Centre for Tropical Water and Aquatic Ecosystem Research

PORT OF WEIPA LONG-TERM SEAGRASS MONITORING PROGRAM: 2000 - 2016

McKenna SA, Carter AB, Sozou, AM & Rasheed MA

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KEY FINDINGS

Seagrass Condition 2016

Likely causes of seagrass condition:
Localised changes to meadows near new infrastructure:

↑ infrastructure & dredging at Evans Landing and Humbug Terminal between 2015 and 2016

↓ available light in to proximal subtidal meadows

- Seagrasses in the Port of Weipa were in an overall satisfactory condition in 2016.
- Biomass, species composition and area for the majority of meadows in the intensive monitoring area (IMA) were near or above long-term averages.
- The exception were substantial loses in area of the two meadows between Lorim Point and Evans Landing.
- Declines were likely the result of localised unfavourable light conditions in the months preceding the 2016 survey for these meadows. Light recorded elsewhere in the IMA remained favourable for seagrasses.
- Between 2015 and 2016 there were a range of activities identified that had the potential to influence the light environment for the affected meadows.
- In response to potentially reduced resilience of the affected meadows, additional monitoring was undertaken in May and June 2017, either side of annual maintenance dredging. This monitoring allowed closer management of activities to occur if required and an update on the assessment of condition of these meadows. The assessments found recovery of some of the lost seagrass area had occurred since the 2016 annual survey and indicated that the losses that were recorded were temporary, with seagrasses sufficiently resilient to recover.
- Dugong feeding activity was evident within the Port with feeding trails throughout the large *Halodule uninervis* monitoring meadow.

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 (last conducted in 2014).

Seagrasses in the Port of Weipa were in a satisfactory condition in 2016, with biomass, area and species composition of most meadows in the IMA near or above the long-term averages. The exception was the substantial decrease in area in the two subtidal-intertidal *E. acoroides* meadows closest to port operations (A6 & A7) which led to the overall decrease in Weipa seagrass condition from good in 2015 to satisfactory in 2016 (Figure 1). 2016 was the third consecutive year these meadows had a declining condition. Elsewhere in the IMA seagrass meadow area had expanded resulting in the total area of all seagrasses within the IMA being relatively stable over the past decade (Figure 2).

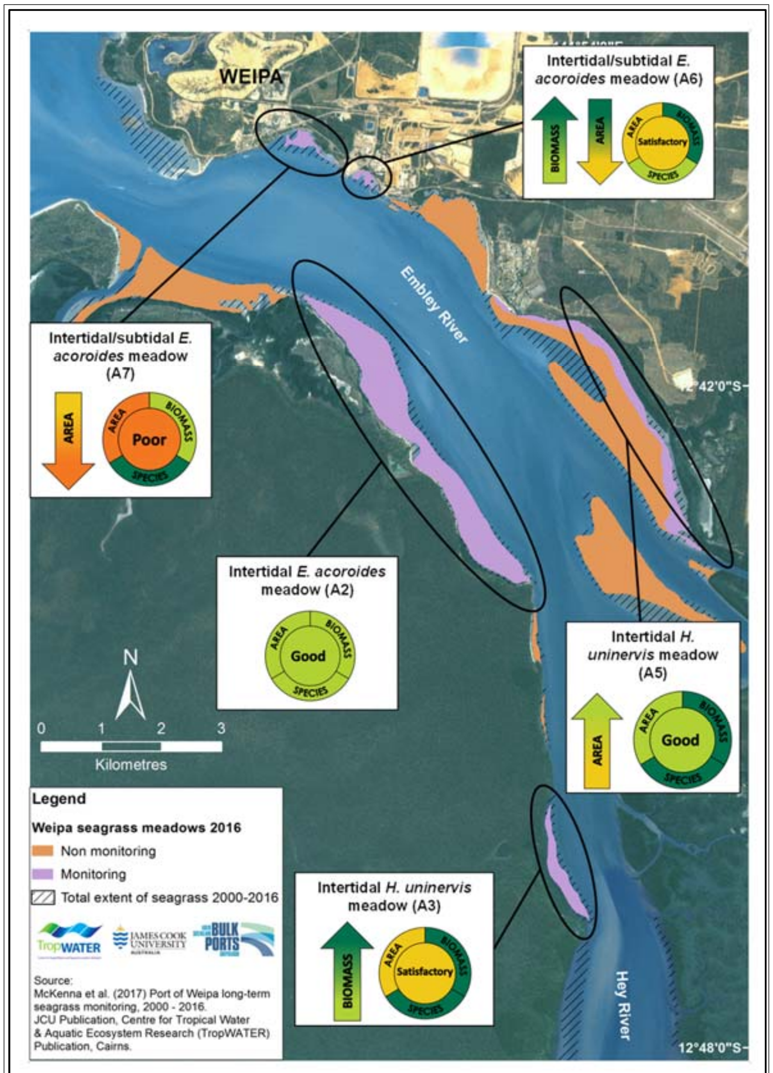


Figure 1. Seagrass meadow condition in the Port of Weipa 2016.

It is likely that the reason for the decline of meadows A6 and A7 was due to a localised lack of light during 2016. The light monitoring station in meadow A7 recorded substantial periods of time between December 2015 and August 2016 with light below the requirements for growth of *E. acoroides,* the dominant seagrass species. This effect appeared to be confined to this area of the port with light recorded at other locations maintained above requirements, and seagrass in these areas maintained in above average condition.

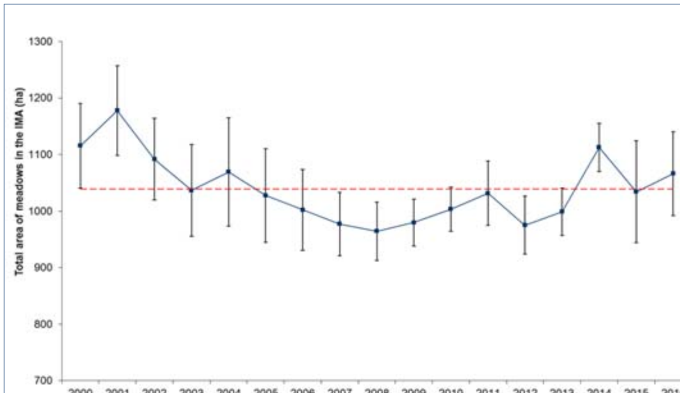


Figure 2. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2016. (error bars = "R" reliability estimate). Red dashed line indicates 17-year mean of total meadow area.

In general overall climate conditions in Weipa were favourable for seagrass growth between

2015 and 2016 with below average tidal exposure, below average rainfall and average solar exposure leading to an environment where seagrasses tend to thrive (Figure 3). This combined with the favourable light at other monitoring stations means that the reduction in light measured near the declining meadows was unlikely to be due to broader climatic issues and point rather to a localised cause. The reduced light occurred in an area where there where a range of activities between 2015 and 2016 that could potentially have contributed to a short term reduction in the local light environment through an increase in suspended sediment in the water column. These included:

- Relocation of the Evans Landing community boat ramp
- Development of the Humbug Terminal and barge landing associated with the Amrun Project
- Temporary issues with sewerage treatment discharge adjacent to the meadows.
- Localised increase in vessel traffic associated with facility development and relocations.

Despite the declines in area of these two meadows, substantial seagrass still remained with biomass and species composition remaining in a good condition and likely to provide an ability for the meadows to recover as more favourable light conditions occur.

In order to assess the continuing resilience of these seagrasses, additional seagrass assessments and light monitoring stations were commissioned during 2017 to monitor recovery and inform potential management actions should there be any further deterioration. Results of these surveys in May and June 2017 will be reported on as part of the next annual monitoring report, but initial results found that seagrasses had been able to recover some of the area that was lost and indicated that the changes observed in 2016 were temporary with seagrasses able to recover.

The longer term persistence of seagrass in Weipa captured in this monitoring program is an indication of the resilience seagrasses have to periodic low light, tidal exposure and 'typical' port activities such as maintenance dredging.

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/portseagrassqld).

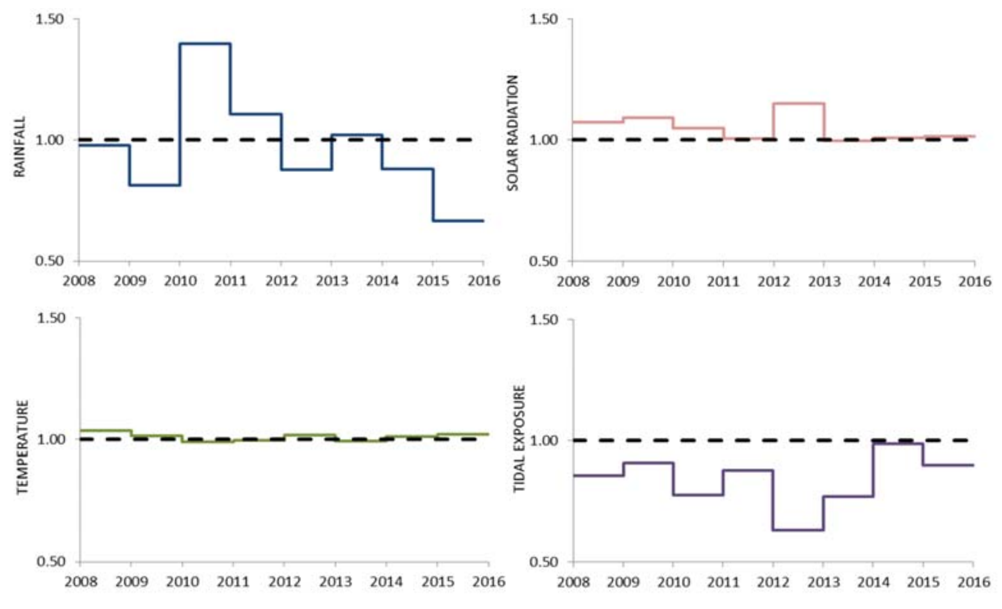


Figure 3. Recent climate trends in Weipa: Change in climate variables as a proportion of the long-term average from 2009/10 to 2015/16. (See section 3.5 for detailed climate data).

TABLE OF CONTENTS

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 2016 the annual maintenance dredge campaign commenced on June 24th and was completed in 25 days, with 516,239m^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), 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 13). 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 13). 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. Preliminary results are presented in this report for the first time.

This report presents the results of the long term seagrass monitoring assessments conducted at the end of August 2016. 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 of seagrass meadows within the IMA;
3. Assess changes in seagrass meadows with previous monitoring surveys;
4. Assess light and temperature conditions within seagrass meadows;
5. Incorporate the results into the Geographic Information System (GIS) database for the Port of Weipa.

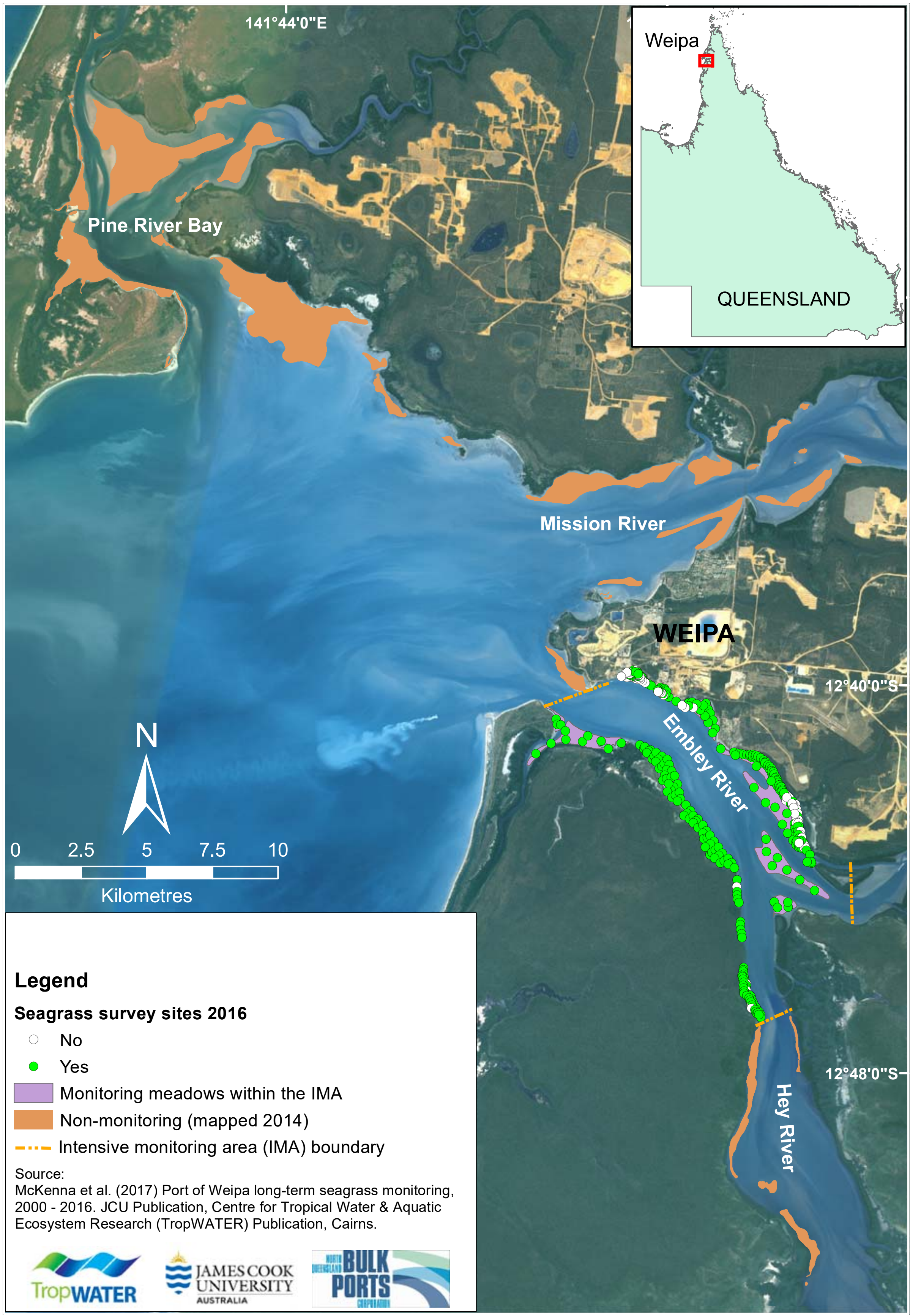


Figure 5. Location of 2016 seagrass survey sites and seagrass meadows in the Port of Weipa.

2 METHODS

2.1 Annual monitoring within the Intensive Monitoring Area

Annual seagrass monitoring within the Port of Weipa was conducted August 29th – 31st 2016. 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.

Two levels of sampling were used in the August 2016 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).

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 2016 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

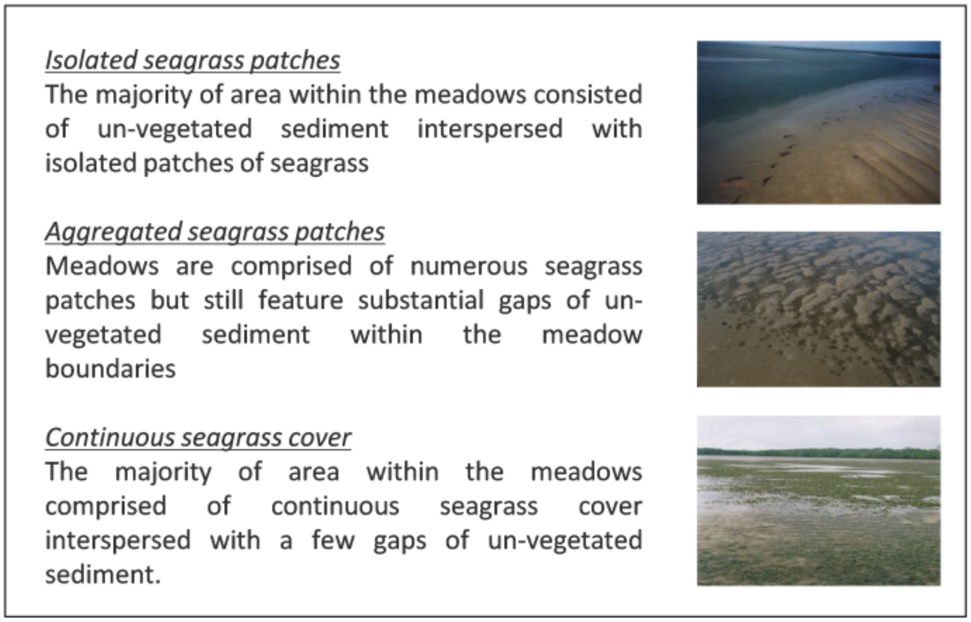


Figure 7. Landscape categories for seagrass meadows in Queensland

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 2016.

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.

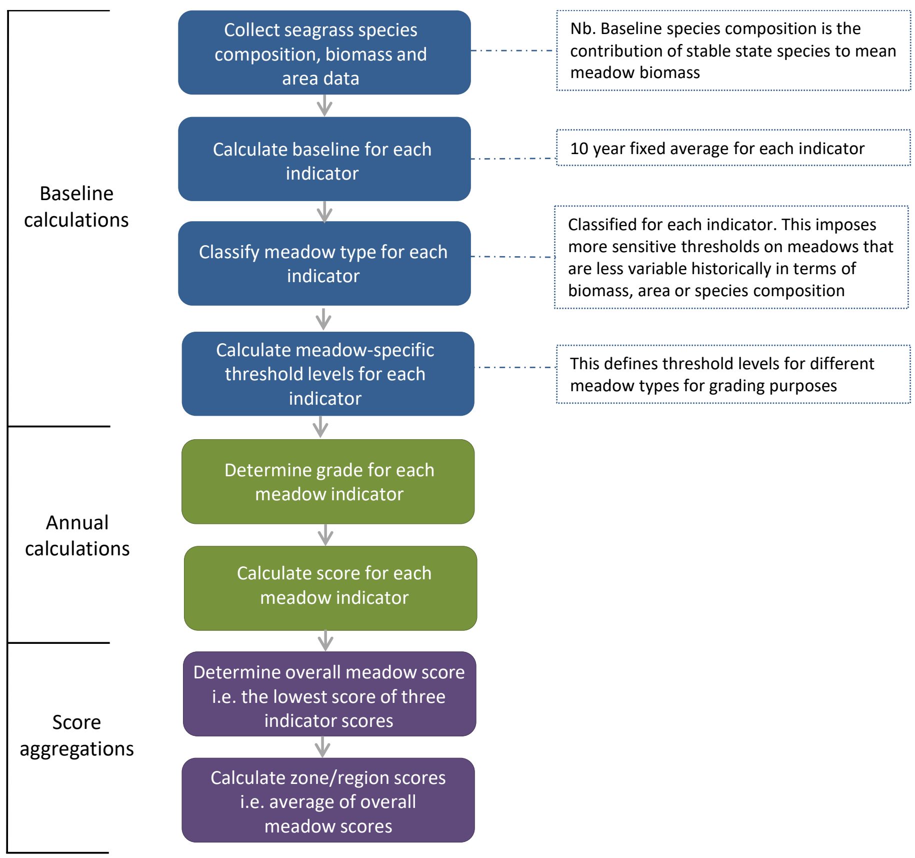


Figure 8. Flow chart to assess seagrass monitoring meadow condition.

2.3.1 Baseline Conditions

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 2000–2009 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). In 2016 an additional rule was applied: 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 Section 2.3.4 and Figure 9).

2.3.2 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, area and species composition was classified as either stable or variable (Table 4). One further classification for meadow area was added in the 2016 reporting year: highly stable (Table 4). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each condition indicator.

Table 4. 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	-	CV < 40%	CV ≥ 40%	-
Area	< 10%	CV ≥ 10, < 40%	CV ≥ 40, <80%	CV ≥ 80%
Species composition	-	CV < 40%	CV ≥ 40%	-

2.3.3 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 5).

Table 5. 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		

2.3.4 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 6; see 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 (described in Section 2.3), allocating a grade for each indicator by comparing 2016 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 6). 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 1.

Table 6. Score range and grading colours used in the 2016 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 9). 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 9). 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 9).

The decision tree used in 2016 expands on the 2015 model and provides a more thorough assessment of species composition condition. Specific changes include the separation and positioning of *Z. muelleri* subsp. *capricorni* above *H. uninervis* (grouped as equivalent species in 2015), the separation and positioning of *H. spinulosa* above *H. ovalis* (also grouped as equivalent species in 2015), and triggering the directional change assessment if the species composition score was <1.00 (the trigger was based on a grade less than very good in 2015, meaning no score adjustment occurred in the highest grade even if more persistent species present could have improved the score).

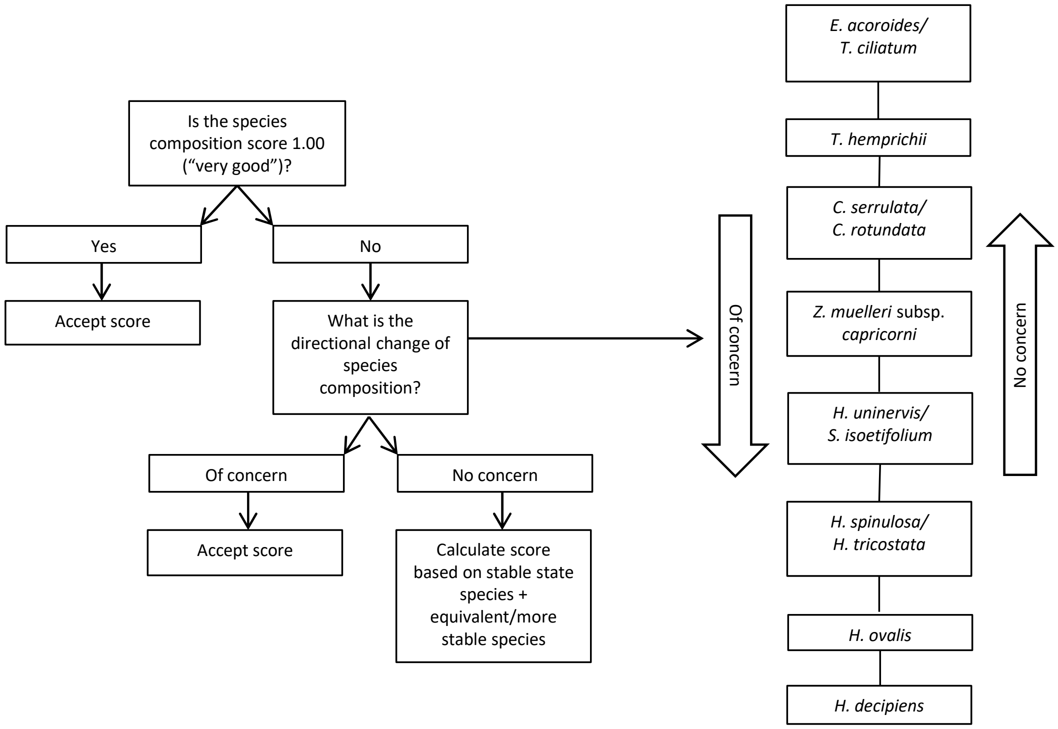


Figure 9. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in the Port of Weipa.

2.3.5 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 (Figure 8; Table 6). Where multiple meadows were present within the port, meadows were not subjected to a weighting system at this stage of the analysis. The classification process (outlined in Section 2.3.2) at the meadow analysis stage 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.

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 13) since September 2010 using custom built benthic data logging stations (Figure 10). 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 10. Logging station consisting of a stainless steel frame, PAR loggers, electronic wiper unit and temperature loggers.

2.5 Environmental parameters and intertidal seagrass change

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 13). The aim of conducting seagrass assessments coupled with collecting light and temperature data is to produce local biologically relevant light requirement values for the dominant seagrass species in the Weipa area; *E. acoroides*. Preliminary results are presented in this report for the first time.

Two permanent transect sites were established in June 2015 at each logging station in the A2 meadow; one site at the northern logging station (A2-1a) and one site and the southern logging station (A2-1c) (Figure 13). In June 2016 a second permanent transect site was established at the northern logging station (A2-1b) (three permanent transect sites in the A2 meadow in total). The reason behind establishing the third permanent transect site was that the species composition at A2-1a had changed significantly enough that *E. acoroides* was no longer the dominant species in this part of the meadow. The second site at A2-1 (A2-1b) better captured the dominant species in the area.

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.

Sampling methods for the program was adapted Seagrass-Watch methodology. 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. In addition to the Seagrass-Watch standard methodology, seagrass above-ground biomass was determined using a "visual estimates of biomass" technique as described previously (See section 2.1).

3 RESULTS

3.1 Seagrass species in the Port of Weipa

A total of 371 seagrass habitat characterisation sites were surveyed in the Weipa IMA area in 2016, with seagrass present in 81% of sites (Figure 5). Five seagrass species (from two families) were identified. *Halophila decipiens* was not present in survey sites in 2016. A full list of species present in the broader Weipa area is available in previous reports.

Table 7. Seagrass species present in the Port of Weipa 2016.

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
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 2016 within the Intensive Monitoring Area (IMA) (Figure 13). The total combined seagrass meadow area was 1066 ± 74 ha, a slight increase in area from 2015 (Figure 11). Individual meadow area within the IMA ranged from 2.5 ha to 253 ha.

E. acoroides dominated seagrass communities in eleven of the fourteen meadows within the IMA, including the core monitoring meadows A2, A6 and A7 (Figure 13; Appendix 2). *Halodule uninervis* was the dominant species in monitoring meadow A5 on the eastern side of the Embley River, and meadow A3 on the western bank of the Hey River. *Thalassia hemprichii* was the dominant species in the small meadow to the north west of meadow A1. This meadow was dominated by *E. acoroides* in 2015.

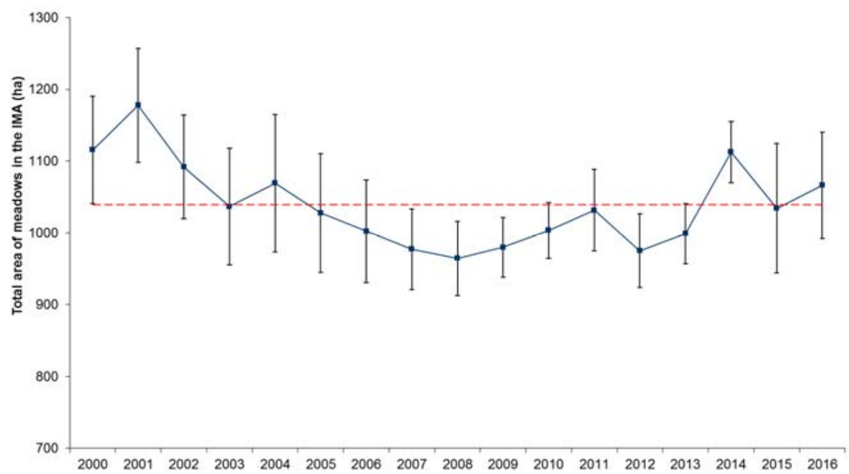


Figure 11. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2016 (error bars = "R" reliability estimate). Red dashed line indicates 15-year mean of total meadow area.

The condition known as burning, i.e. the browning and subsequent death of seagrass blades (Figure 12a), was observed at 32% of sites, across all meadows within the IMA in 2016; an increase from 2015 and the highest percentage since 2010 when these observations were first recorded (Figure 12a).

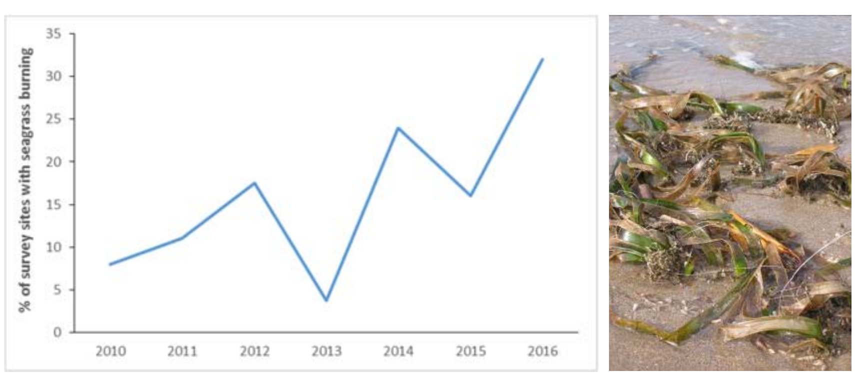


Figure 12a. Percentage of sites within the IMA that have evidence of *Enhalus acoroides* burning in the Weipa IMA meadows.

Dugong feeding trails were observed in three meadows within the IMA in 2016; A3, A5 and the large meadow between Lorim Point and Napranum (Figure 12b & 13). Prior to 2014, dugong feeding trails had not been observed in these meadows. This is the second year in a row that there has been an increased presence of dugong feeding trails in the IMA.

Figure 12b. Examples of in the A5 Weipa monitoring meadow.

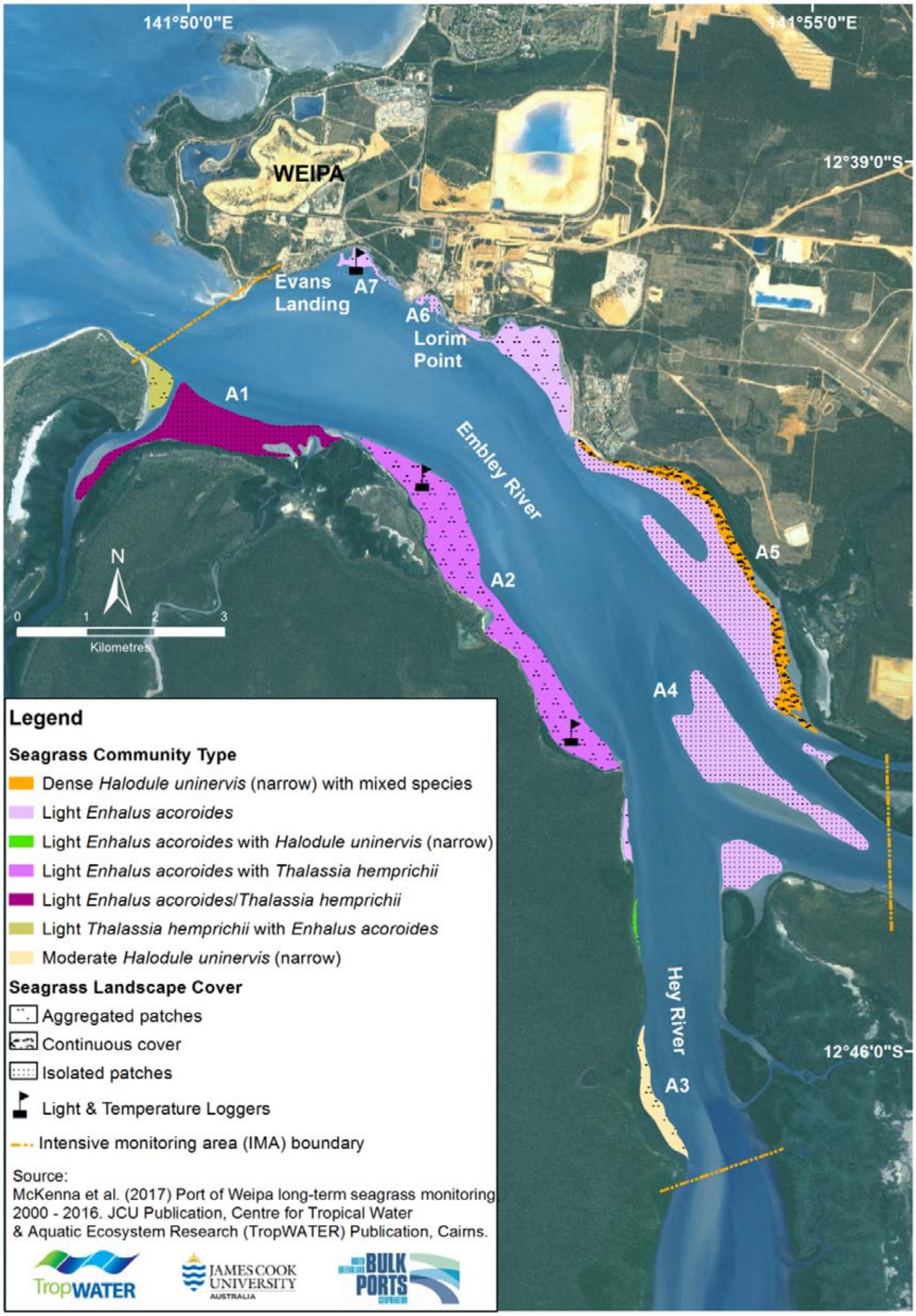


Figure 13. Meadow type and landscape cover for seagrass within the Intensive Monitoring Area 2016.

3.1.2 Seagrass condition in the core annual monitoring meadows

The overall condition of seagrasses in Weipa in 2016 was classed as satisfactory (Table 8). For all of the core meadows biomass and species composition were in either very good or good condition (Figures 14-18; Table 8). The reduced area of the two meadows closest to Port operations (A6 and A7) was responsible for the overall condition score in Weipa decreasing from good in 2015 to satisfactory in 2016. For individual meadows, two were classed as good (A2 and A5); two were satisfactory (A3 and A6); and A7 was classed as poor (Table 8; Figures 14-18).

Seagrass biomass was near or above the long term average for all monitoring meadows. There was no evidence of substantial shifts in species composition towards colonising species that would cause concern for any of the monitoring meadows (Figures 14-18).

The declines in area for the subtidal-intertidal A7 meadow (between Evans Landing and Humbug Terminal) were first noted between 2014 and 2015. Since the 2015 report, this meadow, as well as the neighbouring meadow; A6 (between Humbug Wharf and the main loading facilities at Lorim Point), underwent further considerable declines in area, downgrading their condition to satisfactory (A6 – 38% decline in area) and poor (A7 – 28% decline in area) (Figures 17 & 18; Table 8). This resulted in 2016 documenting the lowest area recorded for these meadows since 2007/2008.

The decline in area of meadow A7 first occurred (2014-2015) at the deeper edges and at the Evans Landing end of the meadow; towards what is now the relocated community boat ramp. Between 2015 and 2016 further declines occurred at the boat ramp end of the meadow, the deeper edges of the meadow and at the opposite end of the meadow closest to Humbug Terminal. The majority of this seagrass loss has occurred outside the area approved for direct seagrass disturbance associated with the Amrun Humbug Ferry Terminal development (Figure 18).

The other *E. acoroides* dominated monitoring meadow (A2) on the opposite bank of the Embley River remained in a good condition between 2015 and 2016 (Figure 14; Table 8). Biomass across this meadow has varied spatially through time and in 2016 had become patchier compared with 2015, with hotspots of higher biomass toward the northern end of the meadow (Figure 19). Mean above-ground biomass in this meadow has ranged from 4.65 ± 0.63 g DW m^{-2} (2008) to 33.63 ± 5.82 g DW m^{-2} (2000) (Figure 14; Appendix 2a). Area of this meadow remained relatively stable, with meadow area in 2016 similar to the long-term average (Figure 14).

Biomass in the intertidal *H. uninervis* dominated meadows (A3 and A5) has been in 'very good' or 'good' condition since 2008/2009 (Figures 15 and 16). The A3 meadow in the Hey River was in satisfactory condition in 2016, similar to 2015 (Figure 15). The A5 meadow in the Embley River improved from satisfactory to good, due to an increase in area (Figure 16). This reversed the declining trend in area for the meadow that had occurred over the previous four years (2012-2015) (Figure 16).

The majority of seagrass monitoring meadows in Weipa had a light density of seagrass cover for their community type (Table 2), with only one of the meadows; meadow A5 consisting of a dense cover of *H. uninervis*. The landscape cover for this meadow continued to increase from isolated patches in 2014, aggregated patches in 2015, and to continuous cover in 2016 indicating a more consistent spread of *H. uninervis* throughout the meadow.

Table 8. Grades and scores for seagrass indicators (biomass, area and species composition) for the Port of Weipa.

Meadow	Biomass	Area	Species Composition	Overall Meadow Score
A2	0.68	0.81	0.70	0.68
A3	0.89	0.64	0.93	0.64
A5	0.94	0.69	0.94	0.69
A6	0.85	0.52	0.81	0.52
A7	0.74	0.41	0.88	0.41
Overall Score for the Port of Weipa				**0.59**

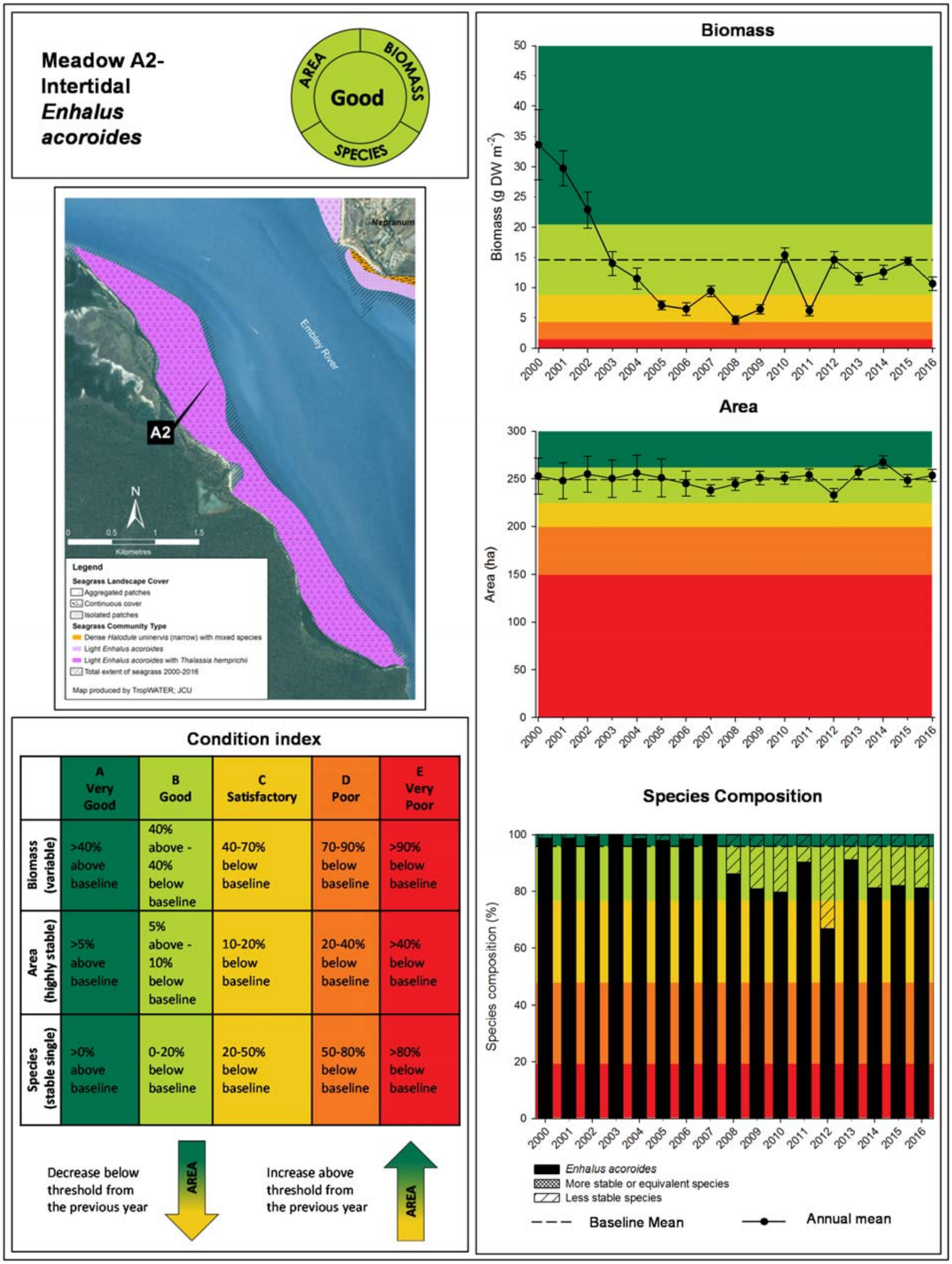
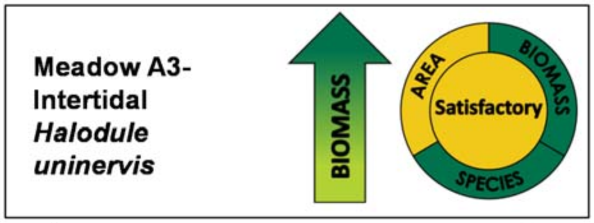


Figure 14. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A2 in Weipa from 2000 to 2016 (biomass error bars = SE; area error bars "R").



Condition index

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

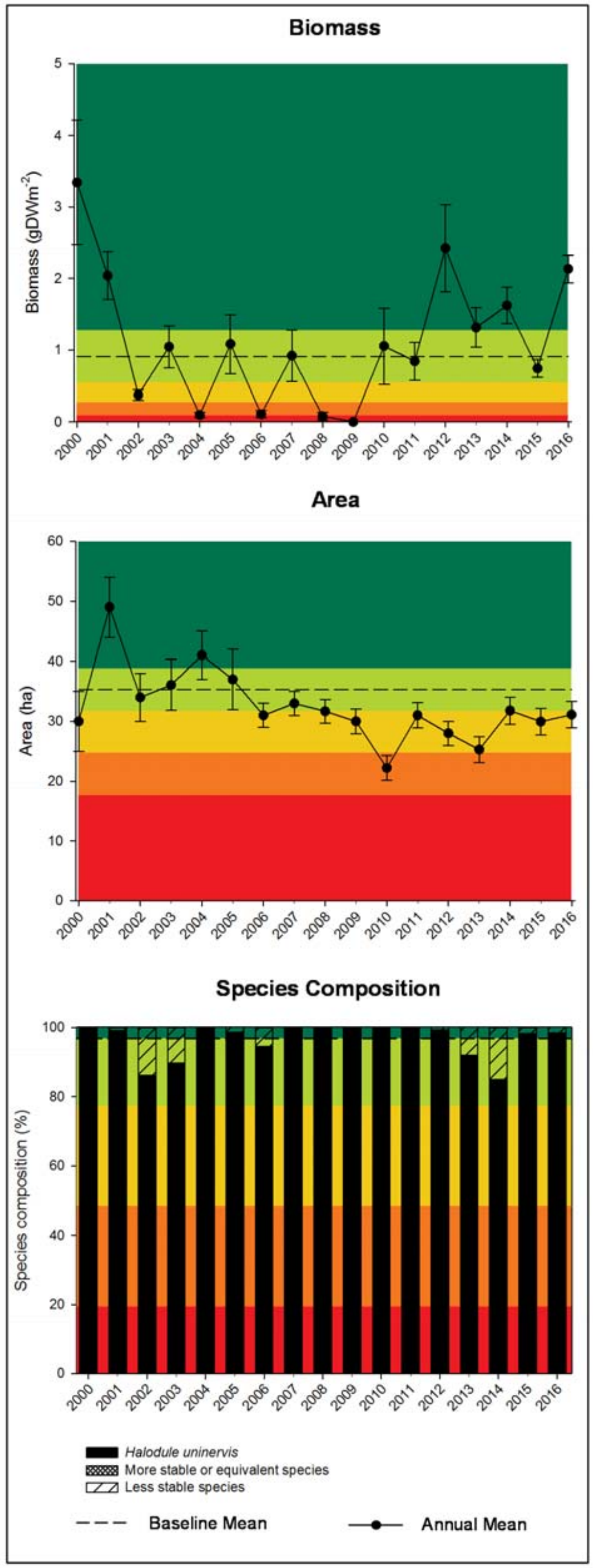


Figure 15. Changes in biomass, area and species composition for the *H. uninervis* dominated core monitoring meadow A3 in Weipa from 2000 to 2016 (biomass error bars = SE; area error bars "R").

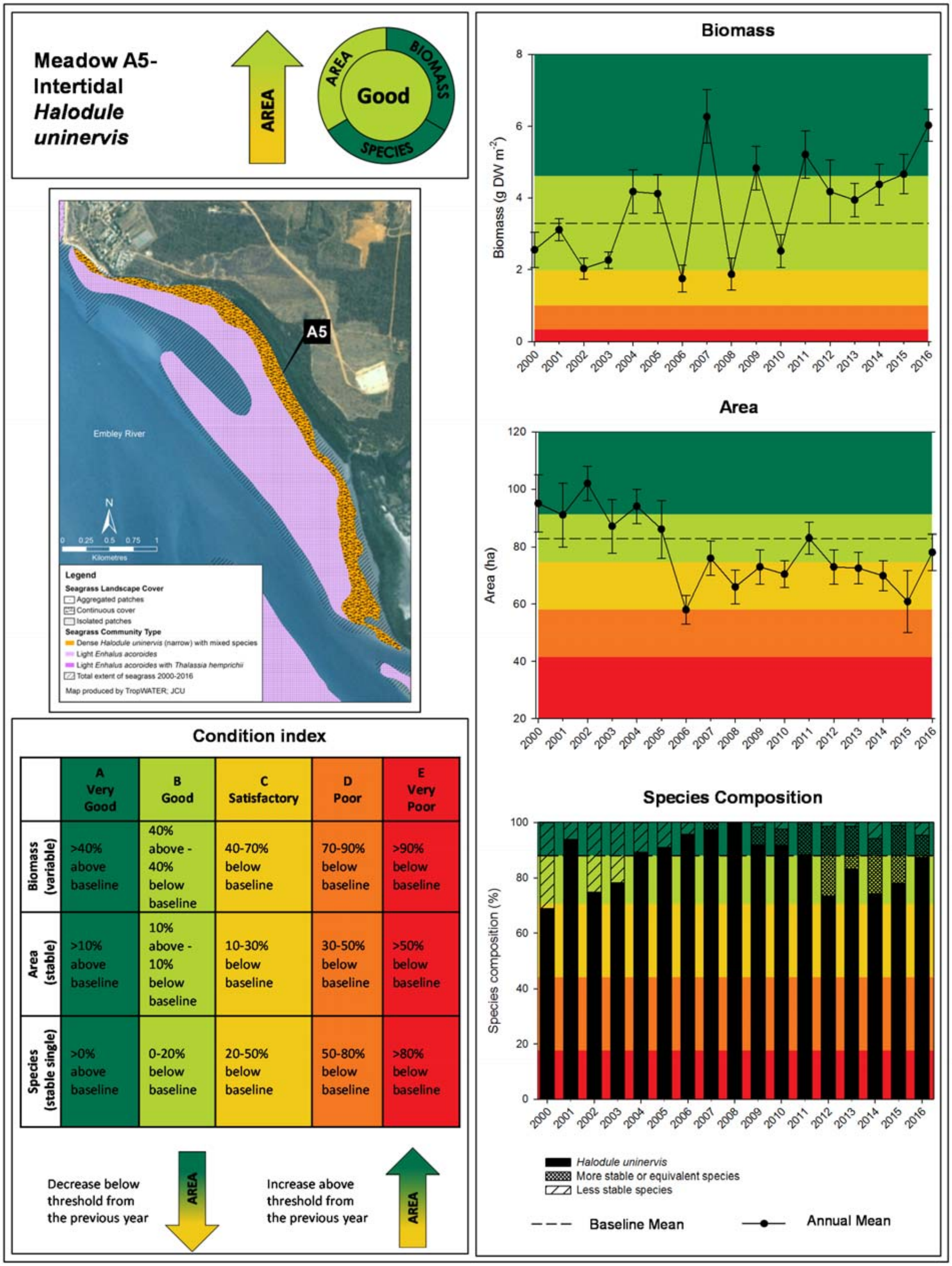


Figure 16. Changes in biomass, area and species composition for the *H. uninervis* dominated core monitoring meadow A5 in Weipa from 2000 to 2016 (biomass error bars = SE; area error bars “R”).

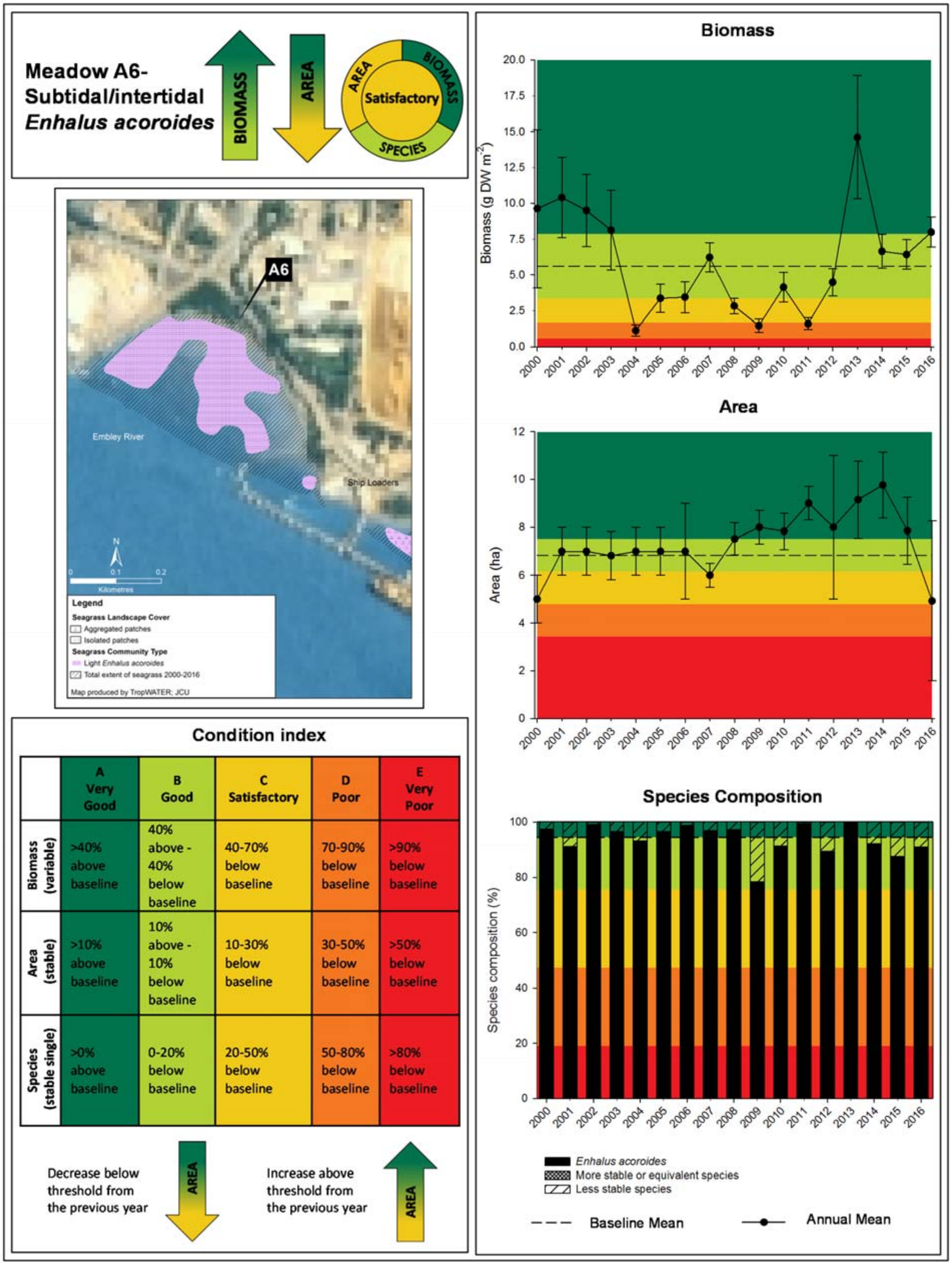


Figure 17. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A6 in Weipa from 2000 to 2016 (biomass error bars = SE; area error bars "R").

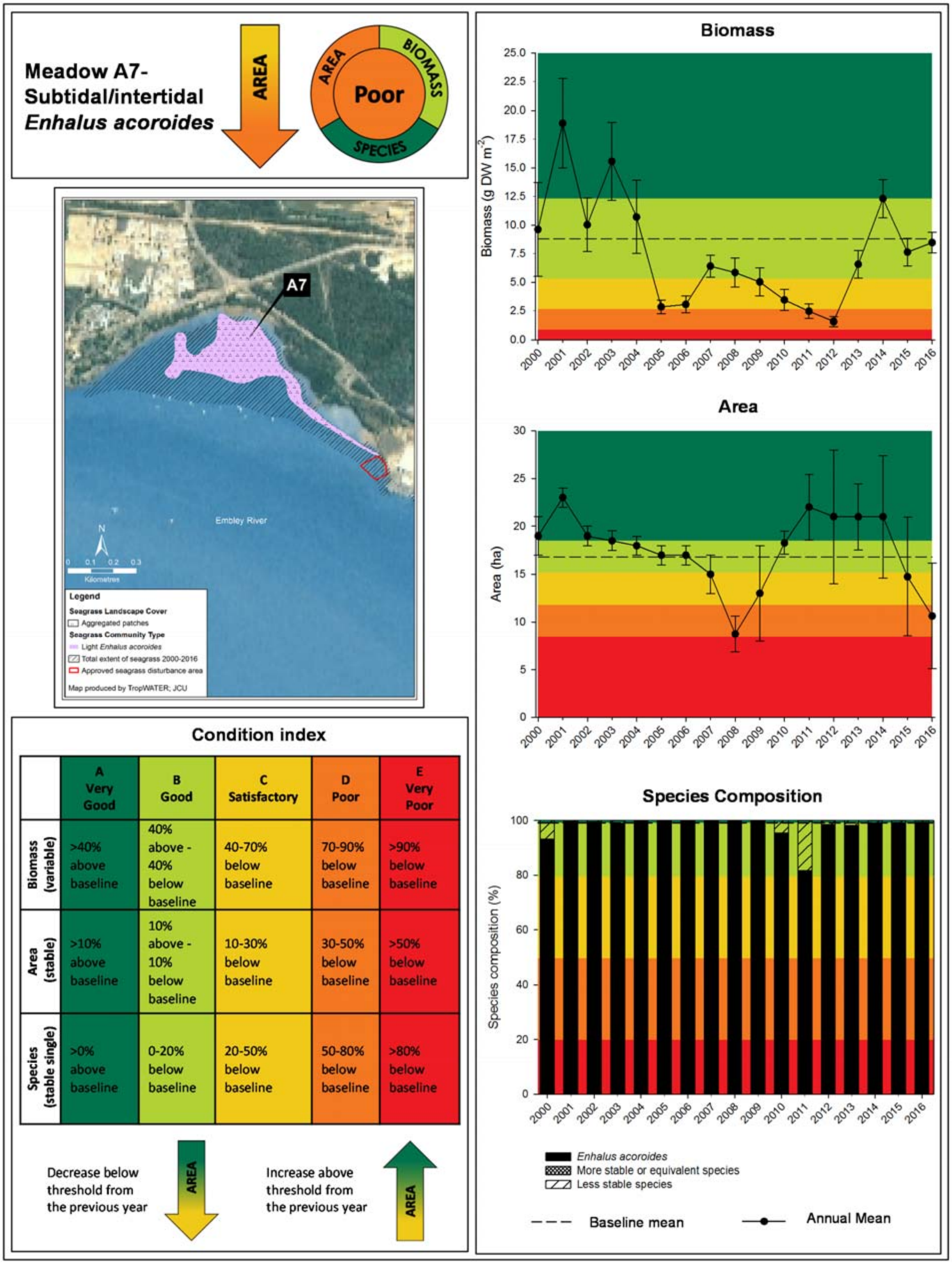


Figure 18. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A7 in Weipa from 2000 to 2016 (biomass error bars = SE; area error bars "R").

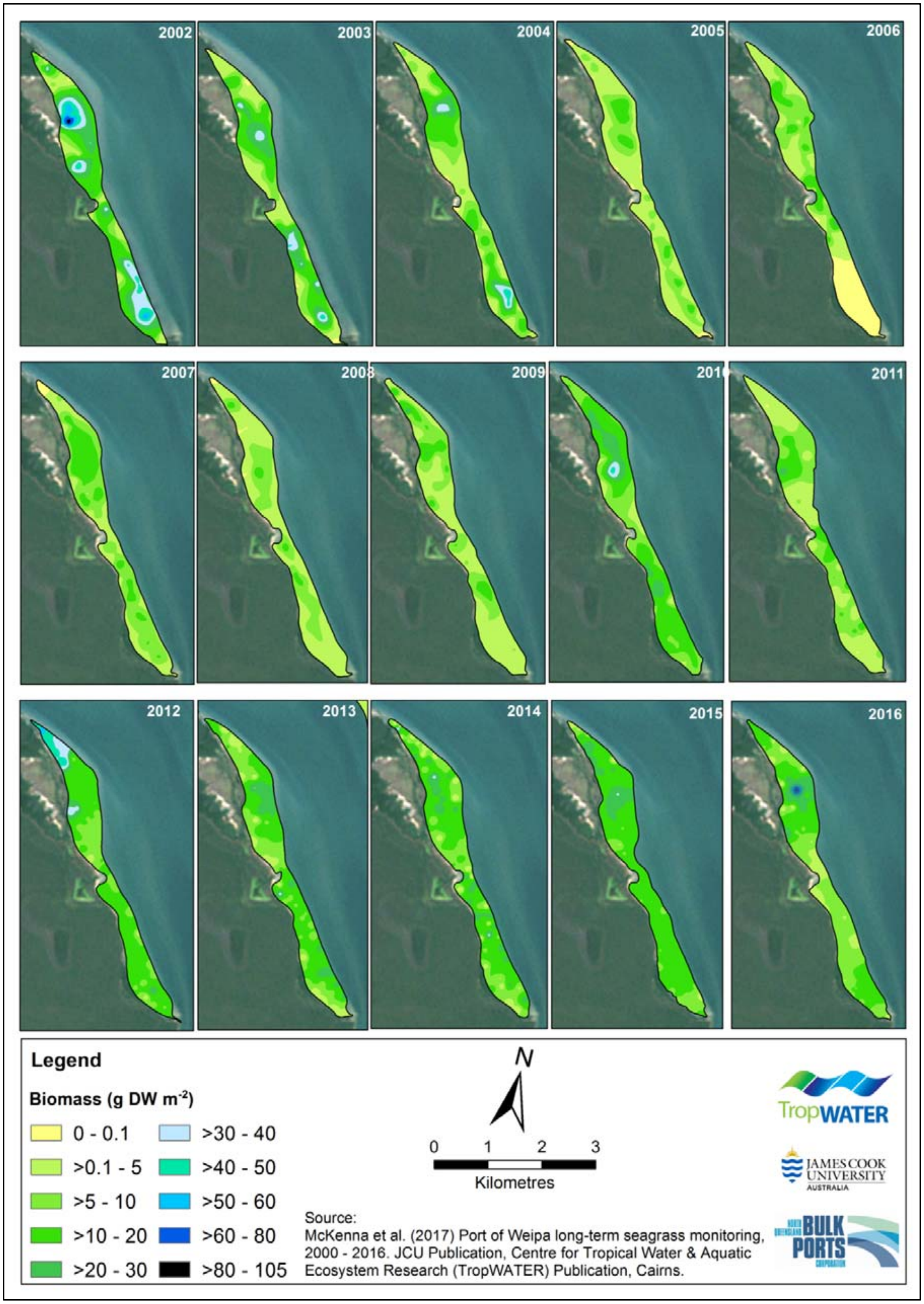


Figure 19. Seagrass biomass changes in the A2 monitoring meadow, 2002-2016.

3.2 Weipa climate data

3.2.1 Rainfall

Total annual rainfall in Weipa has been below the long term average of 1964 mm for the last two years (Figure 20a). Between June and August 2016 only 4.6 mm of rain was recorded, however May 2016 recorded an unusually high amount of rainfall (120.6 mm), nearly 6 times the long term average (Figure 20b).

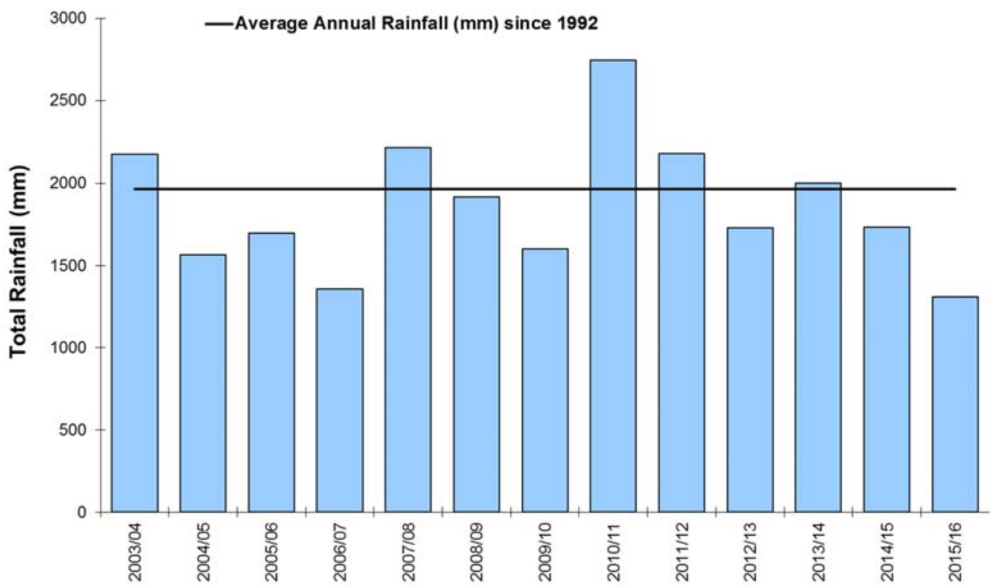


Figure 20a. Total annual rainfall recorded at Weipa Airport; 2002-2016. Twelve month year (2015/16) is twelve months prior to survey. Source: Bureau of Meteorology (BOM), Station 027045, available at www.bom.gov.au

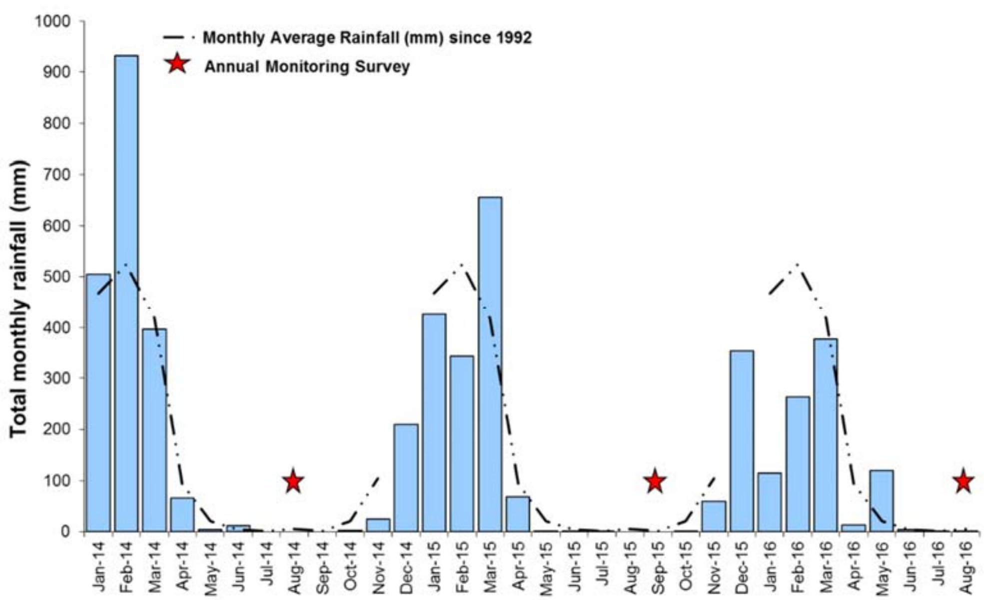


Figure 20b. Total monthly rainfall (mm) between January 2013 – August 2016. Source: Bureau of Meteorology (BOM), Station 027045, available at www.bom.gov.au

3.2.2 Daytime tidal exposure

Intertidal banks at Weipa were exposed to air during the day for 360 hours in the 12 months prior to the 2016 monitoring survey and was below the 17 year long-term average. Tidal exposure has been below the long-term average since 2008/09 (Figure 21a). Tidal exposure for intertidal seagrass meadows in Weipa generally exhibit a greater amount of exposure during the winter/dry months, with July exposure peaking at 100 hours, and low to no exposure during the summer/wet season (Figure 21b). Daytime exposure one month prior to the 2016 survey was lower than the previous two years and below the 17 year long-term average (figure 21c). Similarly, in the three months preceding the survey daytime tidal exposure was well below the long-term average and below that recorded in 2015 (Figure 21c). Previous studies by the group in Weipa have shown that it is tidal exposure in the previous month to the survey that has the most significant impacts on seagrass biomass (Unsworth et al. 2012).

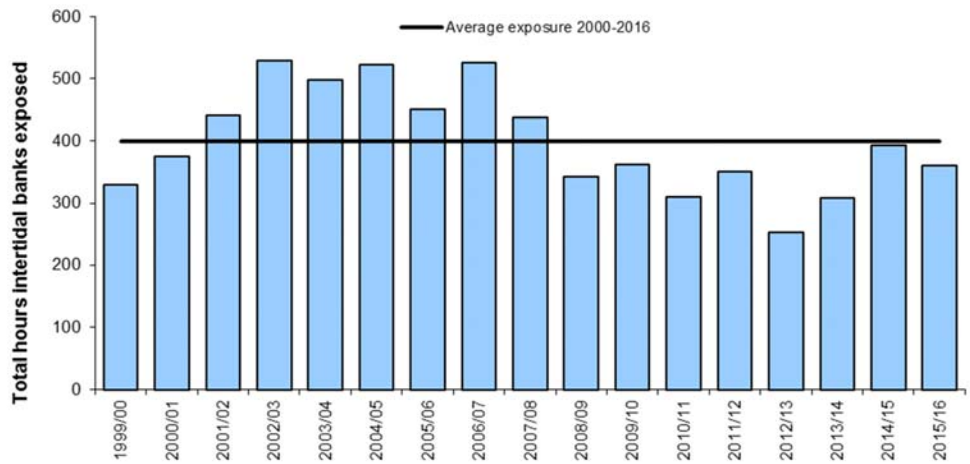


Figure 21a. Annual total daytime tidal exposure (hours; ≤0.9m tidal height) in Weipa; 1999/00 -2015/16. Twelve month year is twelve months prior to survey. 2016 tidal data © State of Queensland (Department of Transport and Main Roads).

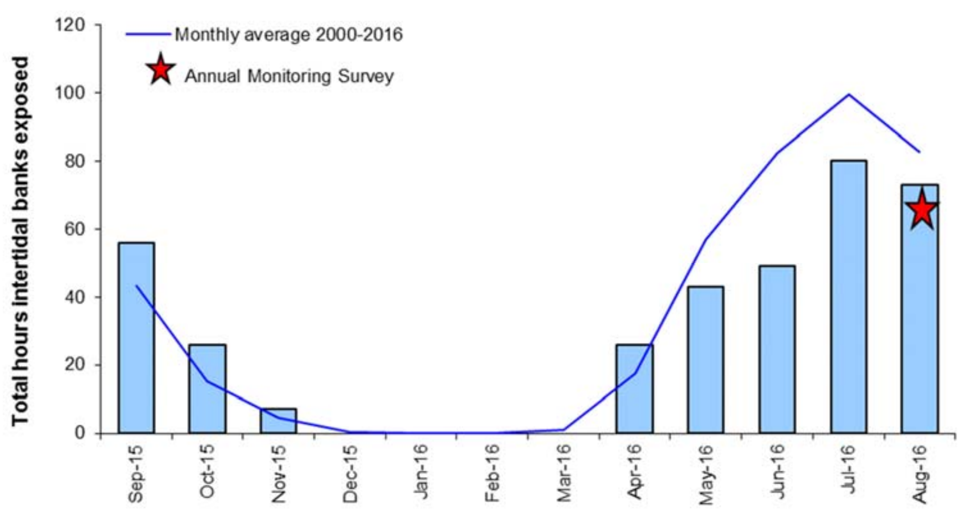


Figure 21b. Monthly total daytime tidal exposure (hours; ≤0.9m tidal height) in Weipa in the 12 months preceding the 2016 monitoring survey. 2016 tidal data © State of Queensland (Department of Transport and Main Roads).

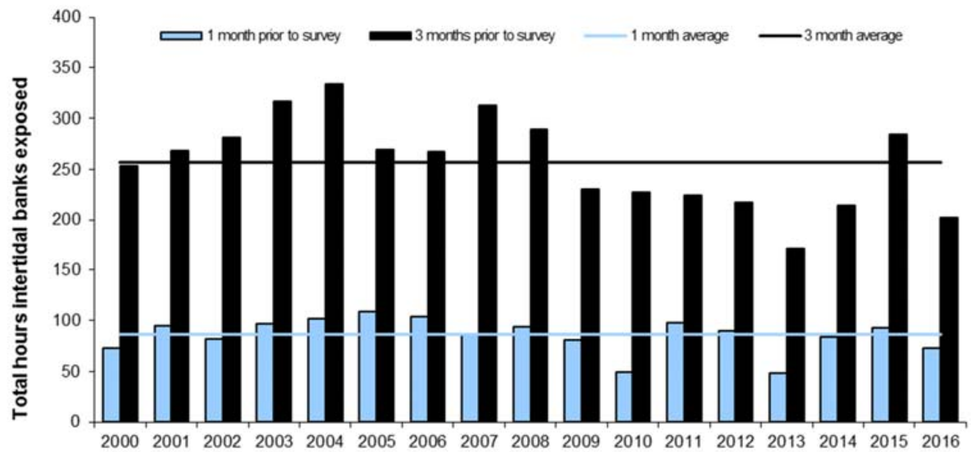


Figure 21c. Total daytime tidal exposure (hours; ≤0.9m tidal height) in Weipa in the 1 and 3 month preceding each monitoring survey; 2000-2016. 2016 tidal data © State of Queensland (Department of Transport and Main Roads).

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) in 2015/16 has been slightly higher than the long-term average for the past two years (Figure 22). The highest daily global exposure recorded in the area in recent years occurred in 2012/13.

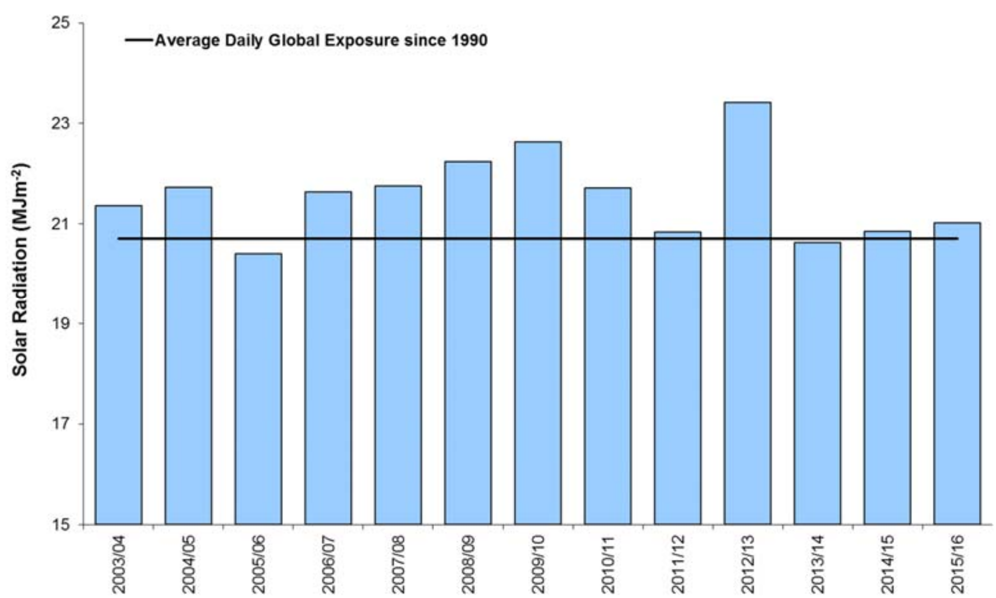


Figure 22. Average annual solar radiation (mJ m^{-2}) for the 12 months preceding each survey; 2003/04 – 2015/16. Source: Bureau of Meteorology (BOM), Station 027045, available at www.bom.gov.au

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

Total daily PAR in the shallower intertidal A2 meadow was greater and more variable than in the deeper subtidal/intertidal A7 meadow, as would be expected as benthic light reduces as a function of depth (Figure 26 and 27). Total daily PAR in the 12 months prior to the survey ranged from 0.01 to 36.65 mol photons m^{-2} day^{-1} in the A2 meadow, and from 0.16 to 13.54 mol photons m^{-2} day^{-1} in the subtidal A7 meadow (Figure 26).

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). We do not yet have specific locally derived light requirements for *E. acoroides* or *H. uninervis* in Weipa and although these may differ from the values suggested in Collier et al. (2016) they are still likely to provide a reasonable guideline for assessment. During 2016 PAR in Weipa fell below the acute threshold for *E. acoroides* suggested in Collier et al. (2016) for:

- 97 consecutive days in meadow A7 between December 2015 and March 2016; coinciding with the wet season and similar to previous wet seasons. Also coinciding with Humbug terminal work between 21 – 27th March 2016.
- 72 consecutive days in meadow A7 between June 2016 and August 2016; up to the day of the annual survey.
    - Such low PAR outside of a wet season or not coinciding with high rainfall has not occurred since 2012.
- The above annual rainfall in May 2016 did not reduce PAR in A7 below the threshold for longer than three days.
- PAR did not fall below the acute threshold for longer than 14 consecutive days (December/January 2015) in the A2 meadow.

Total daily PAR was on average higher in the 2016 wet season compared to the previous two years, which coincided with lower rainfall in 2016. PAR in the dry season however, was lower in 2016 particularly in the A7 meadow compared to previous years (Figure 27).

3.2.5 Water temperature

Mean daily water temperature in the A2 meadow was 29.4°C (at both north and south sites) and 29.3°C in meadow A7 in the twelve months prior to the survey (Figure 26). Maximum daily water temperature peaked at over 40°C in 2016, and was sustained at this level for at least two days on multiple occasions in the intertidal A2 meadow.

In the subtidal/intertidal A7 meadow, temperatures only peaked over 35°C on three days. This is in contrast to 2015 where temperatures were sustained over 35°C for consecutive days at least four times preceding the 2015 survey.

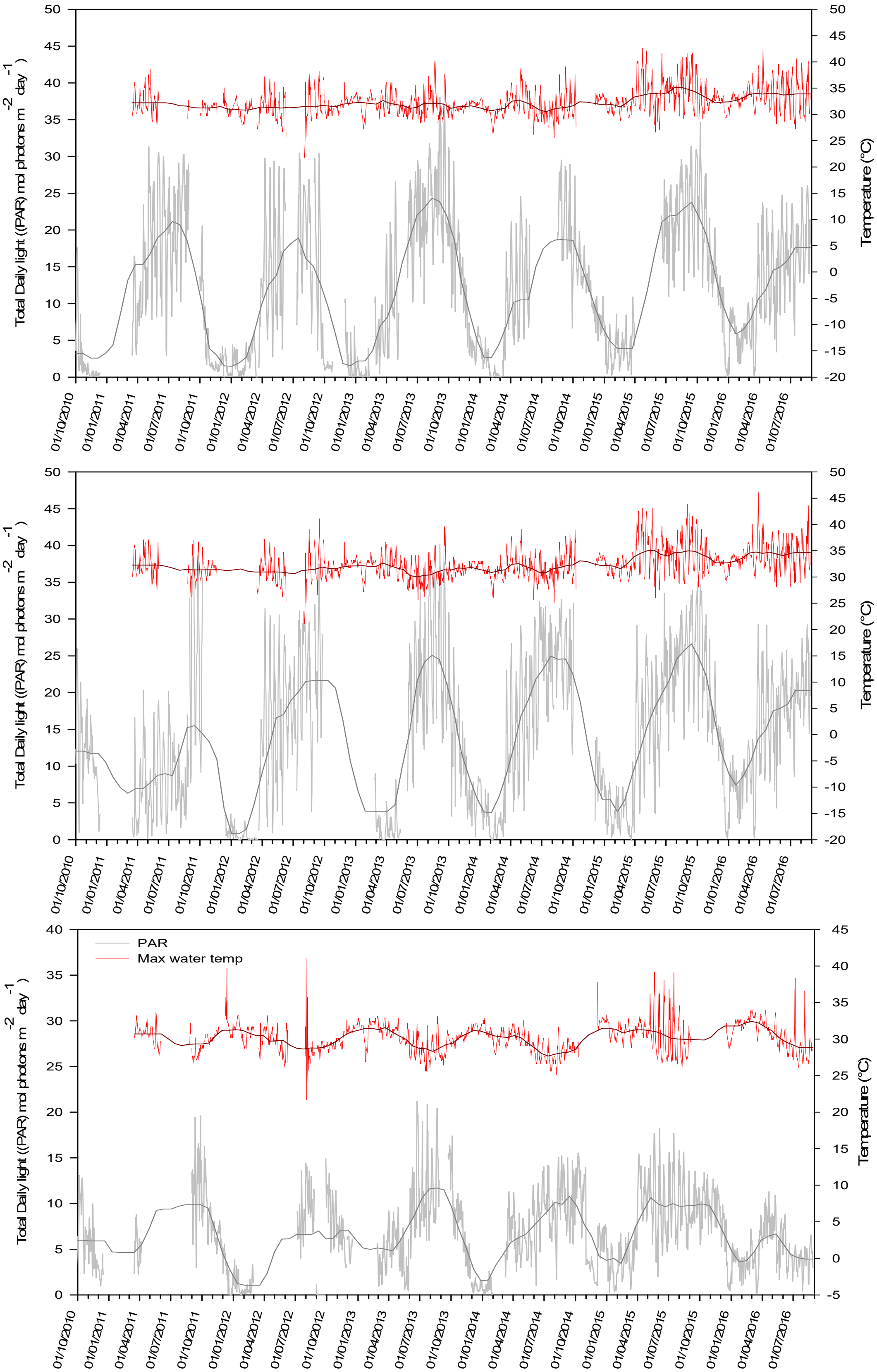


Figure 26. Daily photosynthetically active radiation (PAR mol photons m^{-2} day^{-1}) and mean and maximum daily water temperature (°C) at Weipa, 2010 – 2015, at meadow A2 (a & b) and meadow A7 (c).

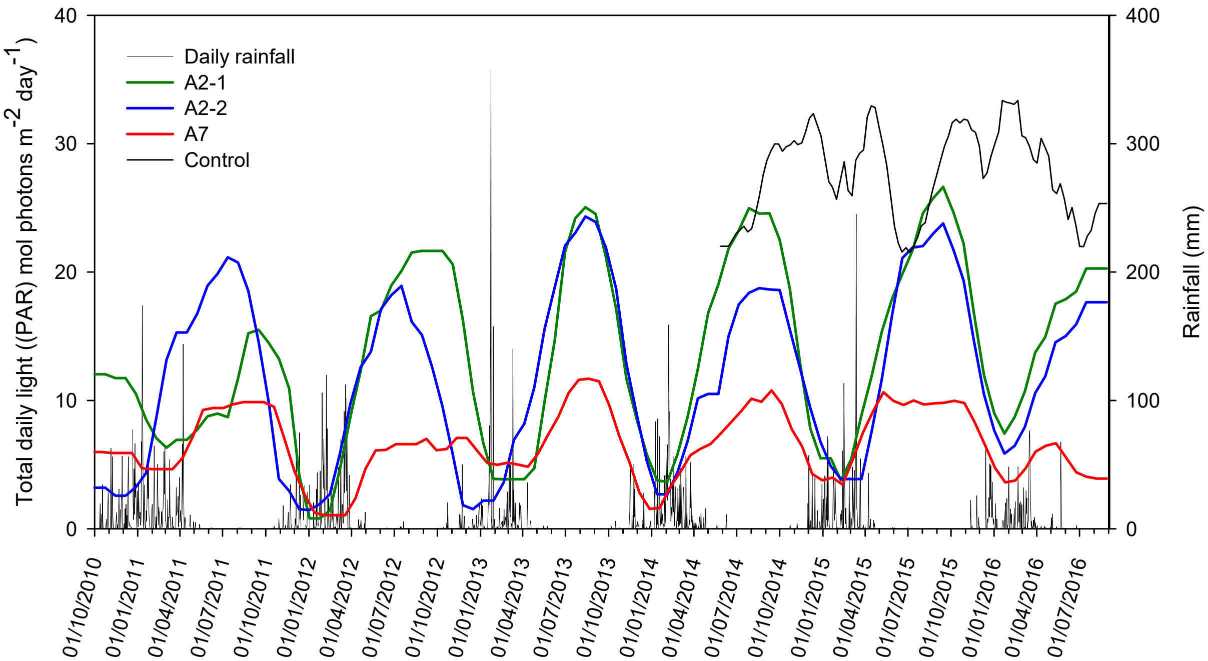


Figure 27. Daily photosynthetically active radiation (PAR; mol photons m^{-2} day^{-1}) and total daily rainfall (mm) at Weipa, October 2012 – September 2015, at Meadow A7 and Meadow A2 northern (A2-1) and southern (A2-2).

3.3 Environmental parameters and intertidal seagrass change

Seagrass at permanent transect sites where light monitoring is conducted ranged in biomass from 12.18 ± 1.06 g dw m^{-2} in December 2016 (A2-1b) to 47.94 ± 3.94 g dw m^{-2} in April 2016 (Figure 28). Preliminary results indicate that seagrass biomass changed over time and generally followed seasonal increases and decreases in light (PAR) through the wet and dry seasons (Figure 28).

During the period that seagrass data has been collected at the permanent transect sites (June 2015 – December 2016) PAR fell below the likely acute light threshold (5 mol m^{-2} day^{-1} over an integration time of 14 days) during a single 14 day period in January/December 2016. Lower light levels at this time of year are typical for the area during the wet season with the previous year recording 76 days below this threshold between January and March 2015 (Figure 28).

At least another 12 months of data needs to be collected before correlative analysis of seagrass change with light and temperature trends, as well as other environmental parameters, can be conducted to develop local biological light thresholds.

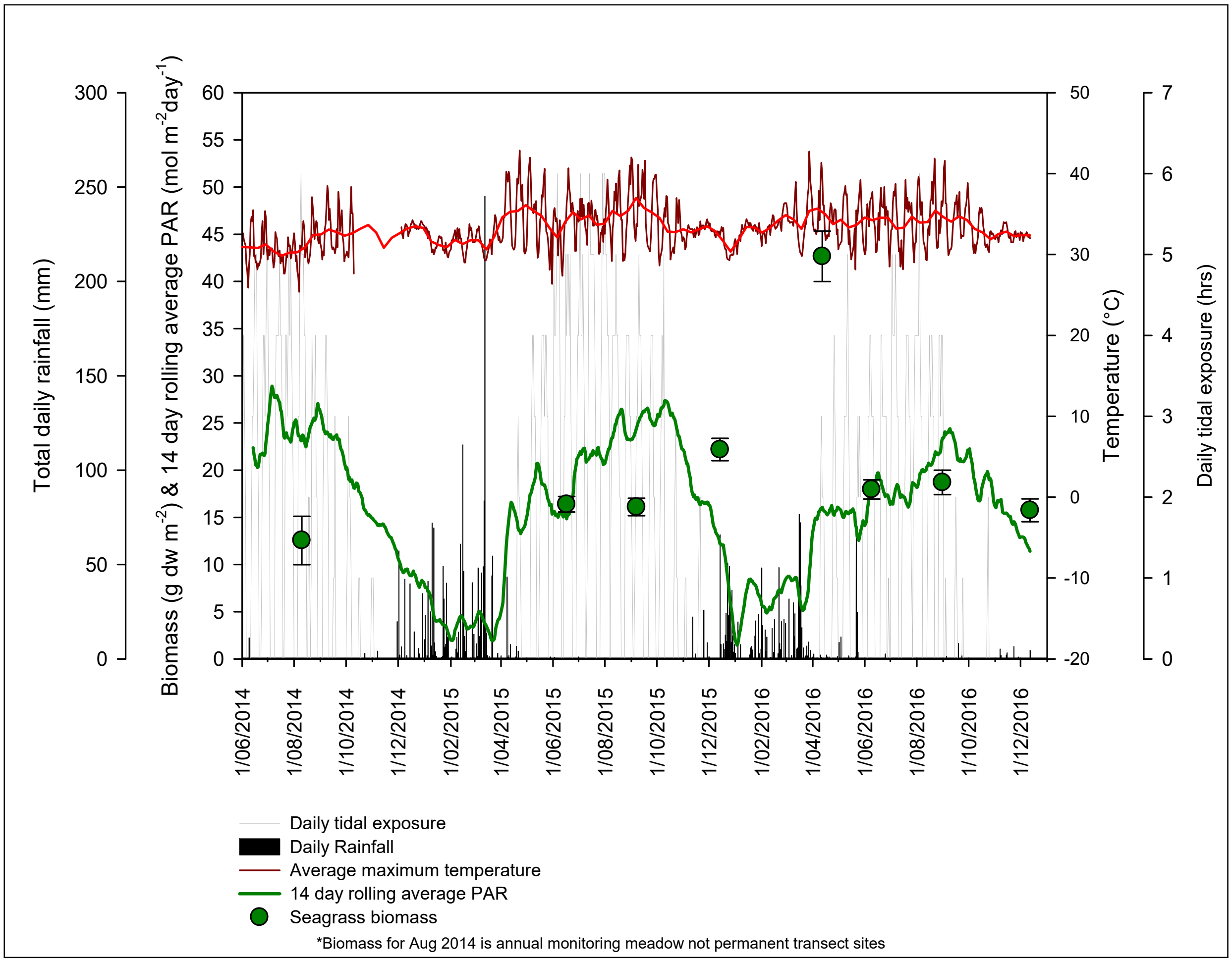


Figure 28. Total daily light 14 day rolling average (PAR; mol photons m^{-2} day^{-1}), seagrass biomass (g dw m^{-2}), maximum sea temperature within the seagrass canopy (◦C), total daily rainfall (mm) and total daily hours intertidal banks are exposed to air (hrs) in Weipa June 2014 – December 2016 in the A2 intertidal monitoring meadow.

4 DISCUSSION

Seagrasses in Weipa were in an overall satisfactory condition in 2016, and for the majority of the survey region seagrass condition was considered good or very good. In the area closest to port and town activity (Intensive Monitoring Area (IMA)), seagrass biomass, area and species composition remained near or above the long-term averages for the majority of meadows. The exception was the substantial decrease in area in the two subtidal-intertidal *E. acoroides* meadows closest to port operations (A6 & A7) which led to the overall downgrading of seagrass condition in Weipa from good in 2015 to satisfactory in 2016.

It is likely that the declines in the two meadows were linked to localised reductions in light confined to this area of the port. Light monitoring conducted in one of the affected meadows (A7) revealed an unusual period of low light during the seagrass growing season (dry season) which resulted in at least 72 consecutive days of light below likely seagrass requirements between June and August, a period of time where higher light conditions usually prevail. Ambient light reaching the water surface and benthic light recorded at other sites in the port were not effected in the same way during this period. Similarly overall climate conditions were not likely to have been behind this seagrass and light decline, with below average tidal exposure, below average rainfall and average solar exposure leading to an environment where seagrasses tend to thrive in Weipa, which was the case for the other meadows monitored in the port.

It is widely recognised that seagrass condition and resilience is largely driven by light (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). Seagrasses have numerous strategies to cope with light reduction, however despite these inbuilt strategies, seagrasses can be acutely sensitive to reduction in light beyond “typical” conditions, which leads to shoot and even meadow-scale seagrass loss (Hughes et al. 2008; Collier et al. 2012; Petus et al. 2014; Rasheed et al. 2014).

The local light environment can be degraded by poor water quality caused by an increase in suspended sediment in the water column (Erftemeijer and Lewis 2006; McMahon et al. 2017). While the exact cause of the decline in benthic light in the affected area of Weipa is unclear, there were a range of activities and events in this area of the port that had the potential for short term impacts on local water quality. These included:

- Development of the new recreational boat ramp at Evans Landing
- Expansion of the Humbug Terminal for a roll on/roll off barge facility to service the Amrun project
- Increased localised boating/barge activity
- Temporary issues with sewerage treatment discharge adjacent to the meadows.

These activities included minor dredging, grubbing and pile driving, and associated modifications to the landscape on shore which had the potential to impact water quality and hence light availability. Follow up seagrass surveys in May and June 2017 (see later in discussion) indicate that these seagrass declines were temporary rather than chronic with stabilisation and natural recovery of the lost seagrass area underway.

In recent times seagrass condition in Weipa has also been impacted by periods of high temperatures. Between 2014 and 2015 periods of extremely high water temperature occurred coupled with tidal air exposure of the meadows (McKenna et al. 2016), conditions that are known to lead to seagrass decline in Weipa (Unsworth et al. 2012). Extreme water temperatures can affect the balance between photosynthesis and respiration in seagrasses and cause sharp reductions in photosynthetic efficiency after temperatures exceed optimum thresholds (Balthius 1987; Perez and Romero 1992; Ralph 1998; Campbell et al. 2006; Collier and Waycott 2014). In 2016 however, even though some high temperatures in the seagrass meadows were periodically recorded, these were not sustained for long periods of time, as they were during 2015. This likely explains why intertidal seagrasses in the port (most effected by high temperatures) generally expanded in biomass and area during 2016.

The role that light plays in the condition and resilience of *E. acoroides* and the species' biological light threshold has received little attention in the literature. As part of this program we are endeavouring to develop local biological light/biomass relationships for *E. acoroides* that over time will lead to locally applicable light thresholds for management of this species. At this stage, more data is required to refine the local relationship between *E. acoroides* and PAR and temperature. In the absence of sufficient studies on the light requirements of *E. acoroides*, Collier et al. (2016) recommended that an acute management light threshold of 5 mol m^{-2} day^{-1} over an integration time of 14 days be adopted as a threshold until further information becomes available. As mentioned above, PAR fell below this threshold for long periods of time both during the wet season; a pattern 'typically' seen at this time of year, but also fell below this threshold during the dry season for the meadows that declined; a pattern not 'typically' seen in Weipa at this time of year.

The persistent occurrence of seagrass recorded in Weipa in the long-term monitoring program is a reflection of the resilience of seagrasses in the region to periodic low light, tidal exposure and 'typical' port activities such as maintenance dredging. However, the significant decline in distribution in the two meadows closest to port operations, and the increased activity that has occurred in the main port area over the last two years, may indicate that these meadows have reduced resilience to impacts. In August 2016 despite the declines a significant proportion of the meadows remained, and within the reduced footprint, seagrass biomass remained in above average condition; positive signs that should the conditions that led to the decline be rectified (increase in benthic light), seagrasses should be able to recover to their former area. In response to the decline in these meadows and in order to assess the continuing resilience of these seagrasses, NQBP commissioned additional seagrass assessments and light monitoring stations during 2017 to monitor recovery and inform potential management actions should they be required. At the time of publication of this report two of these surveys had been completed (May and June 2017), with initial results finding that there had been no further deterioration in area of these seagrass meadows between August 2016 and May 2017 and increases in seagrass area in June 2017. This was a good sign that the losses of seagrass were temporary and seagrass had sufficient resilience to recover, particularly as this period covered the wet season, when light and seagrass condition typically decline.

The seagrass and light monitoring program will continue to provide key information on the resilience of seagrasses and the vulnerability of these meadows as part of ongoing management strategies ensuring they remain resilient enough to withstand expected anthropogenic impacts and risks.

The Weipa long-term seagrass monitoring program has been incorporated into the broader Queensland Ports seagrass monitoring program using the consistent state-wide monitoring methodology. This enables direct comparisons with regional and state-wide trends to put local changes into a regional context. Monitoring at other sites in the network has shown a range of results during 2016. For many locations coastal seagrasses have improved (Karumba, Cairns, Townsville, Abbot Point – Sozou & Rasheed 2017; McKenna et al. 2017; Wells et al. 2017; York et al. in prep) yet at others they have declined (Gladstone – Wells et al. in prep). In 2016 it seems local scale climate and activities rather than larger scale regional drivers have been the major influence on seagrass changes, with seagrasses in the Gulf of Carpentaria/Western Cape York, generally remaining in a good condition.

5 APPENDICES

Appendix 1.

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

1. Determine the grade for the 2015 (current) area value (i.e. satisfactory).

2. Calculate the difference in area (A_{diff}) between the 2015 area value (A_{2015}) and the area value of the lower threshold boundary for the satisfactory grade ($A_{satisfactory}$):

$$A_{diff} = A_{2015} - A_{satisfactory}$$

Where $A_{satisfactory}$ 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 area values (A_{range}) in that grade:

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

Where $A_{satisfactory}$ 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 (A_{prop}) that A_{2015} takes up:

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

5. Determine the area score for 2015 ($Score_{2015}$) by scaling A_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

$$Score_{2015} = LB_{satisfactory} + (A_{prop} \times SR_{satisfactory})$$

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

Appendix 2. Species composition of monitoring meadows in the Port of Weipa; 2000 – 2016

Appendix 3a.

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 – 2016.

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
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)
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)
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)
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)
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)

Appendix 3b.

Total meadow area + R (ha) for each core monitoring meadow within the Port of Weipa, 2000 – 2016.

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**
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
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
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
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
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
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**

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