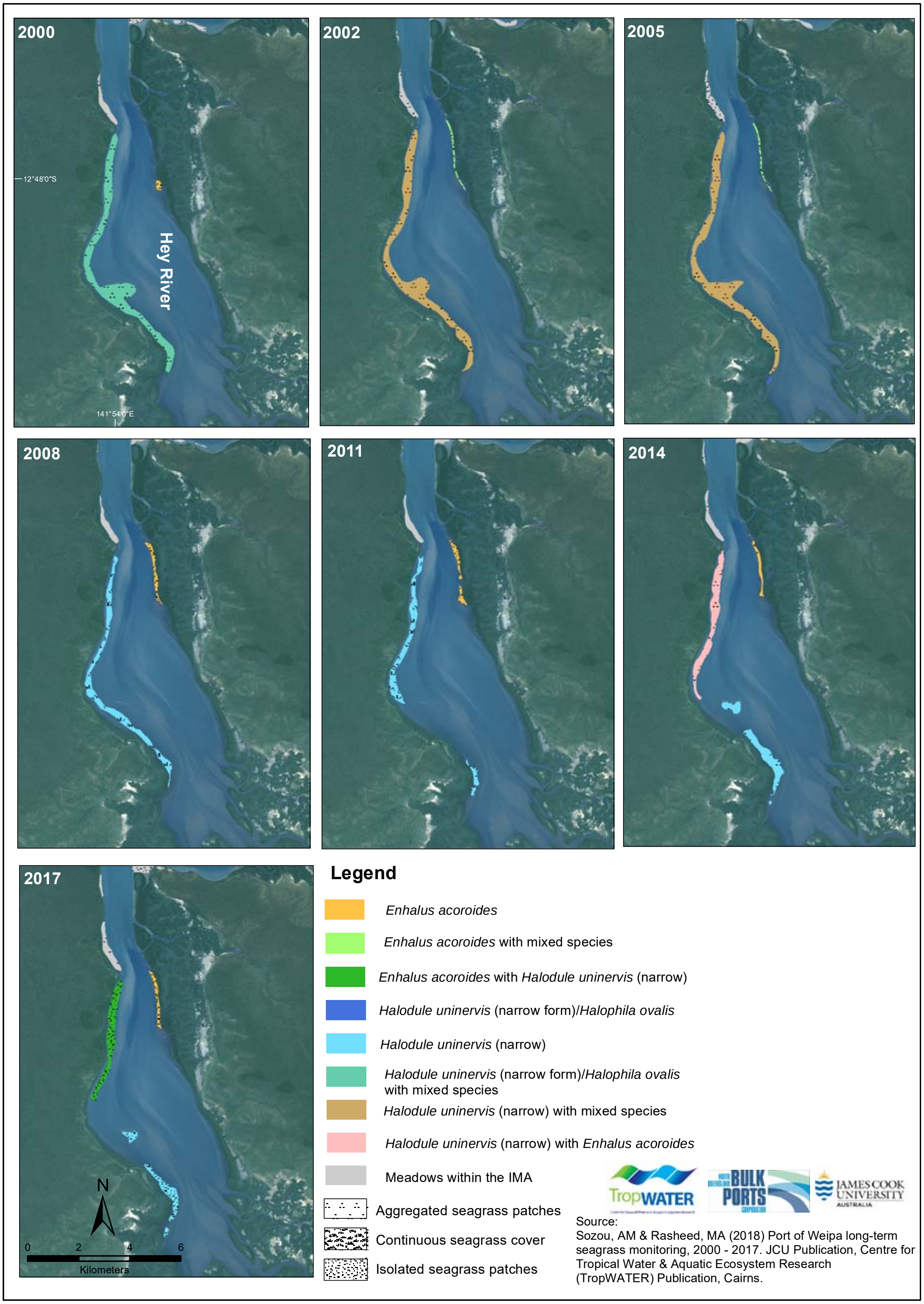

Figure 21. Community type for seagrass meadows in the Hey River, 2000-2017.

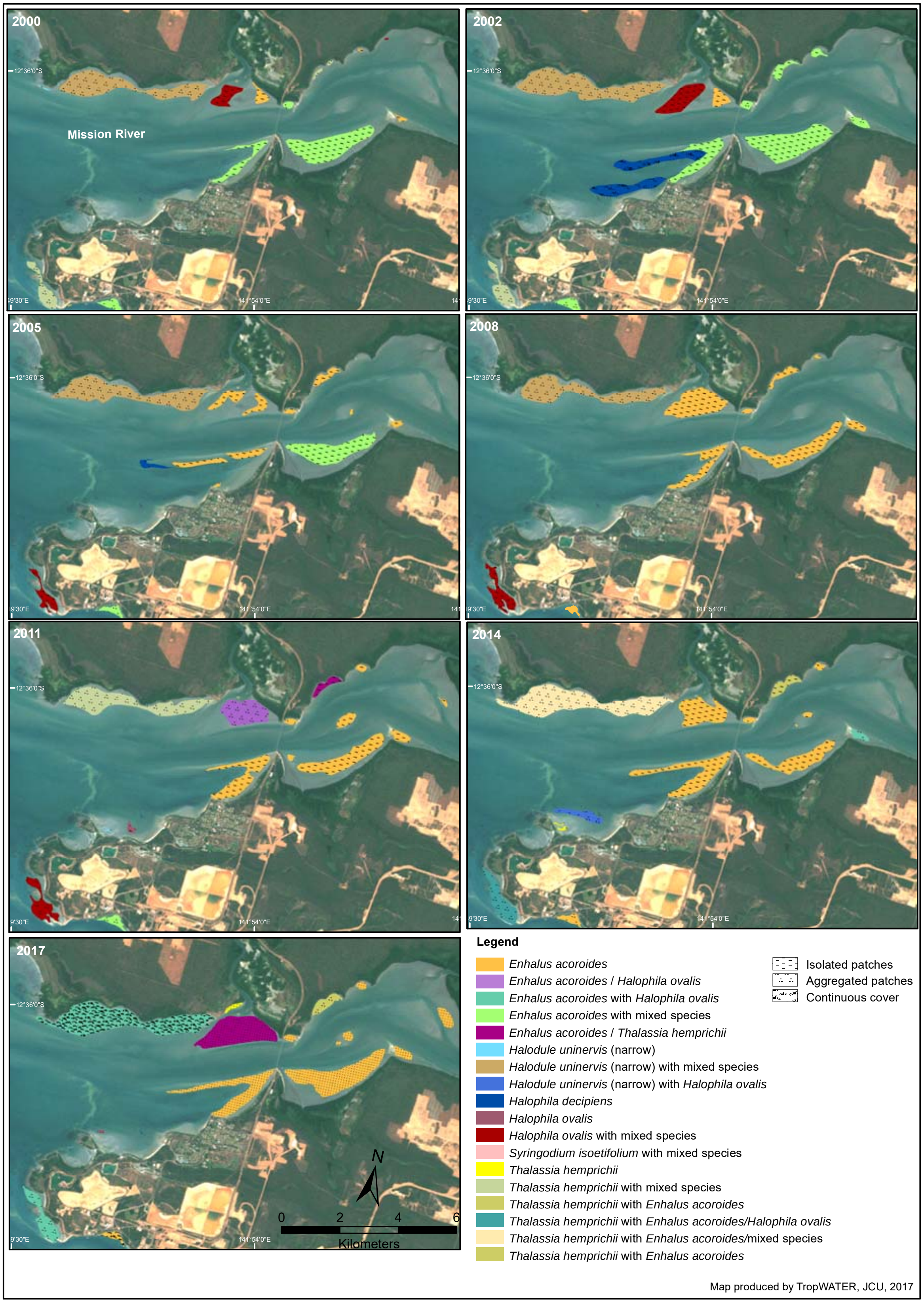

Figure 22. Community type for seagrass meadows in the Mission River, 2000-2017.

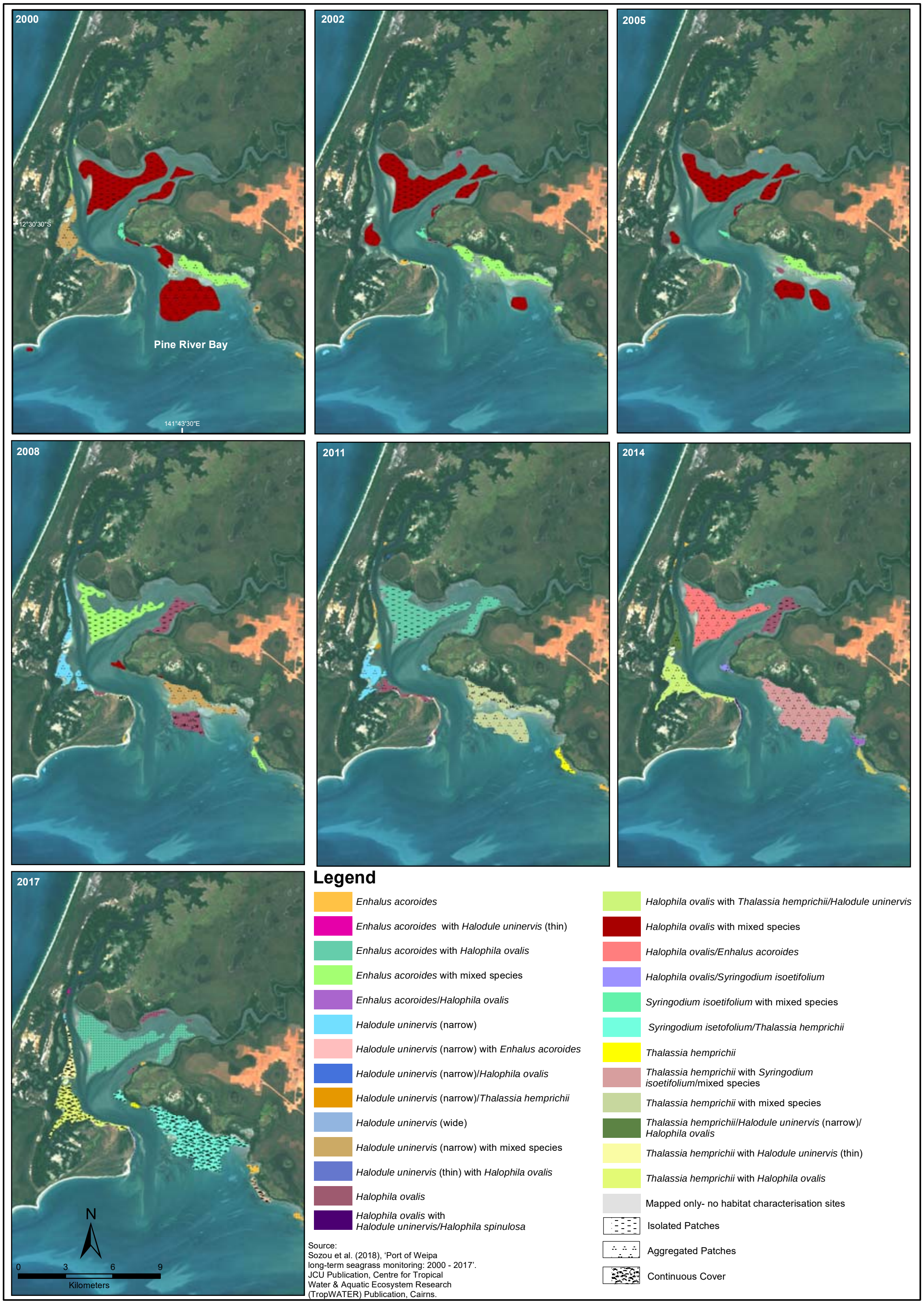

Figure 23. Community type for seagrass meadows in the Pine River Bay, 2000-2017.

3.2 Weipa climate data

3.2.1 Rainfall

Total annual rainfall in Weipa in the 12 months (2016/17) preceding the survey was 1603 mm and has been below the long-term average for the last three years (Figure 24a).Rainfall followed similar wet season trends in the area leading up to the annual survey, with January having the highest rainfall of 593 mm (Figure 24b). Between May and August 2017 only 7.6 mm of rainfall was recorded (Figure 24b).

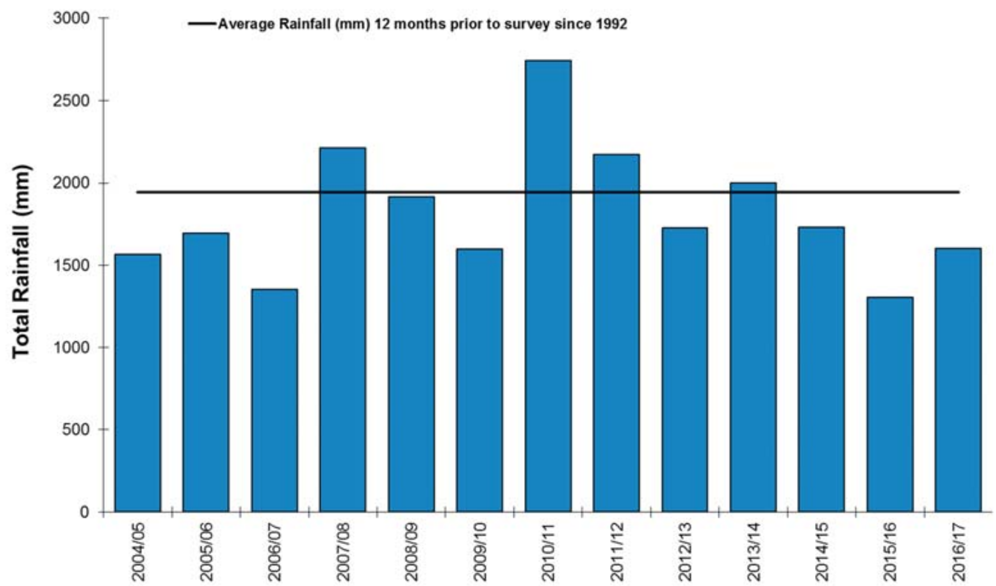

Figure 24a. Total annual rainfall recorded at Weipa Airport; 2004-2017. Twelve month year (2016/17) is twelve months prior to survey. Source: Bureau of Meteorology (BOM), Station 027045, available at www.bom.gov.au

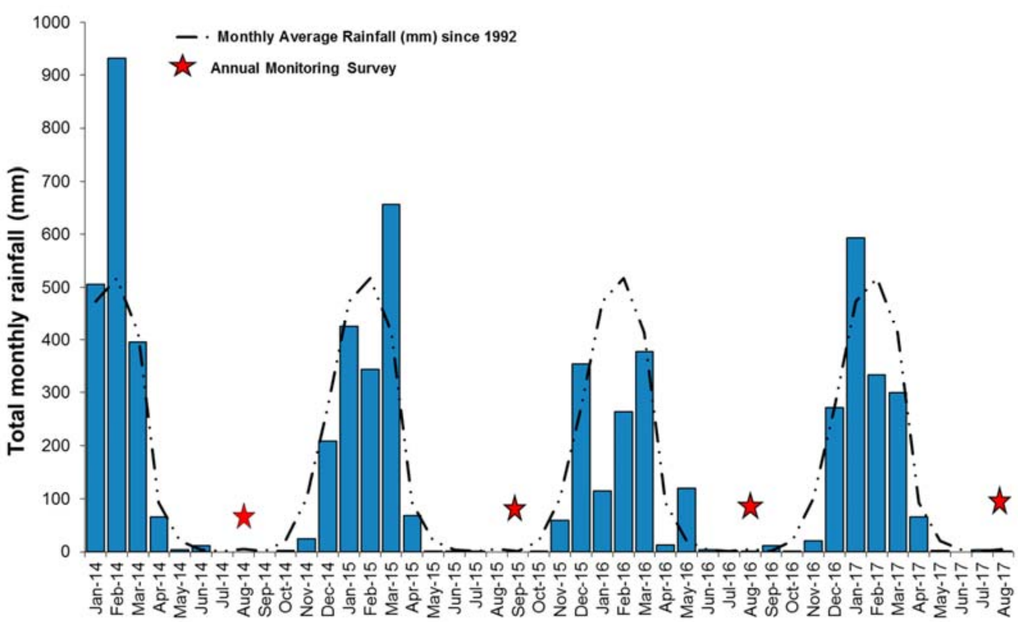

Figure 24b. Total monthly rainfall (mm) between January 2014 – August 2017. Source: Bureau of Meteorology (BOM), Station 027045, available at www.bom.gov.au

3.2.2 Daytime tidal exposure

The amount of tidal exposure to air during the day for intertidal meadows in Weipa in the 12 months prior to the monitoring survey (290 hours) was well below the long term average. Daytime tidal exposure has been below or on the long-term average since 2008/09 (Figure 25a). Intertidal seagrass meadows generally have had a greater amount of daytime exposure during the winter/dry season months and minimal to no exposure during the summer/wet season months (Figure 25b). In the critical times closer to the monitoring survey daytime tidal exposure one month and 3 months prior to the survey were also below the long-term average and the lowest since 2013 (Figure 25c).

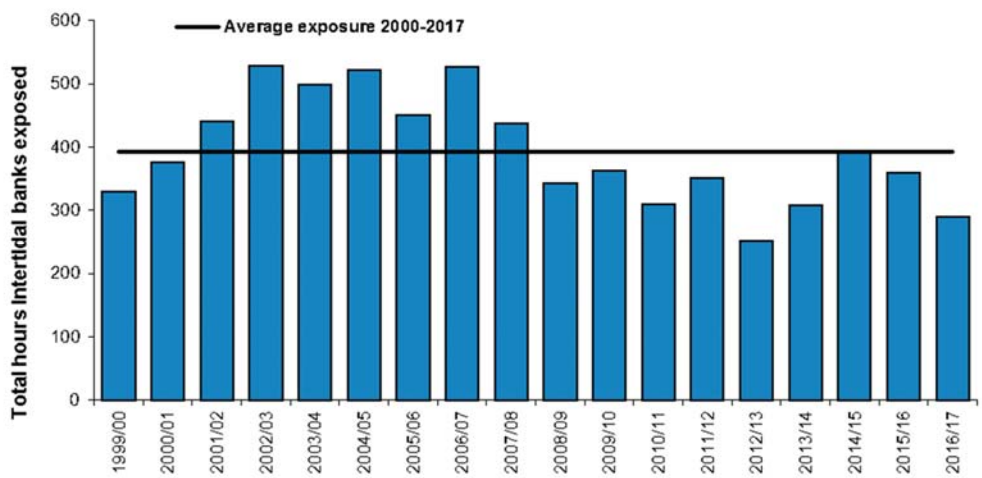

Figure 25a. 1999/00 -2016/17. Twelve month year is twelve months prior to survey. 2016 tidal data © State of Queensland (Department of Transport and Main Roads).

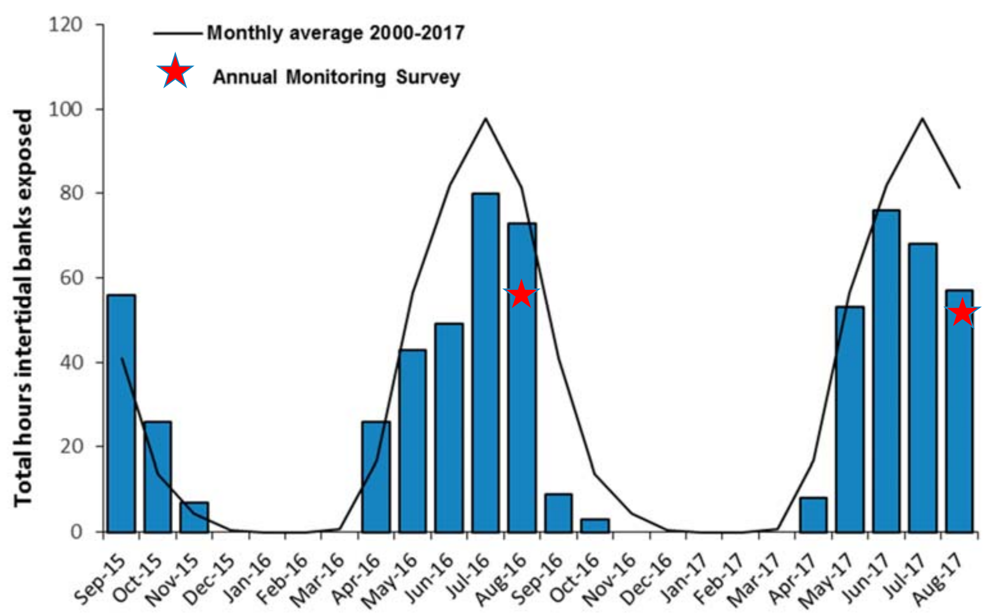

Figure 25b. Monthly total daytime tidal exposure (hours; ≤0.9m tidal height) in Weipa in the 12 months preceding the 2017 monitoring survey. 2016 tidal data © State of Queensland (Department of Transport and Main Roads).

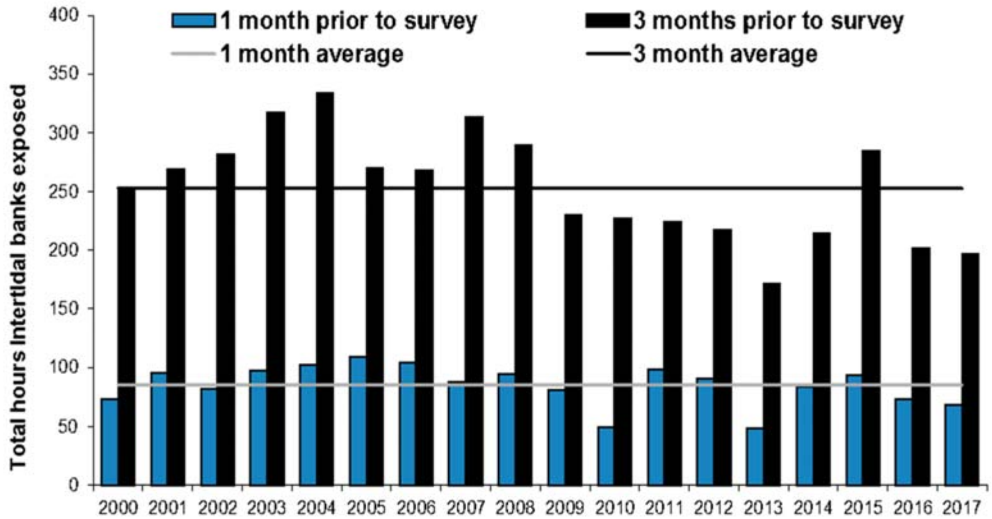

Figure 25c. Total daytime tidal exposure (hours; ≤0.9m tidal height) in Weipa in the 1 and 3 month preceding each monitoring survey; 2000-2017. 2016 tidal data © State of Queensland (Department of Transport and Main Roads).

3.2.3 Solar Radiation

Daily global exposure is a measure of the total amount of solar energy falling on a horizontal surface in one day. Values are generally highest in clear sun conditions during spring/summer and lowest during winter. Mean daily solar radiation (global solar exposure) has been around the long-term average for the past three years, with 2016/17 having the highest daily global exposure (21.425 MJm^{-2}) over the past four years (Figure 26).

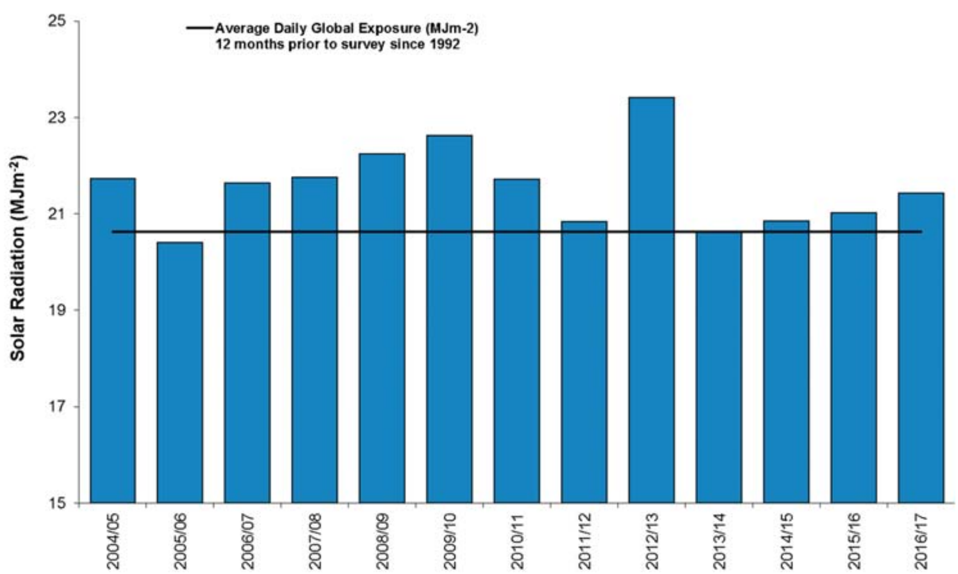

Figure 26. Average annual solar radiation (mJ m^{-2}) for the 12 months preceding each survey; 2004/05 – 2016/17. Source: Bureau of Meteorology (BOM), Station 027045, available at www.bom.gov.au

3.2.4 Benthic daily Photosynthetically active radiation (PAR (light)) and temperature

Total daily PAR is measured at two locations in the shallow intertidal meadow on the south-western bank of the Embley River (A2) and at one location in the deeper meadow between Evans Landing and Humbug Terminal (A7) (Figure 12). As expected overall PAR was less in the deeper A7 meadow than the shallower A2 meadow and in the twelve months prior to the seagrass survey PAR ranged from 0.44 to 35.93 mol photons m^{-2} day^{-1} in meadow A2, and from 0.16 to 13.16 mol photons m^{-2} day^{-1} in meadow A7 (Figure 27; Figure 28).

While no specific light requirement growth thresholds for *Enhalus 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). The longest ongoing period that PAR fell below the acute threshold (twelve months prior to survey) suggested in Collier et.al (2016) during 2017 was:

- 112 consecutive days in the deeper A7 seagrass meadow between November and April 2017 coinciding with wet season/high rainfall in the region and follows similar light trends to previous wet seasons (Figure 27; Figure 28).
- A total of 74 days falling below the threshold in the shallow intertidal A2 meadow, although maximum number of consecutive days was generally less than 14. These low light periods also coincided with wet season/high rainfall weather, between December 2016 and March 2017 (Figure 27; Figure 28).

It appears that wet season low light events are part of the normal cycle of light availability in Weipa and it seems *E. acoroides* is adapted to cope with this (see Discussion). However as noted in the previous year's monitoring report, in 2016, there were an additional 72 consecutive days below the nominal threshold in meadow A7 between June and August 2016 (McKenna et. al. 2017). 2016 has been the only year where extended low light conditions have occurred in the dry season which may be the critical time for *E. acoroides* to replenish energy stores following wet season low light conditions. In 2017 light at meadow A7 returned to a more typical pattern with extended low-light confined to the wet season months (Figure 27).

During 2017, an additional PAR logging site was established in meadow A6. Preliminary data from that site indicates the initial placement may be too far off the edge of the seagrass bank for meaningful light recordings, and may need to be relocated in 2018 further up the bank.

3.2.5 Water temperature

Mean daily water temperature in the A2 meadow was 28.9 °C (at both north and south sites) and 29.0 °C in meadow A7 in the twelve months prior to the survey (Figure 27). Maximum daily water temperature peaked at over 40 °C and was sustained for a least two consecutive days in the intertidal A2 meadow (Figure 27). In the subtidal/intertidal A7 meadow, the highest maximum temperature recorded in the twelve months prior to survey was 38.1 °C, with temperatures over 35 °C sustained also for two days. The overall water temperatures in 2017 at the seagrass meadows remained similar to the previous two years (Figure 27).

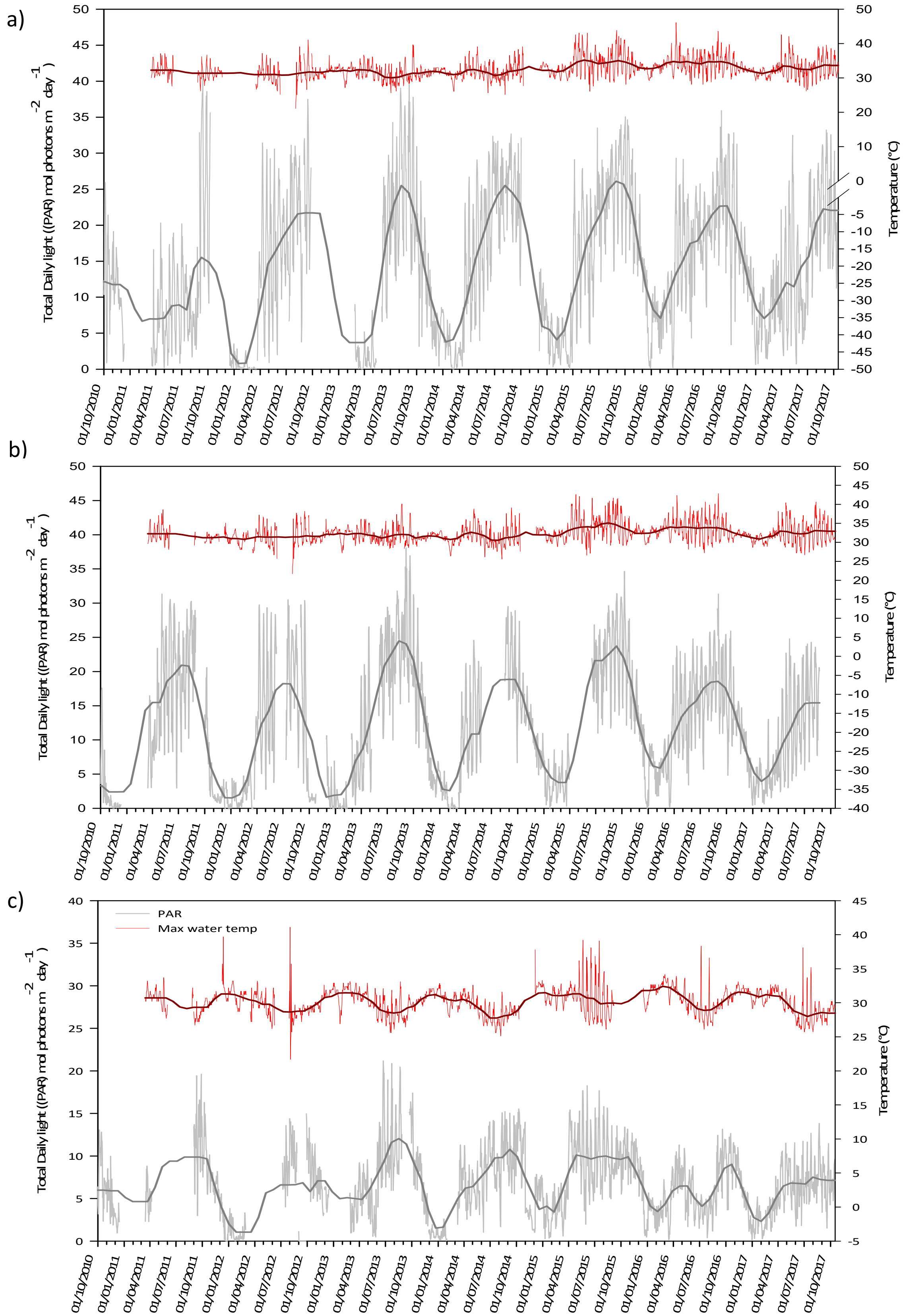

Figure 27. Daily photosynthetically active radiation (PAR mol photons m^{-2} day^{-1}) and mean and maximum daily water temperature (°C) at Weipa, 2010 – 2017, at meadow A2 (a & b) and meadow A7 (c).

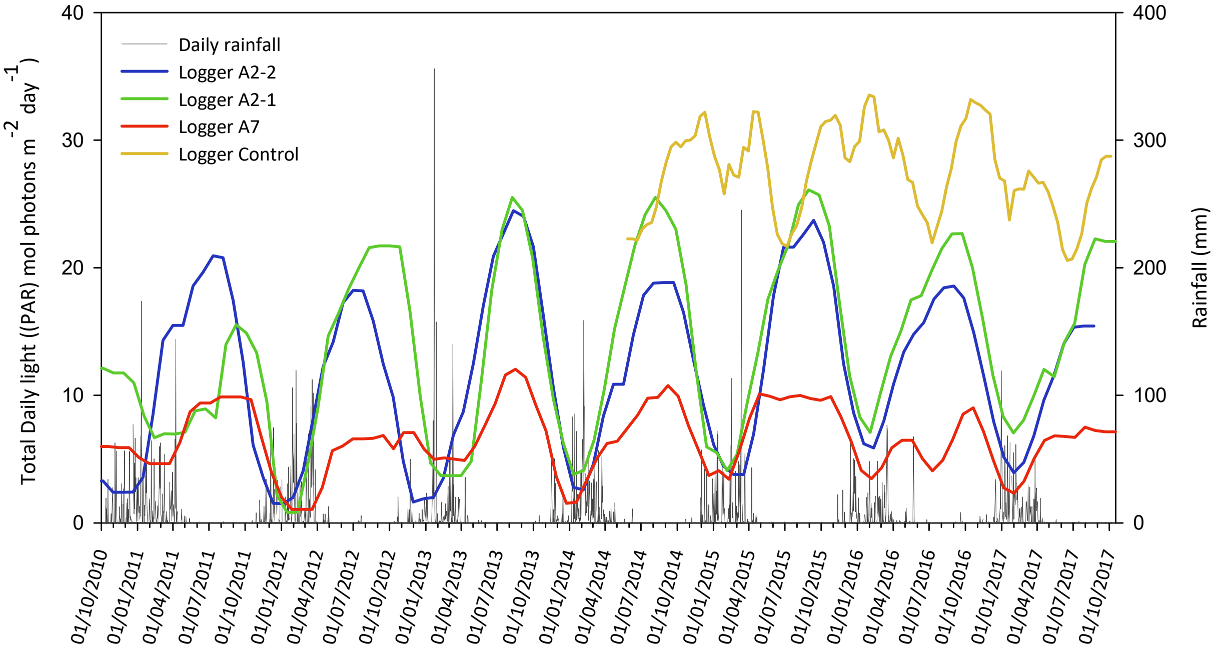

Figure 28. Daily photosynthetically active radiation (PAR; mol photons m-2 day-1) and total daily rainfall (mm) at Weipa, October 2010 – October 2017, at Meadow A7 and Meadow A2 northern (A2-1) and southern (A2-2).

3.3 Light (PAR) 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 2017, quarterly assessments were conducted in March, June, August and October 2017. Biomass at the monitoring sites ranged from 22.10 ± 1.43 g DW m^{-2} to 26.49 ± 1.70 g DW m^{-2} (Figure 29). Since quarterly biomass monitoring has been established there have been some variations in biomass, however there seems to be little impact from periods of natural wet season low light levels on *E. acoroides*. 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 29). During each wet season PAR reaches very low levels and fell below 5 mol m^{-2} day^{-1} for periods of up to 74 consecutive days between December and March. However, *E. acoroides* appears to have a good capacity to resist these wet season low light periods, with biomass recorded in the periods following these low light events being maintained at similar pre-wet season levels (Figure 29).

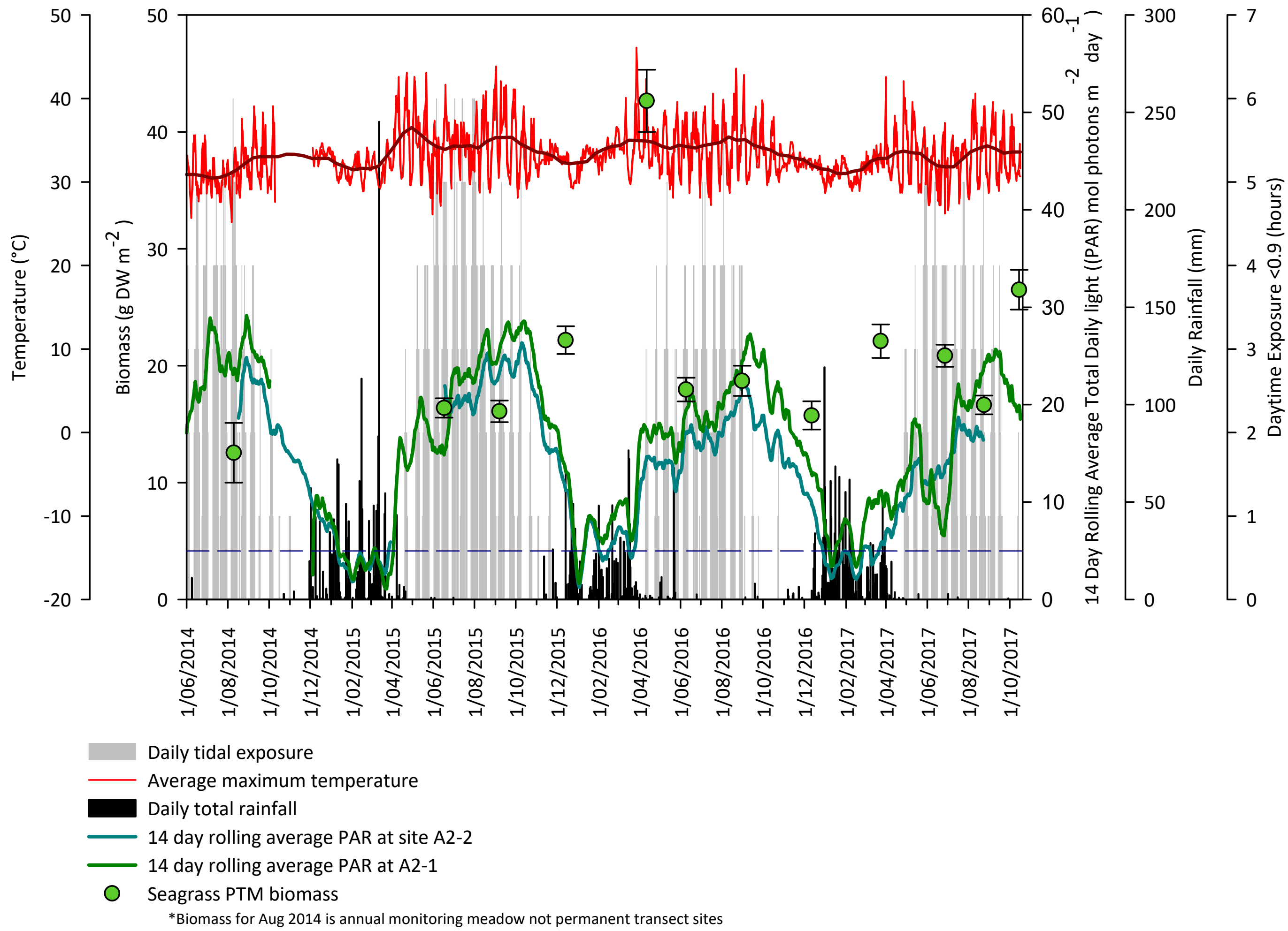

Figure 29. Total daily light 14 day rolling average (PAR; mol photons m^{-2} day^{-1}), seagrass biomass (g dw m^{-2}), maximum sea temperature within the seagrass canopy (◦C), total daily rainfall (mm) and total daily hours intertidal banks are exposed to air (hrs) in Weipa June 2014 – October 2017 in the A2 intertidal monitoring meadow.

4 DISCUSSION

Seagrasses in the Port of Weipa were in a good condition overall in 2017, with biomass and species composition rated good or very good for all monitoring meadows, and area of all but one monitoring meadow also rated as good or very good. In the broader port limits and the intensive monitoring area around the port, total area of seagrasses was one of the highest on record. In addition the meadows between Evans Landing and Lorim Point that had declined between 2015 and 2016 had also recovered. The good condition of Weipa's seagrasses in 2017 means they should remain resilient to planned maintenance dredging activities in 2018 assuming the duration of dredging remains relatively short and that there are no major seagrass losses associated with climate or other impacts leading up to the 2018 maintenance dredging campaign.

The seagrass meadows between Evans Landing and Lorim Point (Meadows A6 & A7) had recovered from localised declines recorded leading up to 2016 (McKenna et al. 2017), and both were classified as being in good condition in 2017. Additional interim monitoring of these meadows conducted in May and June 2017 showed improvements in seagrass had started to occur and by the annual monitoring in August 2017 seagrass had recovered. Light levels at the monitoring station within this region (meadow A7) during 2016 revealed an unusual period of low light in the dry season (McKenna et al 2017), which was the likely cause of the observed declines in seagrass area. This low light period was only recorded locally at this station with other light monitoring sites exhibiting more normal dry season light levels (McKenna et al 2017). In 2017 light at this site had returned to a more normal range and was once again consistent with trends observed at the other light monitoring stations in the port. These results suggest that the causes for the declines of seagrasses in these meadows were likely to be due to an acute or short term event rather than a chronic longer term pressure.

Light is one of the primary drivers of seagrass condition and resilience (Dennison et al. 1993; Collier et al. 2012; Petrou et al. 2013; Collier and Waycott 2014; Chartrand et al. 2017). The availability of light limits their spatial and temporal distribution, and light limitation can drive seagrass loss (Collier et al. 2012; Rasheed et al. 2014; Chartrand et al. 2017). While critically important, the knowledge of how much light different seagrass species require to maintain their growth and reproductive requirements and how this requirement varies seasonally is limited for many of the tropical species. This lack of specific knowledge extends to the dominant large growing species in Weipa, *Enhalus acoroides* (Collier et al. 2016).

To establish a better understanding of *E. acoroides* light requirements we have coupled more frequent (quarterly) monitoring of seagrass condition adjacent to light monitoring stations in Weipa. Results so far have found *E. acoroides* appears well adapted to cope with typical wet-season reductions in light. *E. acoroides* copes with several weeks and up to two and a half months of extremely low light levels during high rainfall and river flow events during the wet season months, with seagrass biomass remaining relatively stable. This suggests that natural periods of low light are not low enough or sustained long enough to considerably degrade *E. acoroides,* a persistent species that has a large storage of carbohydrate energy reserves in below ground structures (Kilminster et al. 2015). Presumably, during these seasonal low light periods *E. acoroides* is relying on these stored energy reserves. While apparently being able to resist extended periods of low light during the wet season, the losses of *E. acoroides* that occurred in 2015 and 2016 between Evans Landing and Lorim Point, when there were additional uncharacteristic localised reductions in light during the dry season, 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.

The climate in Weipa during 2017 was favourable for seagrass growth, with below average rainfall likely contributing to the light environment for seagrasses being above requirements for the majority of the year. The amount of time intertidal banks were exposed to air at low tide during the day, was also below the long term average and the lowest recorded in the last 4 years. These fluctuations occur as part of normal lunar cycles that affect the timing of low tides and have been found to be critically linked to intertidal *E. acoroides* condition in Weipa (Unsworth et al. 2012). Higher amounts of low tide air-exposure, particularly when coupled with high temperatures and low cloud cover, result in the appearance of "burnt" seagrass blades and their subsequent death due to exposure and desiccation stress. In 2017, whilst solar radiation and temperature were above average, the reduction in low tide exposure likely protected seagrasses from the extremes of thermal and desiccation stress.

The condition of seagrasses in the annually monitored section of the port was reflected more generally in seagrasses in the greater port limits region as well. This larger area, surveyed every 3 years, includes the Pine River Bay, Hey River and the tidal sections of the Mission and Embley Rivers outside the region of intensive port activity. In 2017 the greater port limits survey mapped the largest ever distribution of seagrasses, with an increase in the number of meadows that consisted of a continuous seagrass coverage compared with previous whole of port surveys. Of particular note was the substantial increases in both density and area of seagrasses in the Pine River Bay region. Meadows located at the mouth of the Bay had substantial increases in seagrass area as well as increases in meadow biomass, decreases in the level of meadow patchiness and an increase in larger growing species such as *Syringodium isoetofolium* and *Thalassia hemprichii* particularly on the western side of the Bay. The increased prevalence of larger growing species throughout the port limit area is good indication of favourable seagrass growing conditions. These larger growing species generally have higher requirements of light and resources than the smaller more ephemeral or opportunistic species.

The larger and denser seagrass areas in the Weipa region in recent years were likely to be of benefit to species relying on them for food and as habitat. In 2017 large areas of dugong feeding trails were observed in meadows in the Pine River Bay and Mission River. The denser seagrass meadows recorded in 2017 were also likely to be important as habitat for juvenile fish and prawn species, such as tiger prawns that rely on seagrass meadows for early parts of their life cycle in Weipa (Haywood et al 1995). Recent surveys of tiger prawns in the Albatross Bay area indicate higher than average numbers (Kenyon pers com) and although this may not be directly linked to the local Weipa seagrasses, it may reflect the generally good condition of seagrasses throughout the Gulf of Carpentaria in recent years (Shepherd et al. 2018; McKenna et al 2017).

The condition of seagrasses in Weipa reflects broader trends in other monitored locations in the Gulf of Carpentaria (Shepherd et al. 2018) and to the north in the Torres Strait (Sozou et al. 2017). In recent years seagrasses have been in well above average condition in Karumba to the south (Shepherd et al. 2018) and have remained in a generally good condition around Thursday Island to the north of Weipa (Sozou et al. 2017). Along the eastern coast of Queensland there has been 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. While many locations have experienced recovery since then, the trajectory of that recovery has varied between sites and at many locations in the southern two thirds of the Queensland east coast, seagrass remained in a poor condition in 2017 (Reason et al 2017; Wells & Rasheed 2017; York & Rasheed 2017) This variability in recovery generally reflected localised differences in environmental conditions with some places experiencing further storms and extreme weather events. In addition there was a range in the severity of the initial impacts with some areas having complete meadow loss whereas others had remnant seagrass that could more initiate recovery more rapidly.

The Weipa seagrass monitoring program has shown that in 2017 seagrasses were in a healthy and resilient condition and localised meadow declines were able to recover during the year. As an excellent overall integrator of water quality impacts (Dennison et al. 1993), seagrass condition also indicates that Weipa's marine environment was in a healthy condition in 2017.

5 APPENDICES

Appendix 1.

Baseline Calculations

Baseline conditions for seagrass biomass, meadow area and species composition were established from annual means calculated over the first 10 years of monitoring (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 (McKenna et. al 2016). 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. ununervis* 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).

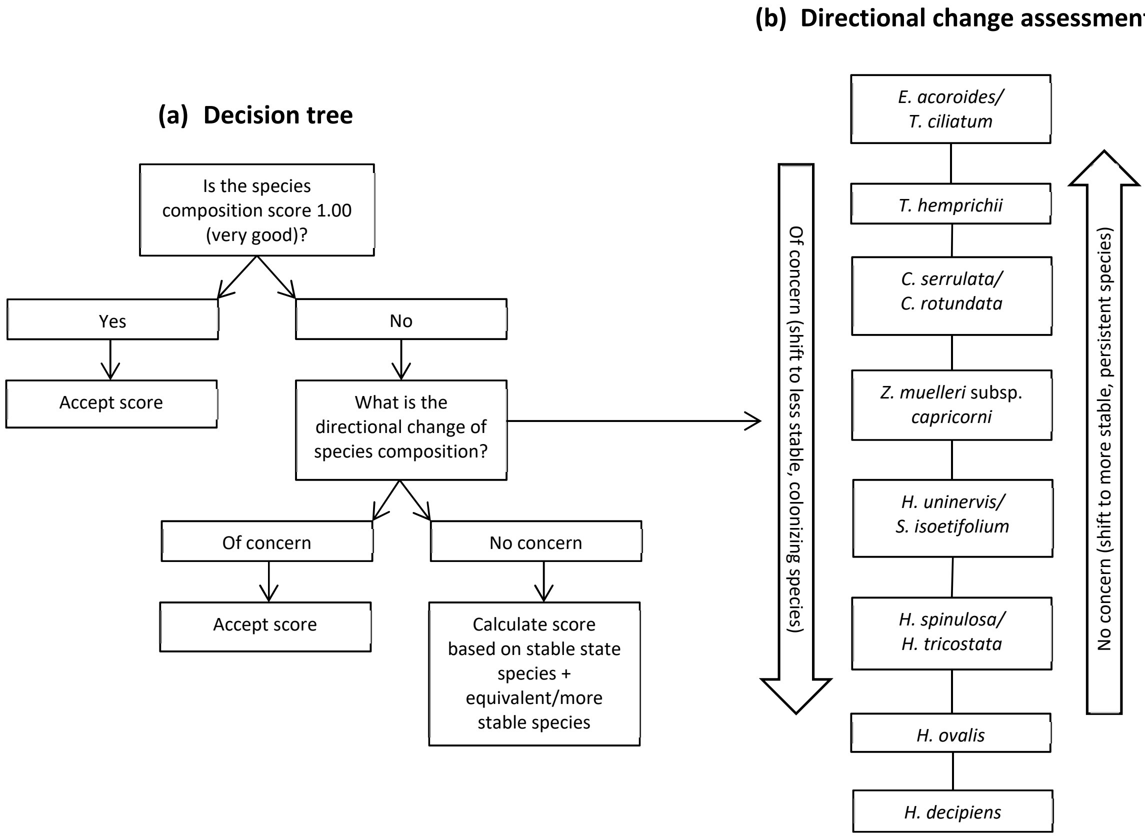

Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in the Port of Weipa.

Score Aggregation

Each overall meadow grade/score was defined as the lowest grade/score of the three condition indicators within that meadow. The lowest score, rather than the mean of the three indicator scores, was applied in recognition that a poor grade for any one of the three described a seagrass meadow in poor condition. Maintenance of each of these three fundamental characteristics of a seagrass meadow is required to describe a healthy meadow. This method allowed the most conservative estimate of meadow condition to be made (Bryant et al., 2014).

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.

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. Species composition of monitoring meadows in the Port of Weipa; 2000 – 2017.

Appendix 4a.

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 – 2017.

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**
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)
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)
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)
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)
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)

Appendix 4b.

Total meadow area ± R (ha) for each core monitoring meadow within the Port of Weipa, 2000 – 2017.

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
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
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
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
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
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
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**

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