Centre for Tropical Water and Aquatic Ecosystem Research

PORT OF WEIPA LONG-TERM SEAGRASS MONITORING:

SEPTEMBER 2013

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Prepared by
Helen Taylor, Michael Rasheed, Alex Carter & Skye McKenna

Centre for Tropical Water & Aquatic Ecosystem Research
(TropWATER)
James Cook University
PO Box 6811
Cairns Qld 4870
Phone : (07) 4781 4262
Email: seagrass@jcu.edu.au
Web: www.jcu.edu.au/tropwater/

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For further information contact:
Skye McKenna
Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)
James Cook University
seagrass@jcu.edu.au
PO Box 6811
Cairns QLD 4870

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KEY FINDINGS

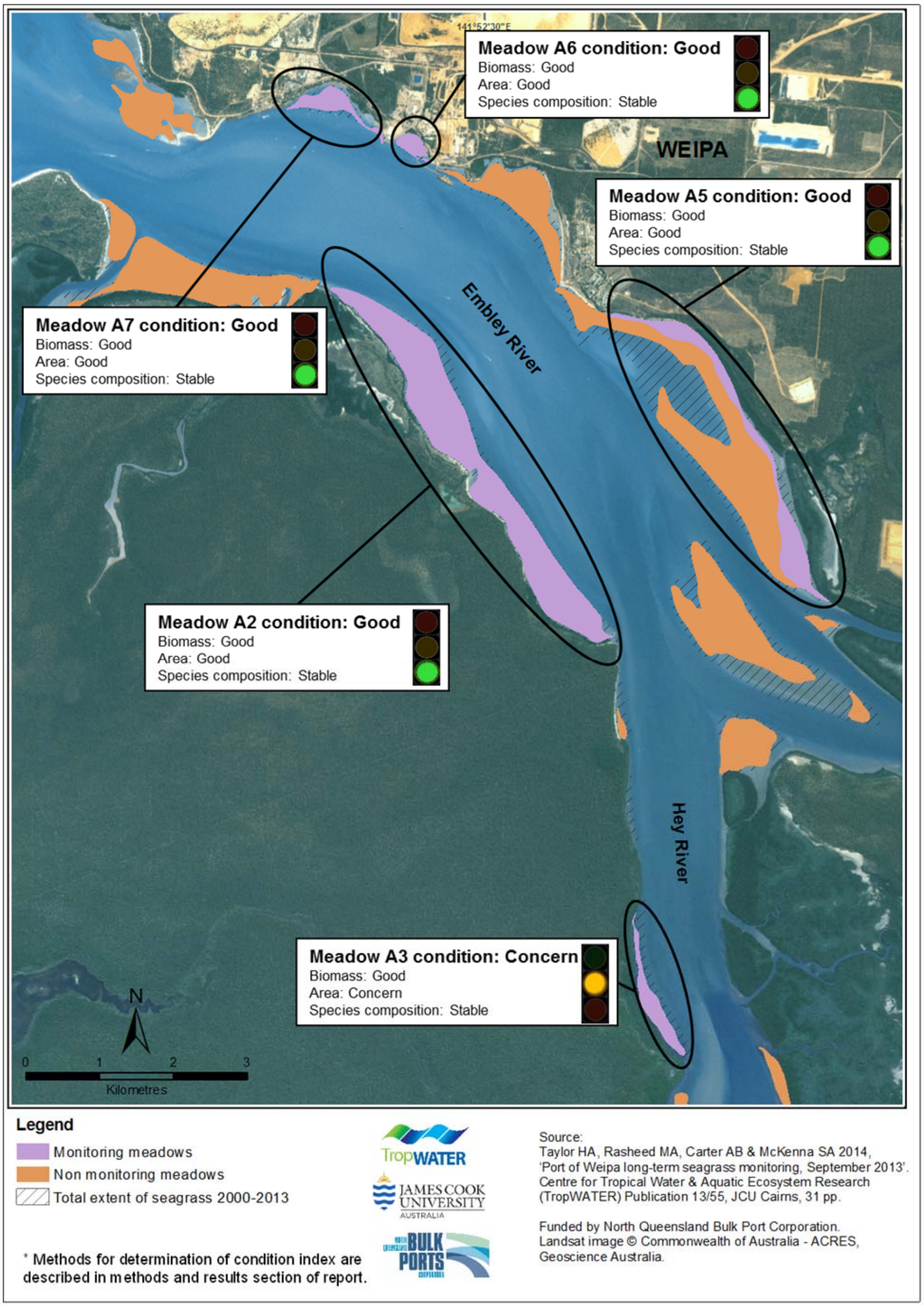
Seagrasses have been monitored annually in the Port of Weipa since 2000. Each year seagrasses around the major areas of port activity are mapped and assessed and every 3 years all seagrasses within the greater port limits are examined. Key findings from 2013 were:

1. Annual monitoring results show seagrasses in the Port of Weipa were in a good condition in 2013 with biomass (density), area and species composition of monitoring meadows all close to or above the long term average.
2. The good condition of seagrasses including the large *Enhalus acoroides* meadow (A2) on the western bank of the Embley River means they should continue to be resilient to planned maintenance dredging activities in 2014 without the requirement for additional mitigation measures.
3. Monitoring of light (Photosynthetically Active Radiation (PAR)) at key seagrass locations indicates that the light environment remained favourable for seagrass growth during 2013.
4. Tidal exposure and solar radiation explain a significant component of previous declines in some intertidal meadows. Additional more frequent assessments of seagrass change in conjunction with PAR monitoring would enable a better understanding of the actual light requirements for seagrasses in Weipa.
5. The good condition of seagrasses in Weipa was similar to other monitoring locations in northern Cape York and the Gulf of Carpentaria which were largely unaffected by some of the major climate related losses of seagrasses that have occurred on the east coast of Queensland.

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 5 core seagrass meadows representing the range of different seagrass community types found in Weipa are assessed for changes in density biomass (density) and species composition. Changes to area biomass and species composition are then used to develop a seagrass condition index and classified as 'good', 'concern' or 'poor' depending on how the most recent survey results compare with the long term average condition (see sections 2.5 & 3.3 of this report for further details). Every 3 years all seagrasses within the port limits are remapped, with the next full survey due in 2014. Seagrasses in the Port of Weipa were in a good condition in 2013, with abundance (biomass), area and species composition of monitoring meadows all close to or above the long term average (Map 1).

Map 1. Seagrass condition index for Weipa seagrass monitoring meadows in 2013



The total area of all seagrasses within the IMA has also been relatively stable over the past decade (Figure 1). The only meadow classified as being of "concern" was the light biomass *Halodule uninervis* meadow (A3) in the Hey River that had declined in area to be more than 20% below the long term average, however density (biomass) of seagrass remained high compared with the average for this meadow.

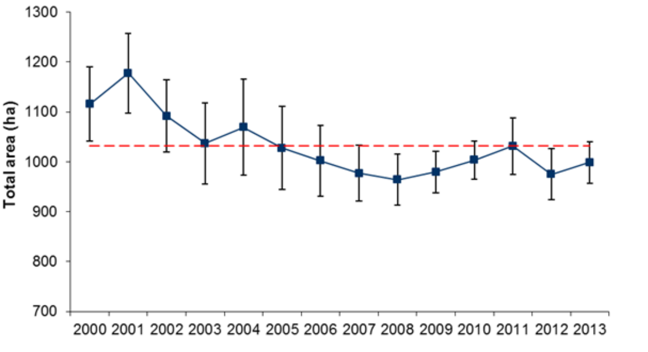


Figure 1. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2013 (error bars = "R" reliability estimate). Red dashed line indicates 14-year mean of total meadow area.

Natural shifts in the amount of daytime tidal exposure of intertidal banks between years has previously led to significant die off and declines in the large and dense *Enhalus acoroides* seagrass meadow opposite Lorim Point (meadow A2) (see Unsworth et al 2012). In 2013, area and density of this meadow were above the long term average despite a relatively high amount of air exposure of these banks prior to the survey. In 2013 there was far less "burning" of seagrass leaves observed indicating lower amounts of exposure related stress. The exact reasons for this are unclear but could be related to factors not directly measured in this program such as cloud cover during exposure periods or lower temperatures that reduced the level of physiological stress to the plants during exposure.

Monitoring of light available to seagrasses in Weipa during 2013 indicates that light availability was likely to be favourable for seagrass growth. Tidal exposure and solar radiation explain a significant component of previous declines in some intertidal meadows. In order to determine the actual light requirements for the local species in Weipa some additional monitoring of seagrass condition during the year at the light monitoring sites is recommended (ideally quarterly).

These results indicate that the marine environment of Weipa including water quality were in a good condition during 2013. Seagrass is likely to have maintained a high resilience to planned maintenance dredging activities in 2014 without the requirement for additional mitigation measures. This is reliant on the maintenance dredging program remaining consistent in duration to previous years and seagrasses not being subjected to major impacts from natural events prior to proposed dredging.

The Weipa seagrass monitoring program forms part of a broader Queensland seagrass program that examines condition of seagrasses in the majority of Queensland commercial ports and a component of JCU's broader seagrass assessment and research program. Seagrasses on western Cape York, Torres Strait and the Gulf of Carpentaria were generally in a good condition which is in stark contrast to seagrasses on the east coast of Queensland that were severely impacted by unfavourable climate events and cyclones in 2013/14. For full details of the Queensland ports seagrass monitoring program see www.jcu.edu.au/PortSeagrassQld

TABLE OF CONTENTS

1 INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem services including coastal protection, support of fisheries production, nutrient cycling and particle trapping (Hemminga and Duarte 2000; Costanza et al. 1997). Seagrass meadows show measurable responses to changes in water quality, making them ideal candidates for monitoring the long-term health of marine environments (Orth et al. 2006; Abal and Dennison 1996; Dennison et al. 1993).

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) (Formally part of Fisheries Queensland/DAFF) in partnership with the various Queensland Port Authorities. While each location is funded separately with a range of requirements for use of the information, a common methodology and rationale is utilised to provide a network of seagrass monitoring locations throughout the state (Map 2).

Map 2 Location of Queensland Port Seagrass assessment sites (red – long term monitoring; blue - baseline mapping only)

A strategic long term assessment and monitoring program for seagrasses in port locations provides mangers and regulators with the key information to ensure that seagrasses and ports can co-exist and using seagrass condition as an indicator inform port development and maintenance programs to ensure minimal impacts on the marine environment. As an excellent integrator of impacts to water quality, seagrasses provide an ideal indicator of overall marine environmental health of the port (Dennison et al. 1993). 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 seagrasses and an understanding of the drivers of tropical seagrass change. It provides a measure of the marine environmental health of the 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 Corporation (NQBP) 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 James Cook University's Centre for Tropical Water and Aquatic Ecosystem Research (JCU-TropWATER) to establish a long-term seagrass monitoring program for Weipa's port since 2000 (Roelofs et al. 2005; 2003; 2001). 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 2013 the annual maintenance dredge campaign commenced mid-June and was completed in 32 days, with 644,525m^3 of dredge material removed. Seagrass monitoring surveys satisfy environmental monitoring requirements as part of the port's Long-Term Dredge Management Plan approved under State and Commonwealth Permits and are used by regulatory agencies to assess the status and condition of seagrass resources in the region. The monitoring program also forms part of Queensland's network of long-term monitoring sites of important fish habitats in high risk areas.

The first three years (2000 to 2002) of the seagrass monitoring program provided important baseline 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 effort on seagrass meadows located near the port and shipping infrastructure and activities. This area is known as the Intensive Monitoring Area (IMA; Map 3). 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 species composition. These meadows represent the range of seagrass meadow communities identified in the region. Every three years (i.e., 2000, 2002, 2005, 2008 and 2011), 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 with the next of these surveys due in 2014 (Map 3).

This report presents the results of the long-term seagrass monitoring conducted in September 2013. The objectives of the 2013 long-term seagrass monitoring of the Port of Weipa were to:

1. Map the distribution and abundance of seagrasses in "core monitoring meadows";
2. Map the distribution and confirm species composition of seagrass meadows within IMA;
3. Assess changes in seagrass meadows and compare results with previous monitoring surveys;
4. Incorporate the results into the Geographic Information System (GIS) database for the Port of Weipa.

Map 3. Location of 2013 seagrass monitoring sites and seagrass meadows in the Port of Weipa

Legend

Seagrass habitat characterisation sites (for core meadows)

- Seagrass absent
- Seagrass present
- Intensive monitoring area (IMA) boundary
- Meadows within the IMA
- Non monitoring meadows (mapped 2011)

Source:
Taylor, HT, Carter, AB, McKenna, SA & Rasheed, MA 2014, 'Port of Weipa long-term seagrass monitoring - September 2013'. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, Cairns.

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2 METHODS

2.1 Annual monitoring within the Intensive Monitoring Area

Annual seagrass monitoring within the Port of Weipa was conducted September 15 - 18, 2013. Annual monitoring over the past 14 years has focused on five core seagrass meadows selected from baseline surveys within the Intensive Monitoring Area (IMA) (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 2012 survey:

1. Assess and map seagrass distribution, species composition and biomass in the five core monitoring meadows (A2, A3, A5, A6, and A7) (Maps 3, 4; Appendix 2).
2. Map seagrass distribution and confirm species composition in non-core monitoring meadows within the IMA (Maps 3 & 4).

Seagrass meadows were surveyed using a combination of helicopter aerial assessment and boat-based camera surveys (Plate 1). At each site surveyed seagrass meadow characteristics were recorded including seagrass species composition, above-ground biomass, per cent algal 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).

Seagrass community type in non-core monitoring meadows within the IMA was determined by a visual inspection of species composition (from helicopter assessments), as only core monitoring meadows were assessed specifically for biomass and species composition.

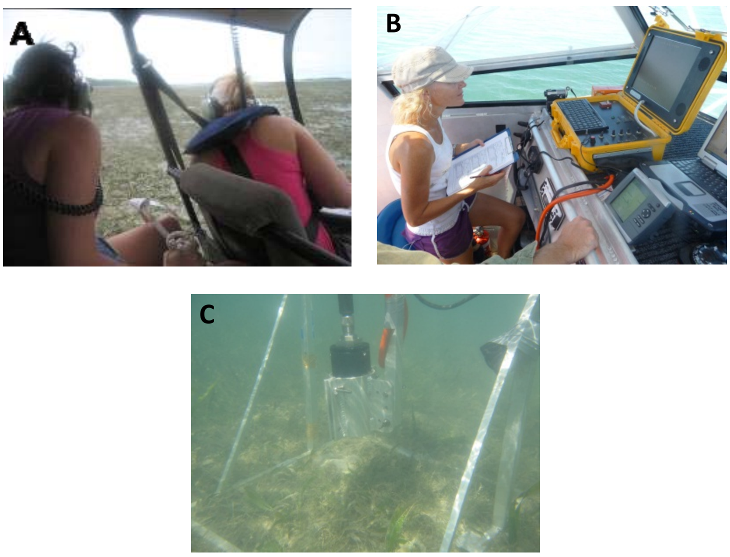


Plate 1. Seagrass methodology utilising (A) helicopter aerial surveillance, and (B,C) boat-based CCTV surveillance.

Results from previous baseline surveys suggested the analysis of biomass for meadows where the large growing species *Enhalus acoroides* was present but not dominant required a different approach 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 *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* within the IMA. The exclusion of *E. acoroides* was not necessary in 2013 in A5 as *E. acoroides* was absent from the meadow. There was one biomass site for A3 that was excluded.

2.2 Geographic Information System

Spatial data from the September 2013 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.

2.2.1 Site information

This includes site data containing seagrass per cent cover and above-ground biomass (for each species), dbMSL, sediment type, time, latitude and longitude from GPS fixes, sampling method and any comments.

2.2.2 Seagrass meadow characteristics

This includes 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 between annual monitoring surveys. Identification numbers for core monitoring meadows are also used to reference meadows throughout the results section. Seagrass community types were determined according to species composition from nomenclature developed for seagrass meadows of Queensland (Table 1).

Each seagrass meadow was assigned a mapping precision estimate (±m) based on the mapping method used for that meadow (Table 2). Mapping precision estimates ranged from <5m for isolated intertidal seagrass meadows to 10 - 50m for larger patchy intertidal/ 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 aerial photographs into base maps and with GPS fixes for survey sites were embedded within the meadow reliability estimates.

Table 1. Nomenclature for community types in the Port of Weipa 2013.

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. Mapping precision and methods for seagrass meadows in the Port of Weipa 2013.

Mapping precision	Mapping method
1-5m	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 aerial photography aided in mapping.
10-50m	Meadow boundaries determined from helicopter and camera/grab surveys; Inshore boundaries mapped from helicopter; Offshore boundaries interpreted from survey sites and aerial photography; Relatively high density of mapping and survey sites.

2.2.3 Seagrass landscape category

This includes area data showing the seagrass landscape category determined for each meadow.

Isolated seagrass patches
The majority of area within the meadows consisted of unvegetated sediment interspersed with isolated patches of seagrass.

Aggregated seagrass patches
Meadows are comprised of numerous seagrass patches but still feature substantial gaps of unvegetated sediment within the meadow boundaries.

Continuous seagrass cover
The majority of area within the meadows comprised of continuous seagrass cover interspersed with a few gaps of unvegetated sediment.

2.3 Light and water temperature assessments

Maximum daily water temperature (°C) and light (photosynthetically active radiation, PAR, mol m^{-2} day^{-1}) conditions within Weipa's seagrass meadows were assessed for the fourth year. Water temperature and PAR were monitored at a northern and southern site within the intertidal A2 meadow and one site in the intertidal A7 meadow (Map 2) using custom built benthic data logging stations. Each logging station consisted of a stainless steel frame which held up to two PAR loggers (Odyssey Integrated Light loggers Model Z412) with supporting electronic wiper units, and an autonomous iBTag temperature logger (Figure 1). Loggers recorded temperature and PAR within the seagrass canopy every 15 minutes. Loggers were exchanged and downloaded approximately every 90 days. The electronic wiper unit fitted to each PAR logger automatically cleaned the optical surface of the sensor every 15 minutes to prevent marine organism fouling.

Odyssey PAR loggers log a cumulative reading at 15 minute intervals, which is calibrated and summed to gain total daily PAR (mol m^{-2} day^{-1}) at each site. The raw data captured by the loggers is an arbitrary value that requires calibrating to a known light value. A calibration factor was calculated for each logger using a solar simulator and a LI-COR Underwater Radiation Sensor (LI-192) and LI-250A Light Meter. An adjustment for periods when PAR loggers are exposed to air was also made. Air exposure times are calculated using tidal data supplied by Maritime Safety Queensland (MSQ). Periods of exposure were calculated for each site based on the estimated datum depth of the site, with PAR values during these exposure times multiplied by 1.3 as outlined in Collier et al. (2009).

PAR logger in cradle

Deployed PAR logger in cradle on intertidal seagrass meadow

Figure 1. Logging station consisting of a stainless steel frame, PAR logger, electronic wiper unit temperature logger.

2.4 Statistical analyses

Seagrass above-ground biomass was compared between years in three steps. First, a logistic regression was used to determine whether the proportion of habitat characterisation sites without seagrass varied significantly between years. This analysis indicated whether the patchiness of each meadow changed over time. Second, a one-way analysis of variance (ANOVA) was used to determine whether seagrass biomass varied significantly between years. The one-way ANOVA was performed only on those habitat characterisation sites where seagrass was present, because the inclusion of sites where seagrass was absent (zero values) in the data set violated the assumption of ANOVA. Each meadow's data was examined for normality and homogeneous variance and data transformations applied to meet these assumptions (Meadows A2, A3, A5 and A7 were square-root-transformed; Meadow A6 was log-transformed). Tukey's post hoc analysis was used to test for significant differences in biomass between years. Third, a correlation analysis was run on the proportion of sites with seagrass present and mean biomass for that year. This analysis indicated whether seagrass meadow patchiness and seagrass biomass within the meadow were influenced by the same factors. Detailed statistical results are presented in Appendix 1.

2.5 Seagrass meadow condition index

This is the first year of applying and testing the condition index and there is scope for future modifications of the classifications and approach as it is rolled out and tested across the ports monitoring program. This initial index was developed for each of the monitoring meadows based on mean above ground biomass, meadow area and species composition. The index integrates this information to give each meadow a condition rating of "good", "concern" or "poor". For biomass and area the current value for each meadow was compared with the meadow's long term average and categorised into a range that corresponded to the three index categories (Table 3). Ranges for each component of the condition index were selected based on the historical variability within the monitoring meadow representing seagrass condition in a stable meadow (good), in a meadow with reduced resilience to disturbance (concern) and in a meadow with limited resilience and loss of ecosystem function (poor). Two different ranges were used recognising that some monitoring meadows are relatively stable (higher cover meadows dominated by larger species) and other meadow types are naturally variable (patchy meadows dominated by smaller often colonising species) (Table 3).

Species composition was assessed qualitatively as "good" when the species composition has remained relatively stable; of "concern" when there has been a substantial shift (approximately 20% or greater) in species toward colonising species indicating disturbance or stress; or "poor" when the meadow has shifted to become clearly dominated (>80%) by colonising species. It is important to note that species shifts are relative and determined on a meadow by meadow basis taking into account both the current year's species composition and historical trends. Some monitoring meadows in their stable state are always dominated by colonising species. As a result the presence of colonising species in these meadows results in a condition rating of "good" for species composition in the condition index (Table 3).

The final condition of the monitoring meadow is determined by looking at all three factors (biomass, area and species composition), with the lowest of any of the three factors determining the overall condition index. Where additional information is available, such as seagrass seed-bank status, light and temperature stress or other measures of resilience such as flowering and fruiting and carbohydrate stores may be used to modify the overall condition score if they indicate the meadow may be under increased stress.

Table 3. Determination of seagrass condition index for Weipa seagrass monitoring meadows.

Condition Index	**Biomass**		**Area**		**Species Composition**
	Stable higher cover meadows	Patchy highly variable meadows	Stable higher cover meadows	Patchy highly variable meadows	
Good	Less than 20% below the long term average	Less than 50% below the long term average	Less than 10% below the long term average	Less than 20% below the long term average	Relatively stable species composition
Concern	Between 20% and 50% below the long term average	Between 50% and 80% below the long term average	Between 10% and 20% below the long term average	Between 20% and 50% below the long term average	Shift in species composition towards colonisers
Poor	Greater than 50% below the long term average	Greater than 80% below the long term average	Greater than 20% below the long term average	Greater than 50% below the long term average	Colonising species have become dominant

3 RESULTS

3.1 Seagrass species, distribution and abundance

A total of 298 seagrass habitat characterisation sites were surveyed in the Weipa monitoring meadows in September 2013, with seagrass present in 81% of sites (Map 1). Five seagrass species (from two families) were identified. For a full list of species present in Weipa see (Roelofs et al. 2003; 2001).

CYMODOCEACEAE TAYLOR		***Halodule uninervis*** (wide and narrow 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 • Dugong preferred food
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 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

3.2 Seagrass in the Intensive Monitoring Area

Fourteen seagrass meadows were mapped in September 2013 within the Intensive Monitoring Area (IMA) that encompasses the region of port activity (Maps 3 – 4). The total combined seagrass meadow area was 999 ± 51 ha, a 2.4% increase in area from August 2012. Seagrass area was below the 13-year average of 1032 ± 66 ha (Figure 2). Individual meadow area ranged from 0.1 ha to 257 ha. As in all previous years the largest meadow, A2, stretched along the western bank of the Embley River (Map 4).

The dominant seagrass species in each of the core monitoring meadows remained unchanged from 2012. *Enhalus acoroides* dominated seagrass communities in nine of the fourteen meadows within the IMA, including the core monitoring meadows A2, A6 and A7 (Map 2). Large *E. acoroides* meadows were found on the intertidal banks and shallow subtidal areas of the Embley River. *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 two meadows (including meadow A1) at the southern mouth of the Embley River (Map 4).

The condition known as burning, i.e. the browning and subsequent death of seagrass blades, was observed at 3.7% of sites surveyed within the IMA in 2013, a substantial decrease from 17.5% of sites in 2012 and 11% of sites in 2011. The decrease in burning indicates that exposure-related stress was at lower levels for intertidal seagrasses leading up to the survey than in previous years. Dugong feeding trails have not been observed for the past three years in the A2, A4 and A5 meadows despite being recorded in these areas previously.

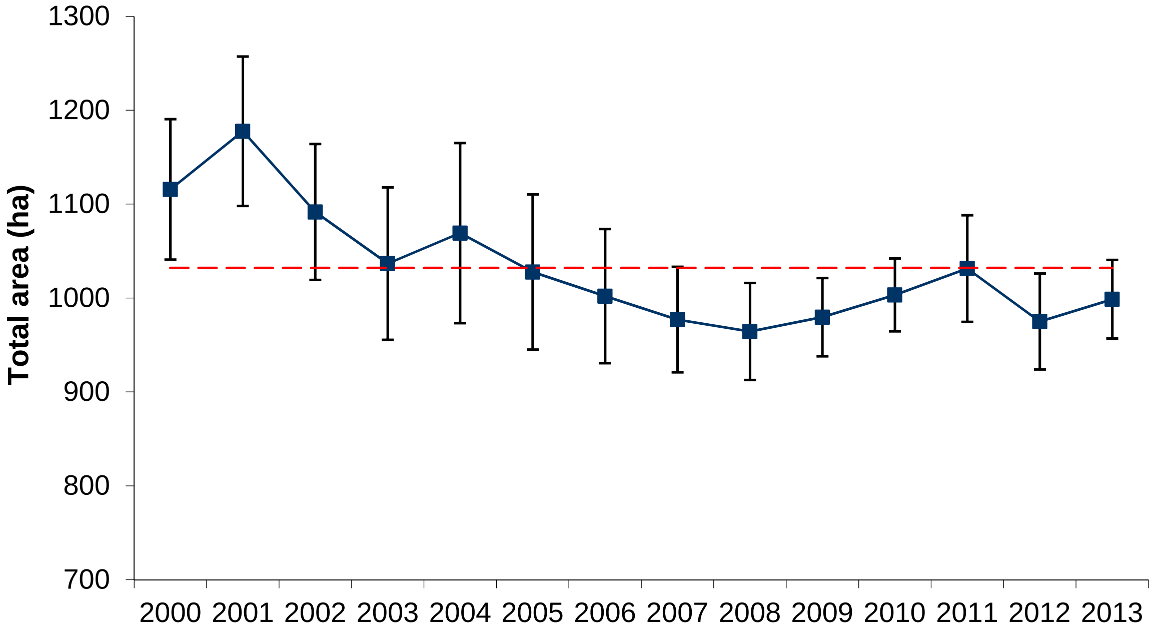
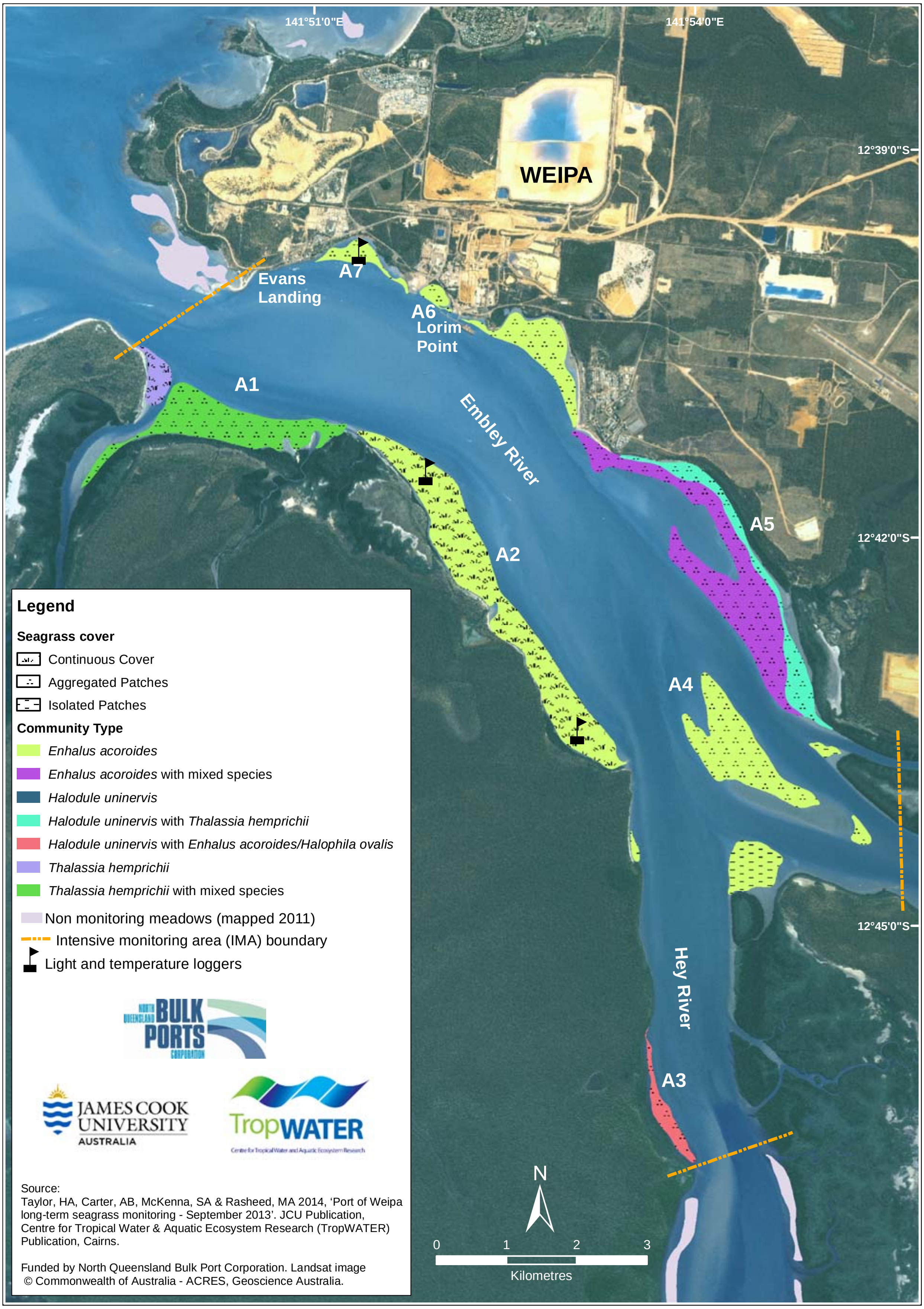


Figure 2 Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2013 (error bars = "R" reliability estimate). Red dashed line indicates 14-year mean of total meadow area.

Map 4. Meadow type and cover for seagrass meadows within the Intensive Monitoring Area 2013



3.3 Comparison of core monitoring meadows

Monitoring in the 5 core representative meadows show seagrasses in the Port of Weipa were in a good condition in 2013 with biomass (density), area and species composition of most monitoring meadows close to or above the long term average (Figures 3-7; Appendix). The only exception was for the *Halodule uninervis* dominated meadow in the Hey River (A3) which had an area more than 20% below the long term average (Figure 4).

Monitoring meadows of the largest growing species found in Weipa, *Enhalus acoroides,* were all in good condition in 2013. The area of all three of these meadows (A2; A6 & A7) was above their long term averages (Figures 3; 6; 7). Biomass for the two meadows on the port infrastructure side of the Embley River (A6 & A7) significantly increased from 2012 to 2013 (Figures 6 & 7; Appendix) and on the opposite side of the river the largest monitoring meadow (A2) had a similar biomass to 2012 and remained close to the long term average. The 2013 monitoring showed a reversal of a 5 year declining trend in biomass for the seagrass meadow between Evans Landing and Humbug Wharves (A7) where a significant increase in biomass was recorded (Appendix; Figure 7). Biomass of meadow A6 adjacent to the Lorim Point wharves was also the highest recorded to date in the 13 years of the monitoring program (Figure 6).

Previously concerns have been raised regarding the resilience of meadow A2 which had a declining trend in biomass from 2000 to 2009 (Figure 3). Biomass of this meadow has stabilised over the last 2 years and was above the long-term average in 2013. An analysis of biomass hotspots within this meadow over time indicates that biomass was more evenly distributed with less obvious areas of low biomass as well as fewer dense hotspots compared with previous years (Map 5). Area of this meadow has been relatively stable over the life of the monitoring program and was at its highest recorded size in 2013.

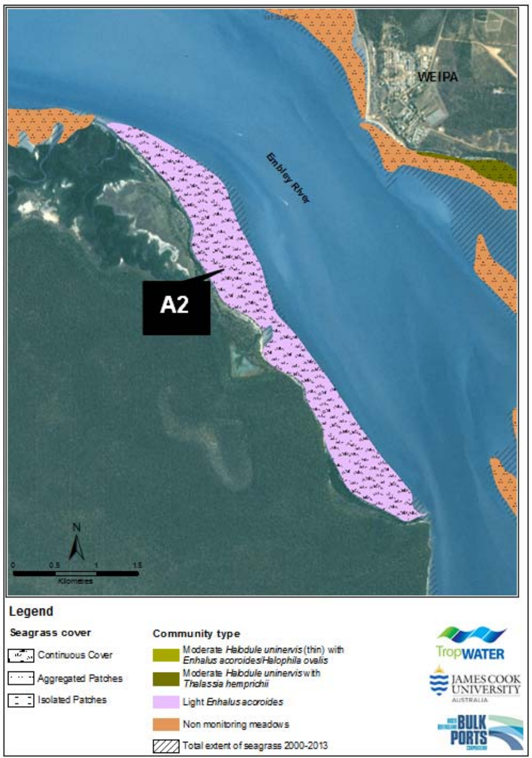
In 2013, the densest meadow was the small *E. acoroides* dominated A6 meadow on the northern banks of the Embley River which more than doubled in biomass from the previous year to 13.9 ± 4.8 g DW m^{-2} (Figure 6). The increase in biomass occurred at the deepest areas of the meadow, whilst biomass of the shallower regions was typical compared to previous years. In the first four years of monitoring (2000-2003) biomass of this meadow was relatively high and stable. In 2004, biomass significantly declined to its lowest recorded density of 1.1 ± 0.4 g DW m^{-2} and had remained relatively low until 2013 (Appendix 2). The increase in this meadow at the deeper margins would suggest improved light conditions had occurred, possibly associated with lower rainfall and an increased occurrence of low tides during the middle of the day in 2013 (see climate section 3.4).

Both intertidal *H. uninervis* dominated meadows (A3 & A5) had biomass above their long term averages in 2013 (Figures 4 & 5). However while biomass increased the area of the meadow declined to be more than than 20% below the long term average resulting in its condition being listed as of “concern” (Map 1; Figure 4). This was the second consecutive year that there has been a decline in meadow area for A3, but the change remained within the range of meadow reliability estimates (see methods 2.2.2) and biomass remained above the long term average.

The species composition of seagrass in the core monitoring meadows was largely the same as that recorded in 2012, with no evidence of substantial shifts in species towards colonising type species that would lead to a concern in meadow condition. There were some declines in the amount of *Thalassia hemprichii* in meadows A2 and A5 from 2012 to 2013, but these were corrections of increases in this species that occurred between 2011 and 2012 (Figures 3 & 5).

Meadow patchiness varied significantly between years in the *Halodule uninervis m*eadows (A3 & A5) (logistic regression, $p < 0.05$), but not in the denser *Enhalus acoroides m*eadows (A2, A6 7 A7).

Meadow A2 condition: Good
Biomass: Good
Area: Good
Species composition: Stable
Enhalus acoroides meadow



Biomass and area condition index

Condition index	Biomass	Area
Good	Less than 20% below the long term average	Less than 10% below the long term average
Concern	Between 20% and 50% below the long term average	Between 10% and 20% below the long term average
Poor	Greater than 50% below the long term average	Greater than 20% below the long term average

—●— Annual mean

– – – Long term mean

Species composition figures

- *Enhalus acoroides*
- *Halodule uninervis* (narrow)
- *Halophila ovalis*
- *Thalassia hemprichii*

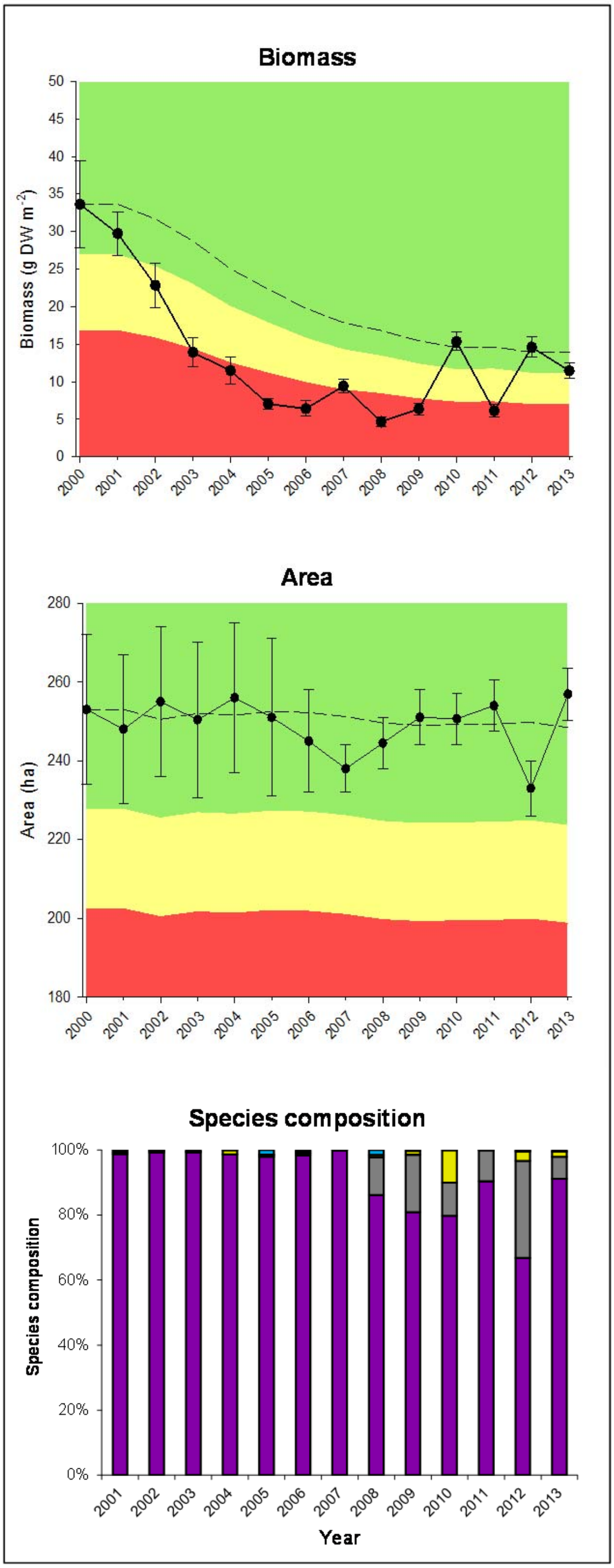
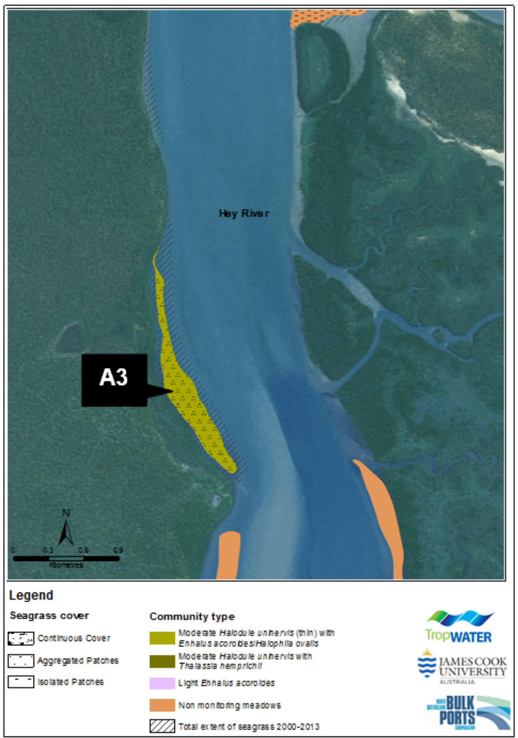


Figure 3. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated core monitoring meadow A2 in Weipa from 2000 to 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadow A3 condition: Concern
Biomass: Good
Area: Concern
Species composition: Stable
Halodule uninervis meadow



Biomass and area condition index

Condition index	Biomass	Area
Good	Less than 50% below the long term average	Less than 20% below the long term average
Concern	Between 50% and 80% below the long term average	Between 20% and 50% below the long term average
Poor	Greater than 80% below the long term average	Greater than 50% below the long term average

Annual mean

Long term mean

Species composition figures

Halodule uninervis (narrow)

Halophila ovalis

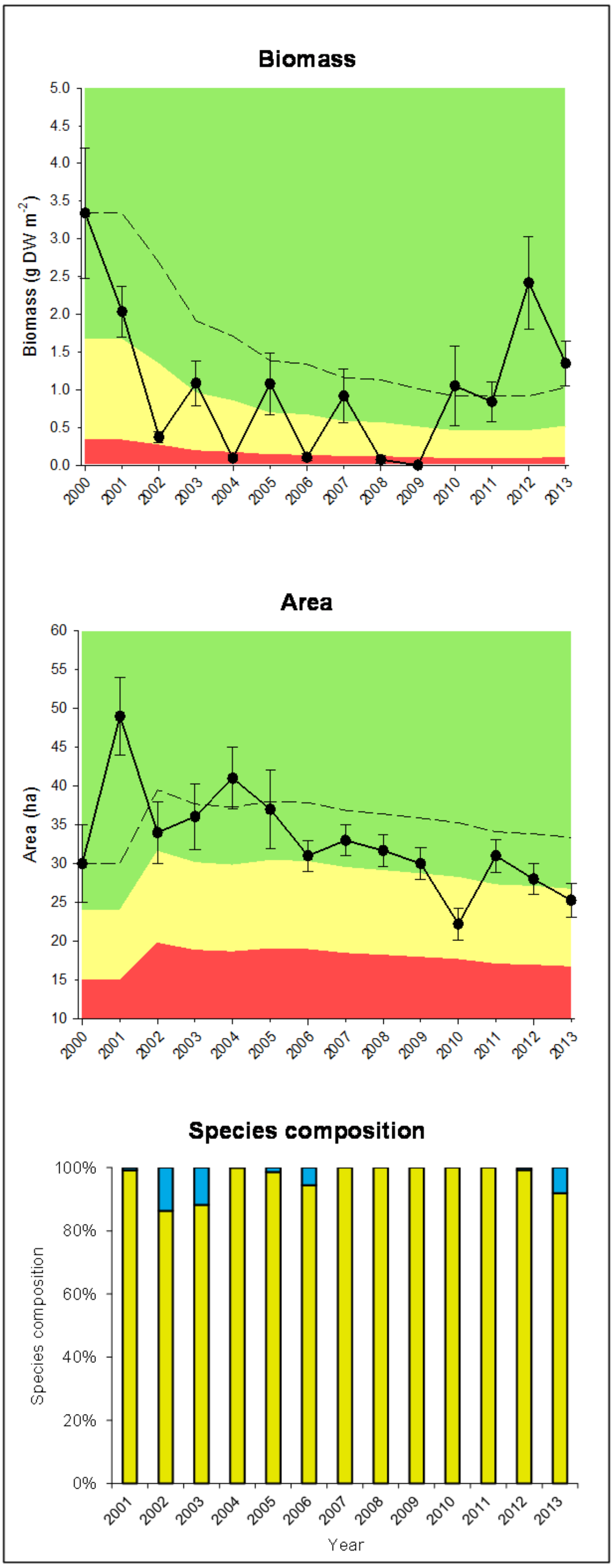
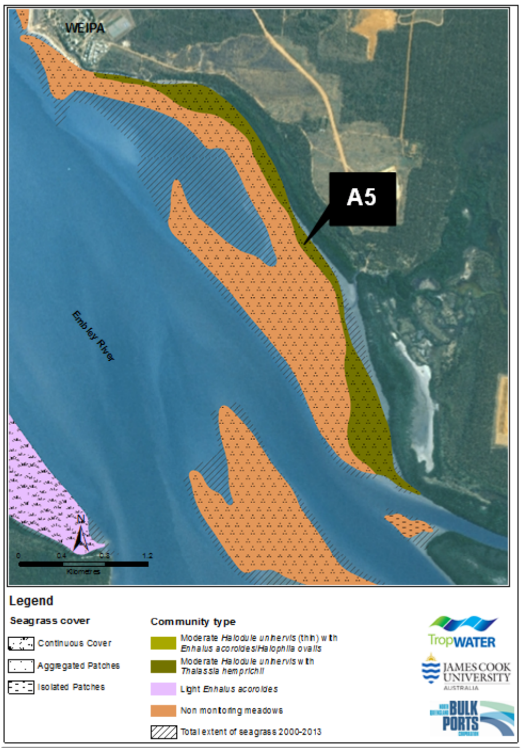


Figure 4. Changes in biomass, area and species composition for the *Halodule uninervis* dominated core monitoring meadow A3 in Weipa from 2000 to 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadow A5 condition: Good
Biomass: Good
Area: Good
Species composition: Stable
Halodule uninervis meadow



Biomass and area condition index

Condition index	Biomass	Area
Good	Less than 50% below the long term average	Less than 20% below the long term average
Concern	Between 50% and 80% below the long term average	Between 20% and 50% below the long term average
Poor	Greater than 80% below the long term average	Greater than 50% below the long term average

Annual mean

Long term mean

Species composition figures

Halodule uninervis (narrow)

Halophila ovalis

Thalassia hemprichii

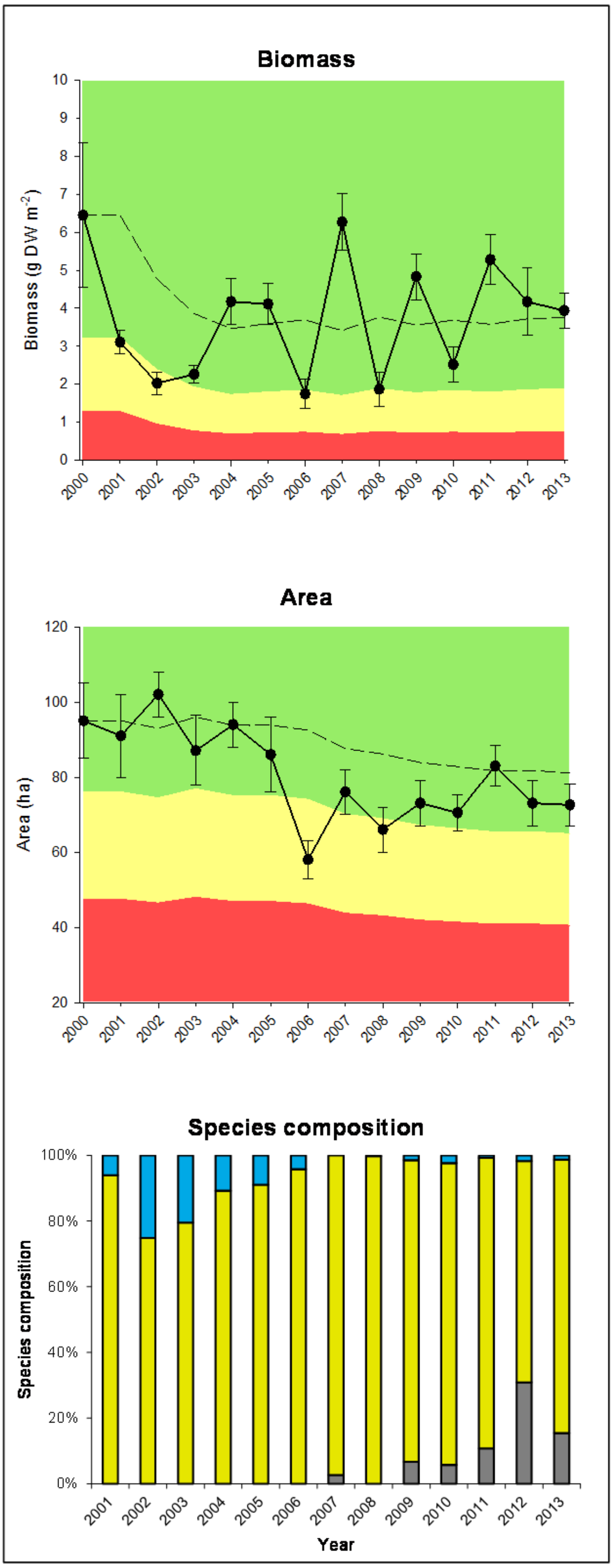


Figure 5. Changes in biomass, area and species composition for the *Halodule uninervis* dominated core monitoring meadow A5 in Weipa from 2000 to 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

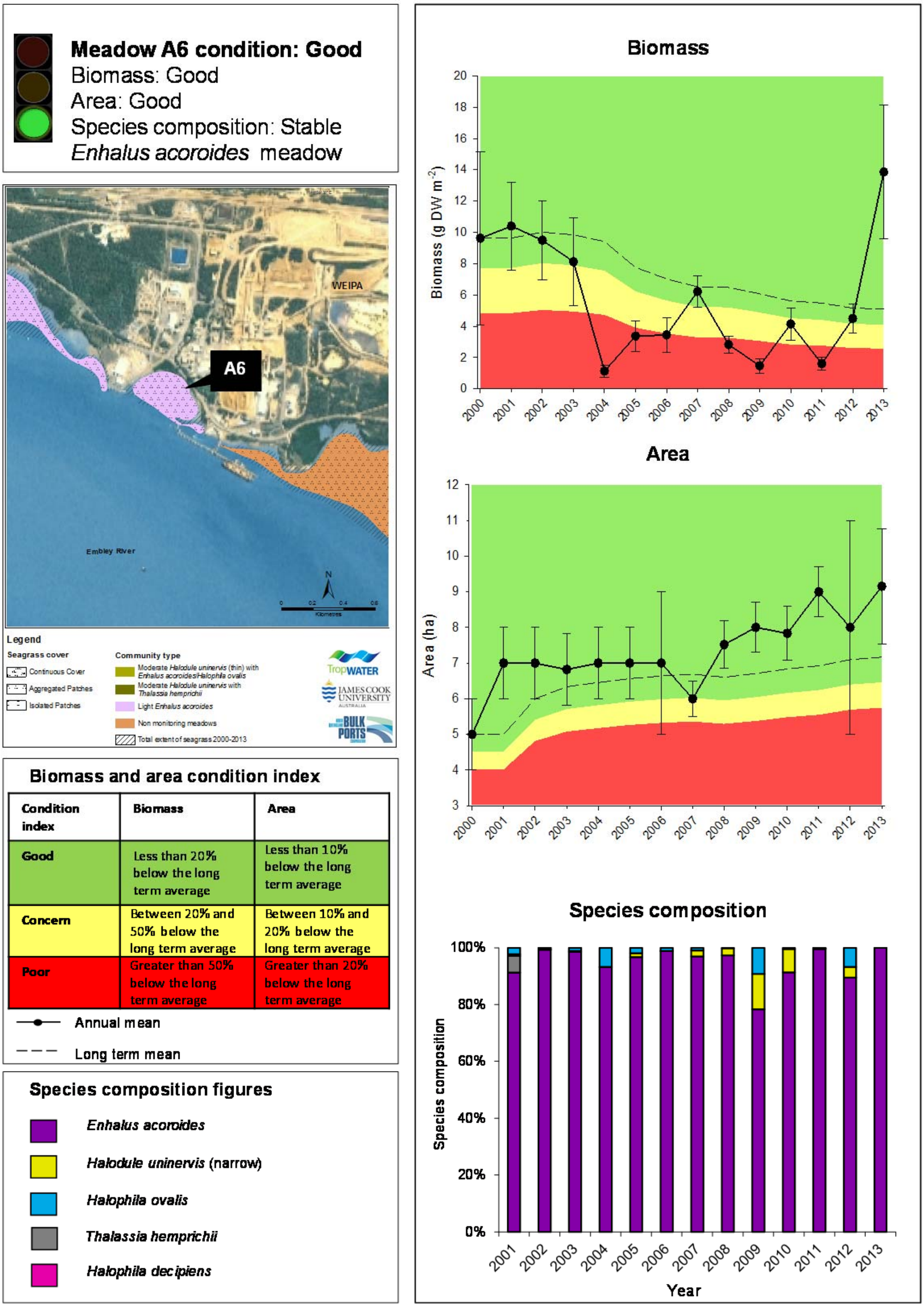
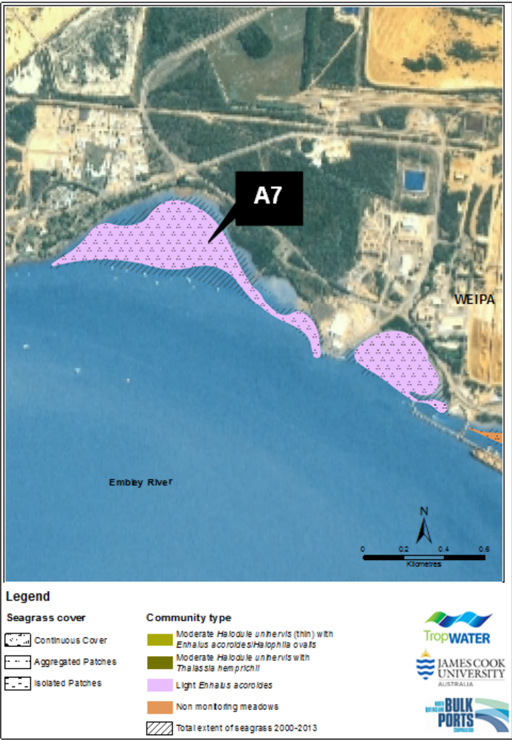


Figure 6. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated core monitoring meadow A6 in Weipa from 2000 to 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadow A7 condition: Good
Biomass: Good
Area: Good
Species composition: Stable
Enhalus acoroides meadow



Biomass and area condition index

Condition index	Biomass	Area
Good	Less than 20% below the long term average	Less than 10% below the long term average
Concern	Between 20% and 50% below the long term average	Between 10% and 20% below the long term average
Poor	Greater than 50% below the long term average	Greater than 20% below the long term average

Annual mean
Long term mean

Species composition figures

- *Enhalus acoroides*
- *Halodule uninervis* (narrow)
- *Halophila ovalis*
- *Halophila decipiens*

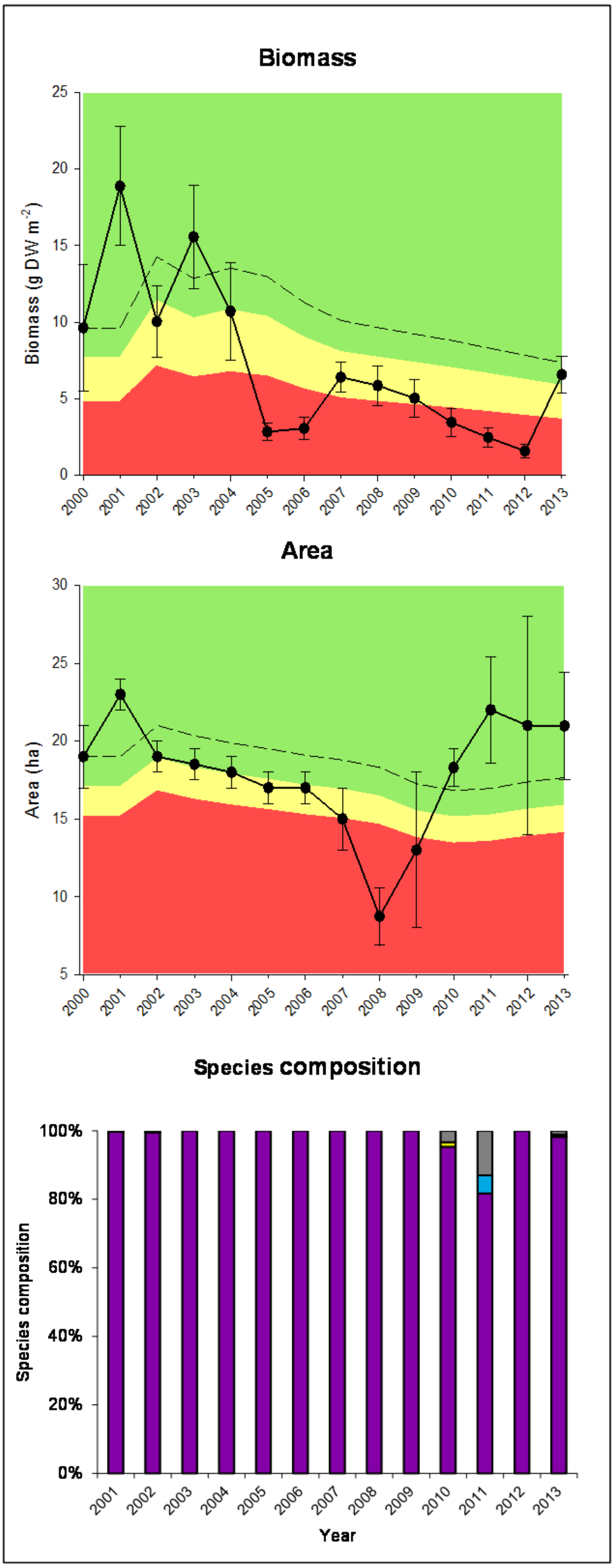
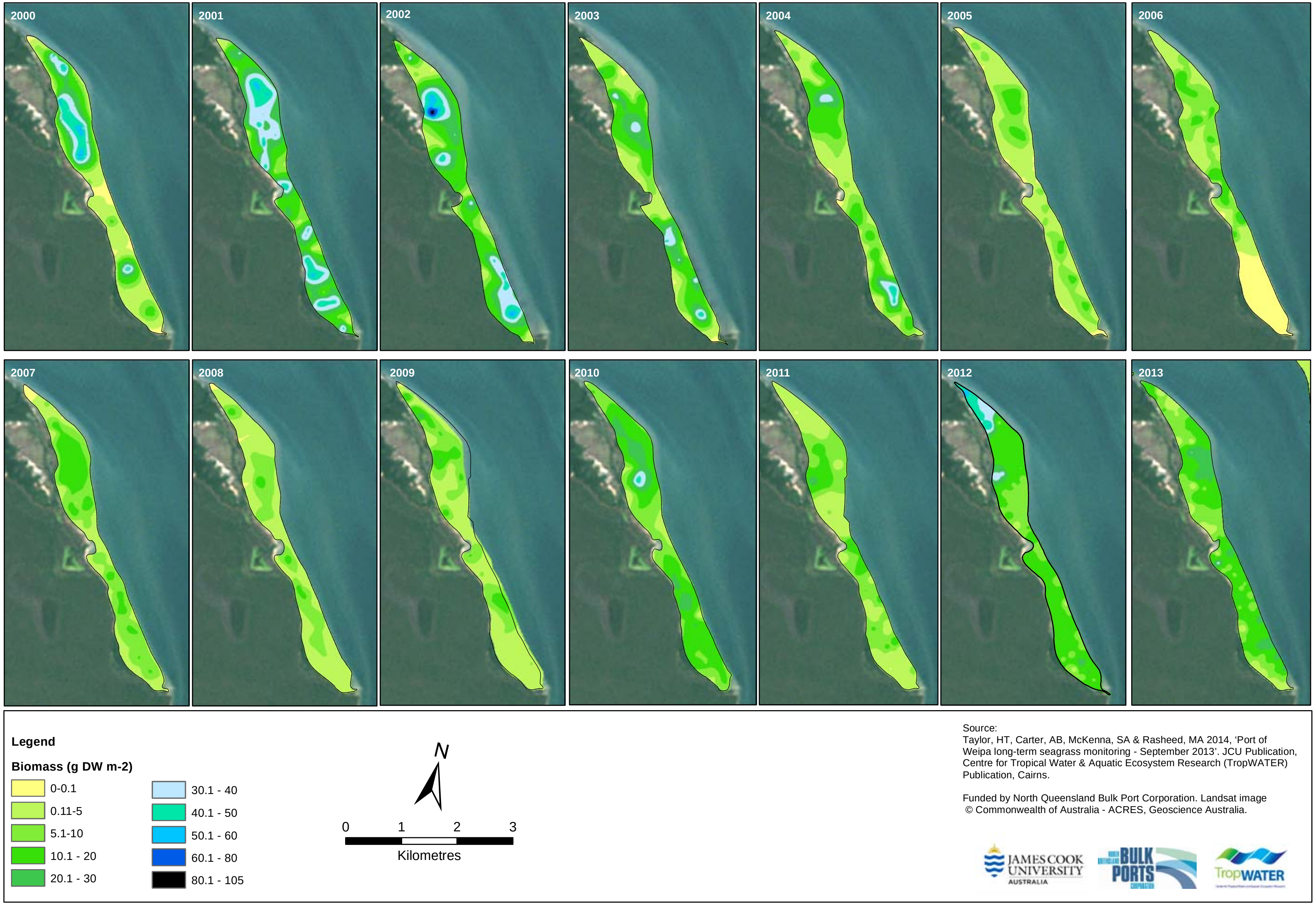


Figure 7. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated core monitoring meadow A7 in Weipa from 2000 to 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

Map 5. Density of seagrass biomass in the A2 meadow from 2000-2013.



3.4 Weipa climate data and seagrass change

3.4.1 Rainfall

Total annual rainfall in Weipa in the 12 months preceding the 2013 survey was 1727 mm. Rainfall in 2013 was 219 mm below the long-term average and much reduced from the high rainfall years experienced in 2012 and 2011 (Figure 8 inset). Rainfall was highly variable between months, and showed a typical tropical wet and dry season pattern. One point of interest in 2013 was that over 52% of the annual rainfall fell during the month of January; it was also the wettest January in the last 20 years (Figure 8).

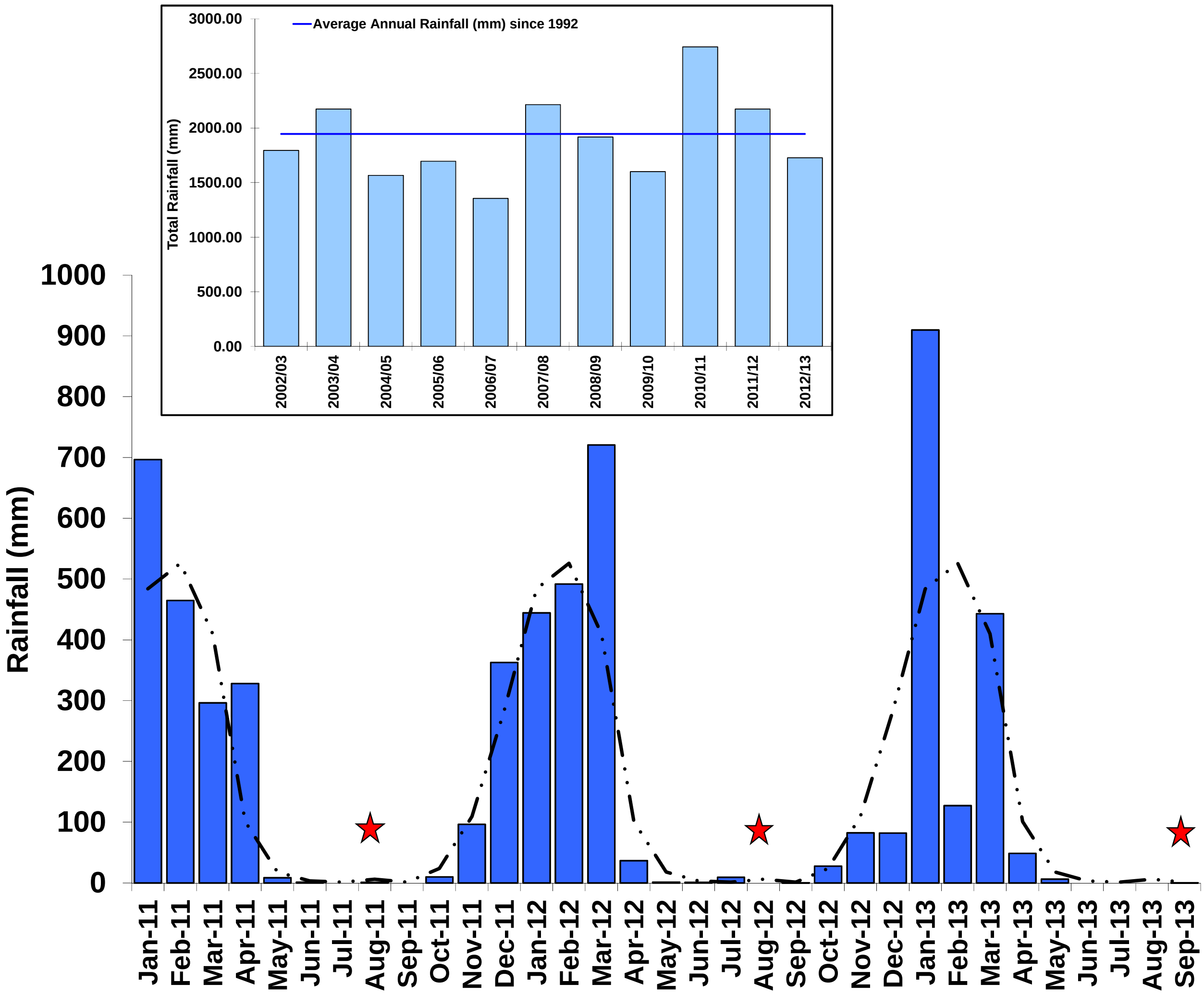


Figure 8. Total monthly rainfall (mm) from January 1 2011 – September 30 2013 and (inset) total annual rainfall for the 12 months preceding each survey from 1999/2000 – 2012/2013 recorded at Weipa airport (Bureau of Meteorology, Station 027045). Red stars indicate timing of annual surveys.

3.4.2 Tidal exposure

Intertidal banks at Weipa were exposed for a record (since monitoring began in 2000) total of 537 hours during the 12 months prior to the September 2013 monitoring survey, a 55% increase from 2012. It was the first time since 2008 that total daytime tidal exposure has been above the total annual 428 hour average (Figure 9). The number of hours intertidal seagrass banks were exposed during the day was generally higher over the winter period, peaking in July at 140 hours average exposure, and lower in summer where intertidal banks rarely exposed (Figure 10). Exposure was above average for the immediate six months preceding the 2013 survey (Figure 10). In 2013 total hours exposed three months prior to the survey was 77 hours above the average 269 hours exposure, in opposition of the trend of relatively low exposure in the three months prior to each survey seen from 2008-2011. In 2013 intertidal meadows were exposed for 98 hours one month prior to the monitoring survey, closer to the average 89 hours measured between 2000 and 2013 (Figure 11).

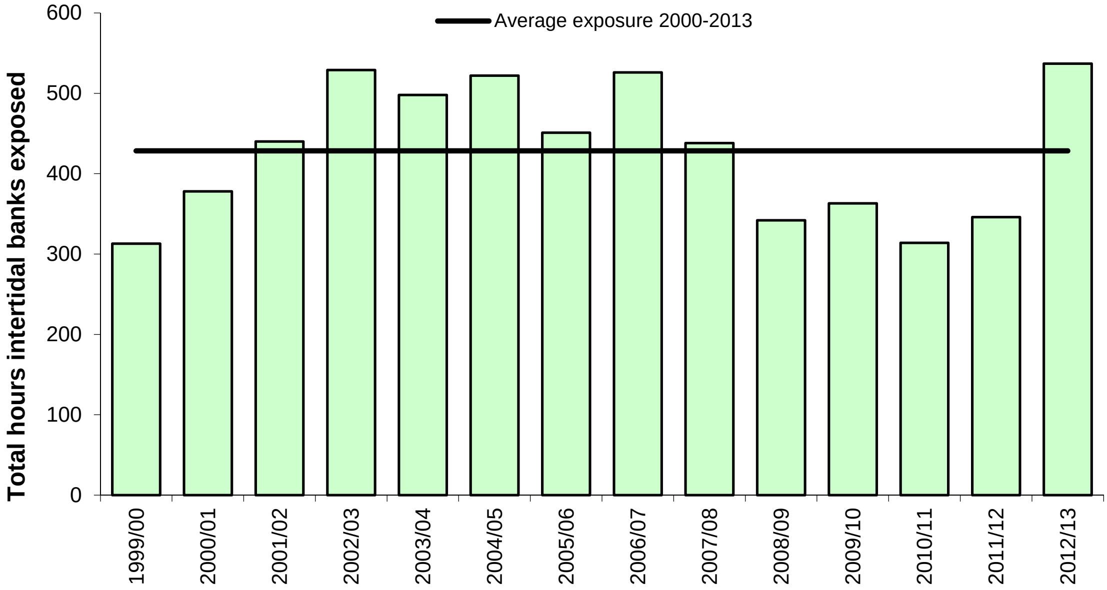


Figure 9. Total number of daytime hours intertidal banks are exposed (<0.9m tidal height) in Weipa in the 12 months preceding each monitoring survey from 2000 – 2013. Tidal data © The State of Queensland (Department of Transport and Main Roads) 2013, Tidal Data.

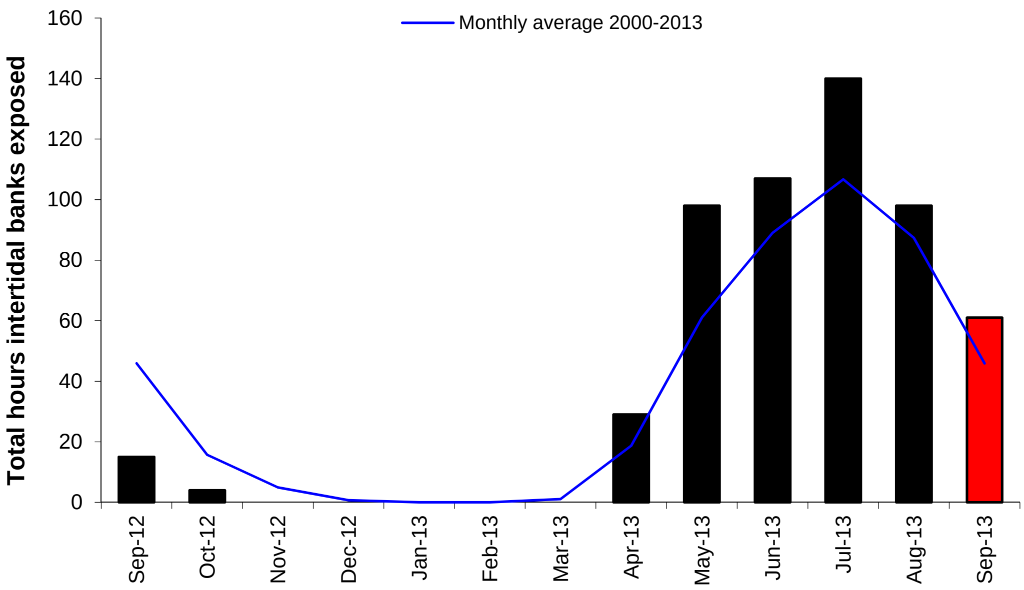


Figure 10. Monthly total number of daytime hours intertidal banks are exposed (<0.9m tidal height) in Weipa in the 12 months preceding the 2013 monitoring survey. Red bar indicates month when monitoring survey occurred. Tidal data © The State of Queensland (Department of Transport and Main Roads) 2013, Tidal Data.

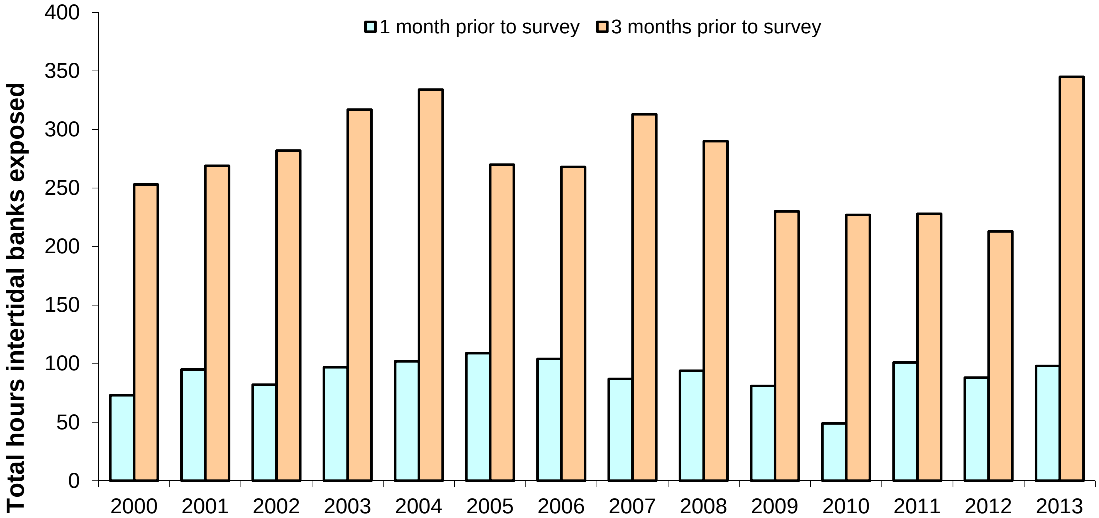


Figure 11. Total number of daytime hours intertidal banks are exposed (<0.9m tidal height) in Weipa in the 1 and 3 months preceding each monitoring survey from 2000-2013. Tidal data © The State of Queensland (Department of Transport and Main Roads) 2013, Tidal Data.

3.4.3 Light

Generally, mean daily PAR levels were between 1-3% higher in 2013 than that recorded in 2012. Total daily PAR in the shallower intertidal A2 meadow was greater and more variable than in the deeper intertidal A7 meadow. Mean daily PAR in the 12 months prior to the September 2013 survey at meadow A7 was 7.7 $\pm$ 0.2 mol m^{-2} day^{-1} compared with 10.7 $\pm$ 0.6 and 13.1 $\pm$ 0.7 mol m^{-2} day^{-1} in the intertidal sites at A2-1 (north) and A2-2 (south), respectively (Figure 12a-c). Total daily PAR ranged from less than 0.001 mol m^{-2} day^{-1} at all three sites, to a maximum daily PAR of 21.2 mol m^{-2} day^{-1} in A7, and 31.8 and 39.1 mol m^{-2} day^{-1} at sites A2-1 and A2-2, respectively (Figure 12a-c). The lowest values recorded were in January 2013 which coincided with historically high rainfall levels (Figure 8). Variation in PAR within the A2 meadow is likely due to loggers deployed approximately 4km apart experiencing slightly different exposure periods.

Tidal cycles accounted for much of the daily variation in PAR. Total daily PAR at intertidal seagrass meadows was heavily influenced by the timing of the low tide. A low tide around midday (defined as between 10am and 2pm) left the PAR loggers exposed during the time when sunlight was strongest, resulting in substantially higher PAR (Figure 12d). In contrast, a midday high tide left the PAR loggers completely submerged during the brightest part of the day with subsequent low total daily PAR values.

Logger failures that have occurred during wet seasons have made it difficult to derive a definitive relationship between PAR and rainfall, however, the PAR data set obtained so far indicates a decrease in PAR between October and March each year, coinciding with increased rainfall (Figure 13). Upgrades to new more robust wiper units were made from June 2013 to decrease the likelihood of data losses during future wet seasons.

3.4.4 Water temperature

The average daily water temperature in the shallow intertidal A2 meadow was 28.8 and 29.1°C (at A2-1 and A2-2 sites respectively) however maximum daily water temperature reached as high as 40.1°C (Figure 12a-c). Average daily water temperature was very similar in the deeper intertidal A7 (32.2°C) although maximum water temperature peaked at a much lower 33.2°C. Within-meadow average daily water temperature was highly variable, ranging from approximately 24°C to 33°C. Peaks in maximum water temperature at the A2 meadow coincided with peaks in PAR (Figure 12b-c). These peaks coincided with midday low tides when shallow water over the seagrass meadow became heated.

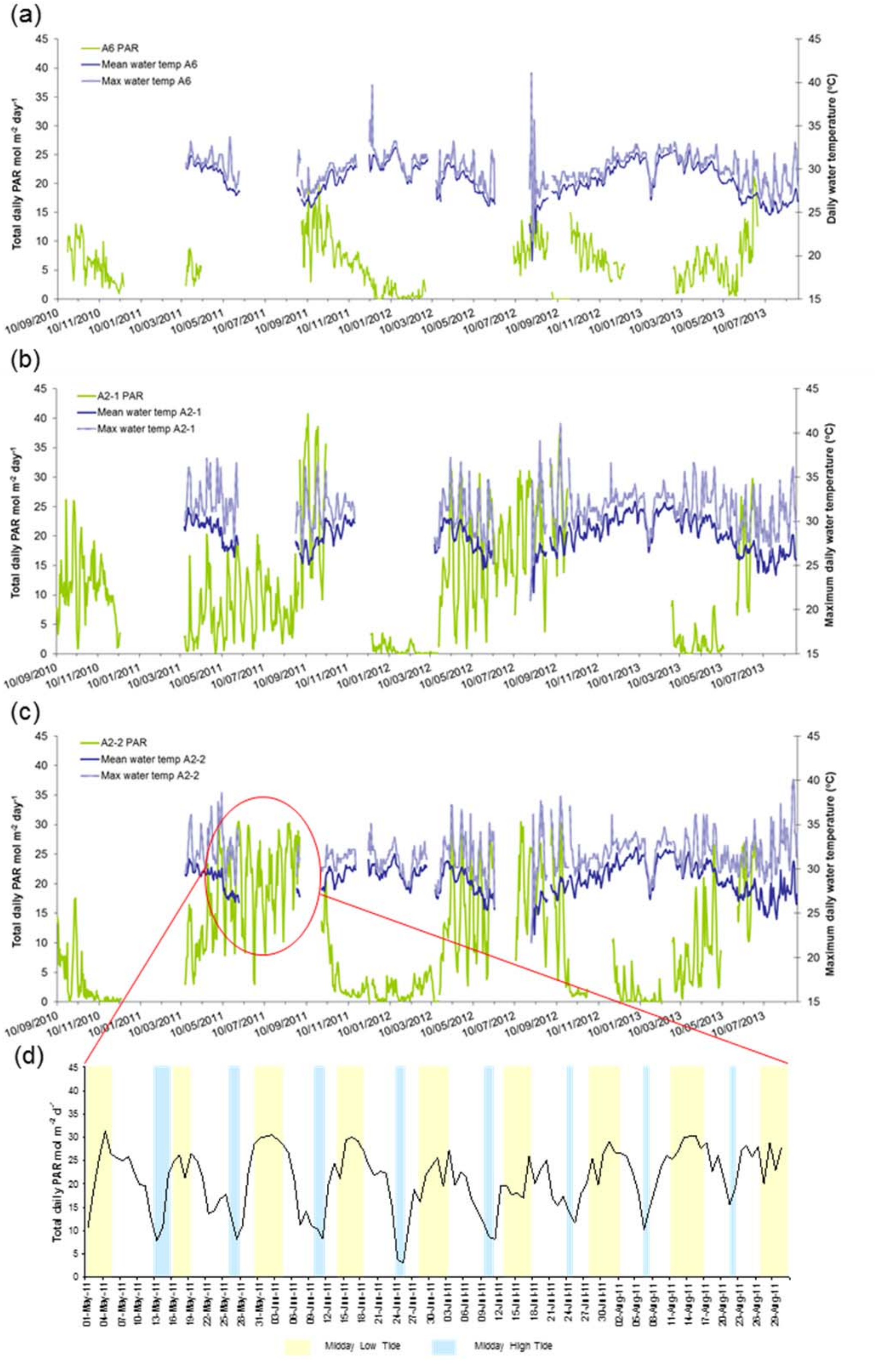


Figure 12. Daily photosynthetically active radiation (PAR mol m^{-2} day^{-1}) and mean and maximum daily water temperature (°C) at Weipa, September 2010 – August 2013, at (a) meadow A7; (b) northern meadow A2-1; (c) southern meadow A2-2; with (d) detail of PAR data with tidal cycles for A2-2, May 1 to Aug 30 2011.

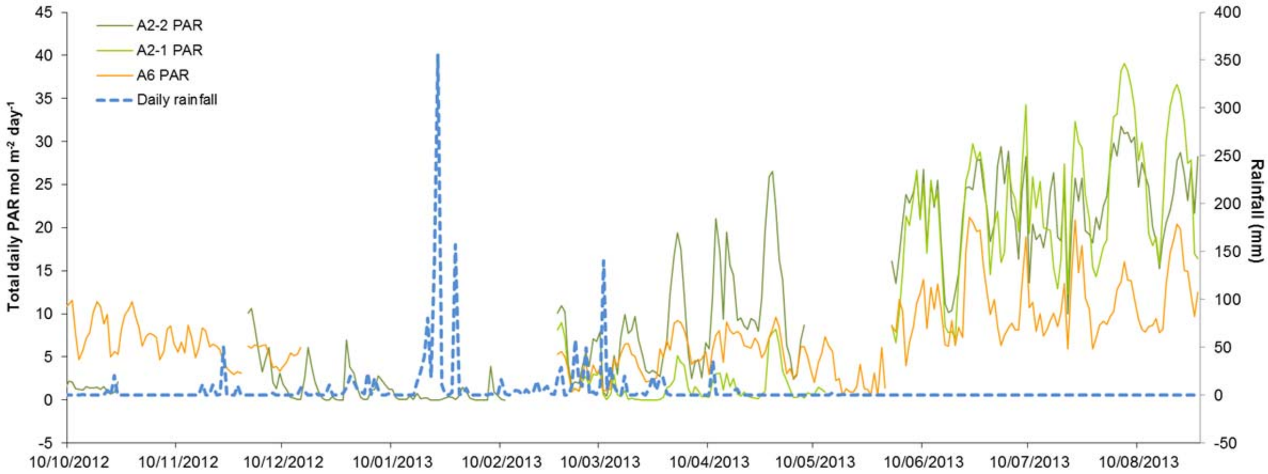


Figure 13. Daily photosynthetically active radiation (PAR mol m^{-2} day^{-1}) and total daily rainfall (mm) at Weipa, October 2012 – August 2013, at Meadow A7 and Meadow A2 northern (A2-1) and southern (A2-2).

4 DISCUSSION

Seagrasses in the Port of Weipa were in a good condition in 2013. Within the Intensive Monitoring Area (IMA) and close to major port operations, seagrass biomass, area and species composition were at or above the long term averages for the meadows. Combined seagrass meadow area in this region increased 6% between 2012 and 2013. The meadow closest to port facilities between Humbug Wharves and Lorim Point recorded its highest biomass and area for the monitoring program since the commencement of monitoring in 2000. In addition the large high biomass *Enhalus acoroides* meadow on the opposite side of the Embley River remained in a good condition and was likely to remain resilient to maintenance dredging operations in the nearby shipping channel.

These results indicate that the marine environment of Weipa including water quality were in a good condition during 2013. Seagrass was likely to have maintained a high resilience to planned maintenance dredging activities in 2014 without the requirement for additional mitigation measures. This is reliant on the maintenance dredging program remaining consistent in duration to previous years and seagrasses not being subjected to major impacts from natural events prior to proposed dredging.

Annual fluctuations in meadow biomass and area in Weipa have been associated with regional and local climate conditions rather than anthropogenic or port-related factors during the life of the monitoring program. In particular, seagrass biomass in Weipa is negatively correlated with tidal exposure during the month prior to monitoring observations, and negatively correlated with the amount of solar radiation (global solar exposure) in the year preceding monitoring observations (Unsworth et al. 2012). Other studies of Indo-Pacific and north Queensland intertidal seagrass meadows have found that long and frequent periods of tidal exposure during the day can result in desiccation, temperature and high light stress, leading to permanent morphological and physiological damage to the plant (Taylor et al. 2013; Unsworth et al. 2012; Stapel 1997; Erftemeijer and Herman 1994). The mechanisms by which exposure leads to seagrass decline are likely related to physiological stress to the leaf structure and photosystems, probably through excess light causing photo damage (Kahn and Durako 2006; Bjork et al. 1999). While clearly tidal air exposure is a major factor in influencing seagrass growth in Weipa there are a range of other variables that are likely to influence seagrass growth as well. Despite above average daytime tidal exposure in July and August 2013 there was a decrease in "burning" of seagrass leaves, indicating Weipa's intertidal seagrasses experienced less exposure-related stress than in 2012 and seagrass remained in good condition. The reasons for this are unclear, but could potentially be due to a range of factors not directly measured in this program such as cloud cover during exposure periods or lower temperatures that reduced the level of physiological stress to the plants during exposure. Also other factors important for seagrass growth such as favourable light and temperature in the lead up to the survey could have offset any negative impacts of air exposure stresses.

Light data collected at Weipa was generally indicative of the naturally turbid environment in which seagrasses grow in the Port of Weipa. Variations in PAR followed the expected responses to weather patterns and tidal exposure, with PAR lowest during midday high tides when a high proportion of PAR is dispersed in the water column. Mean PAR and maximum peaks in PAR were also lower in the deeper intertidal A7 meadow, which remains submerged for longer during low tides compared with the shallower A2 meadow. Data indicates PAR is reduced during the wet season, from approximately October – March each year. Lower PAR in response to rainfall could be due to a high percentage of cloud cover lowering total atmospheric PAR, and/or higher turbidity levels in the water due to an influx of sediment-laden freshwater runoff (Chartrand et al. 2010). The growth, survival and depth penetration of seagrass is directly related to the quality and quantity of light (Dennison 1987; Dennison and Alberte 1985), which is the primary driver of photosynthesis. A thorough analysis of the relationship between PAR and rainfall in Weipa will be conducted as a more complete and longer term data set becomes available. One of the key factors that need to be determined is whether Weipa seagrasses are receiving light levels that meet their minimum light requirements. Collier et al. (2012) reported that *Halodule uninervis* at three island locations in the northern Great Barrier Reef required between 5 and 8.4 mol m^{-2} d^{-1} for growth. The minimum light levels required for growth of *E. acoroides* are poorly studied. Intertidal light levels at Weipa were highly variable and indications were that PAR levels would potentially fall below 5 mol m^{-2} d^{-1} for periods of time during the summer wet season and may play an important role in Weipa seagrass dynamics.

The continued use of light and temperature data loggers within the monitoring meadows will improve interpretations of meadow-scale change (Chartrand et al. 2010). This is because information is recorded on the actual conditions seagrasses experience within the meadow, rather than inferring conditions from regional climate information. In the large *E. acoroides* dominated A2 meadow, where the most significant biomass declines have occurred historically, monitoring of within-meadow variation in water temperature and PAR using loggers in the north and south of the meadow will continue to enhance the ability of the program to pinpoint the causes of seagrass declines and predict where biomass "hotspots" are likely to appear. To better understand the relationships between seagrass change and light and to develop management thresholds that are applicable to the local species, a period of sampling seagrass more frequently, such as quarterly, would be required in the vicinity of the light monitoring stations.

The results of the 2013 survey indicated that current port management strategies and utilisation of the seagrass monitoring in informing dredging have been effective in mitigating potential impacts from port activities. In 2012 there was a capital dredging campaign that occurred where in excess of 900,000m^3 of material was removed, followed by annual maintenance dredging of more than 600,000m^3 in July 2013. The large meadow on the western bank of the Embley River (A2) that is closest to the majority of dredging in the port was in a relatively robust condition in 2013 indicating that it had remained resilient to this increased level of dredging. A large proportion of the capital dredging occurred in the channel in Albatross Bay well away from the seagrass meadow and the condition of seagrasses was assessed prior to the dredging in 2012 to ensure they were not in a vulnerable state. Evidence from the 2013 seagrass monitoring indicates that the seagrasses did not show any measurable impacts from the dredging that occurred in 2012.

The management of seagrass resources in Weipa should remain focused on ensuring the resilience of local seagrasses is maximised and current levels of resilience continue to be considered as part of managing anthropogenic impacts and risks. Repeated pulsed climate impact events on the east coast of Queensland have resulted in a greatly reduced resilience of seagrasses in some areas and reduced their capacity for recovery (Rasheed *et al.* 2014; Petus *et al.* 2014). Given this reduced resilience seagrasses may struggle to withstand stresses that they have previously been able to cope with. Currently the resilience of local seagrasses in Weipa was assessed as being high. This is in stark contrast to many of the seagrasses monitored as part of the Queensland Port's Seagrass Program on the east coast including Cairns (Jarvis *et al.* 2014), Mourilyan (York *et al.* 2014) Townsville (Davies *et al.*2014) and coastal meadows at Abbot Point (McKenna *et al.* 2013) where repeated climate impacts have led to major declines.

In summary, results of the 2013 monitoring indicate:

1. Seagrasses in the Port of Weipa were in a good condition with biomass (density), area and species composition of monitoring meadows all close to or above the long term average.
2. The good condition of seagrasses including the large *Enhalus acoroides* meadow (A2) on the western bank of the Embley River means they should continue to be resilient to planned maintenance dredging activities in 2014 without the requirement for additional mitigation measures.
3. Monitoring of light (Photosynthetically Active Radiation (PAR)) at key seagrass locations indicates that the light environment remained favourable for seagrass growth during 2013.
4. Tidal exposure and solar radiation explain a significant component of previous declines in some intertidal meadows. Additional more frequent assessments of seagrass change in conjunction with PAR monitoring would enable a better understanding of the actual light requirements for seagrasses in Weipa and help to develop relevant light management thresholds.
5. The condition of seagrasses in Weipa and other monitoring locations in northern Cape York and the Gulf of Carpentaria is in contrast to many of the seagrass areas on Queensland's east coast that were significantly impacted by major climate events and remain in a poor or vulnerable condition.

5 APPENDICES

Appendix 1. (A) Logistic regression comparing seagrass presence between years (2001 – 2013) for the Weipa core monitoring meadows A2, A3, A5, A6 and A7. *** Significant difference at $p < 0.001$.

	A2				A3			
	Estimate	**Std. error**	**z-value**	**Pr(>|z|)**	**Estimate**	**Std. error**	**z-value**	**Pr(>|z|)**
Intercept	-20.34	65.56	-0.31	0.76	301.06	51.87	5.80	***
Year	0.01	0.03	0.35	0.73	-0.15	0.03	-5.81	***

	A5				A6			
	Estimate	**Std. error**	**z-value**	**Pr(>|z|)**	**Estimate**	**Std. error**	**z-value**	**Pr(>|z|)**
Intercept	355.50	47.99	7.41	***	6.93e-01	5.62e+01	0.01	0.99
Year	-0.18	0.02	-7.40	***	-2.73e-15	2.80e-02	0.00	1.00

	A7			
	Estimate	**Std. error**	**z-value**	**Pr(>|z|)**
Intercept	1.01	0.21	4.74	***
Year	-0.04	0.03	-1.57	0.12

(B) Results of one-way ANOVA comparing mean biomass between years (2001 – 2013) for the Weipa core monitoring meadows A2, A3, A5, A6 and A7. *** indicates means are significantly different at $p < 0.001$.

Source of variation	A2					A3				
	DF	**SS**	**MS**	**F**	**Pr(>F)**	**DF**	**SS**	**MS**	**F**	**Pr(>F)**
Year	13	608.5	46.81	21.55	***	13	62.53	4.81	9.9	***
Residuals	656	1424.5	2.17			169	82.08	0.49		

Source of variation	A5					A6				
	DF	**SS**	**MS**	**F**	**Pr(>F)**	**DF**	**SS**	**MS**	**F**	**Pr(>F)**
Year	13	142.2	10.96	13.32	***	13	260.6	20.04	7.49	***
Residuals	527	433.6	0.82			240	642.6	2.68		

Source of variation	A7				
	DF	**SS**	**MS**	**F**	**Pr(>F)**
Year	13	243.8	18.75	8.16	***
Residuals	262	602	2.3		

(C) Results of Tukey's post hoc comparison comparing mean above-ground seagrass biomass in the core monitoring meadows A2, A3, A5, A6 and A7 at Weipa. Cells marked with a "Yes" indicates a significant difference in meadow biomass ($p < 0.05$) between comparison years and cells marked "No" indicates no significant difference in meadow biomass between years.

A2	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2000														
2001	No													
2002	No	No												
2003	Yes	Yes	Yes											
2004	Yes	Yes	Yes	No										
2005	Yes	Yes	Yes	Yes	No									
2006	Yes	Yes	Yes	Yes	No	No								
2007	Yes	Yes	Yes	No	No	No	No							
2008	Yes	Yes	Yes	Yes	No	No	No	No						
2009	Yes	Yes	Yes	Yes	No	No	No	No	No					
2010	Yes	Yes	No	No	No	Yes	Yes	No	Yes	Yes				
2011	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes			
2012	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	No	Yes		
2013	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	No	Yes	No	

A3	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2000														
2001	No													
2002	Yes	No												
2003	No	No	No											
2004	Yes	No	No	No										
2005	No	No	No	No	No									
2006	Yes	Yes	No	Yes	No	No								
2007	No	No	Yes	No	Yes	No	Yes							
2008	No	No	No	No	No	No	No	No						
2009	No	No	No	No	No	No	No	No	No					
2010	No	No	Yes	No	Yes	Yes	Yes	No	Yes	No				
2011	No	No	Yes	No	Yes	No	Yes	No	No	No	No			
2012	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No		
2013	No	No	Yes	No	No	No	Yes	No	No	No	No	No	No	

A5	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2000														
2001	No													
2002	No	No												
2003	No	No	No											
2004	No	No	No	No										
2005	No	No	No	No	No									
2006	No	No	No	No	No	No								
2007	No	Yes	Yes	Yes	Yes	Yes	Yes							
2008	No	No	No	No	No	No	No	Yes						
2009	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes					
2010	No	No	No	No	No	No	Yes	No	No	No				
2011	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes			
2012	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	No		
2013	No	No	Yes	Yes	No	No	Yes	No	Yes	No	No	No	No	

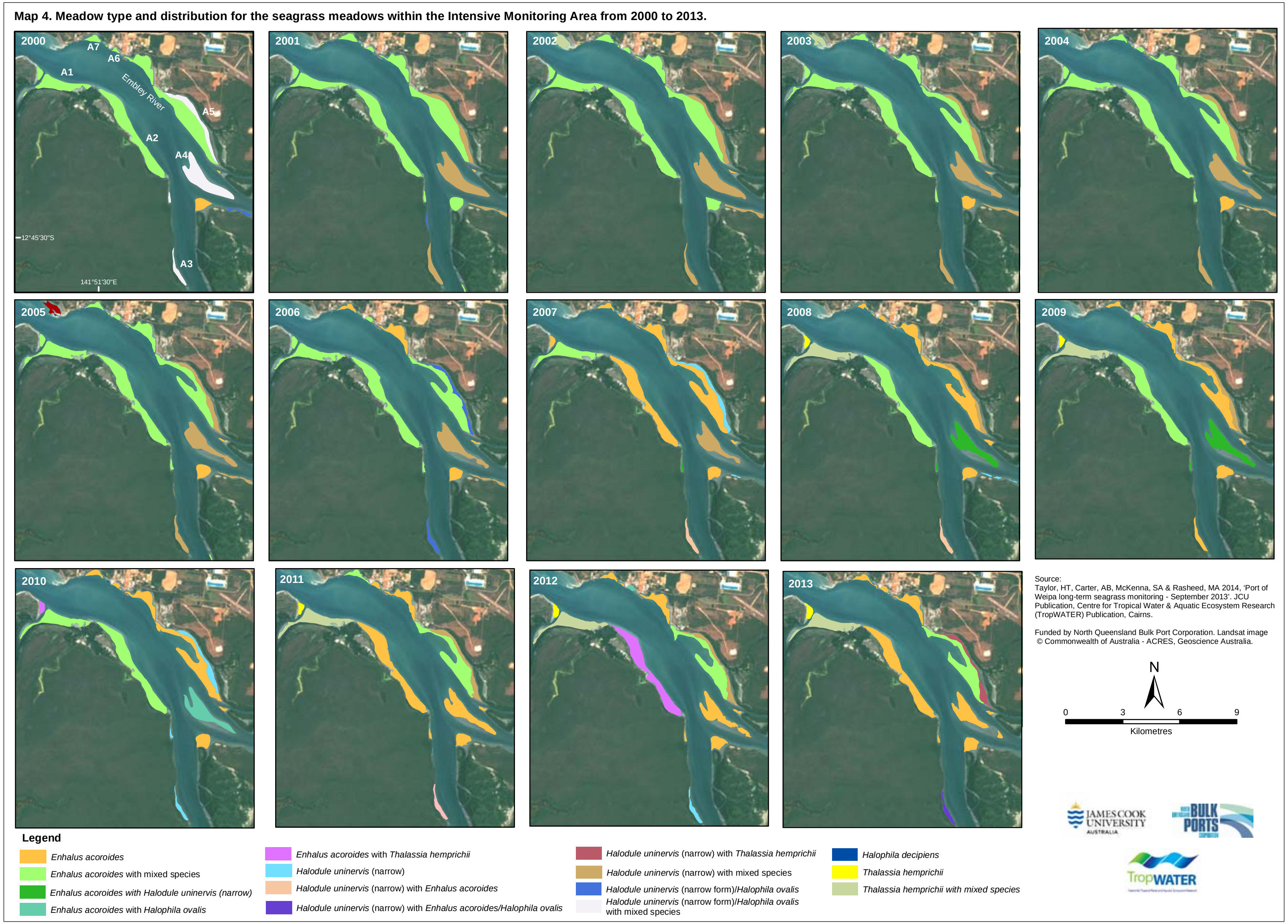
A6	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2000														
2001	No													
2002	No	No												
2003	No	No	No											
2004	Yes	Yes	Yes	Yes										
2005	No	Yes	Yes	No	No									
2006	No	No	No	No	No	No								
2007	No	No	No	No	Yes	Yes	No							
2008	No	No	No	No	Yes	No	No	No						
2009	No	No	No	No	No	No	No	No	No					
2010	No	No	No	No	Yes	No	No	No	No	No				
2011	No	Yes	Yes	Yes	No	No	No	Yes	No	No	No			
2012	No	No	No	No	Yes	No	No	No	No	No	No	Yes		
2013	No	No	No	No	Yes	Yes	Yes	No	No	Yes	No	Yes	No	

A7	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2000														
2001	Yes													
2002	No	Yes												
2003	No	No	No											
2004	No	No	No	No										
2005	No	Yes	No	Yes	Yes									
2006	No	Yes	No	Yes	No	No								
2007	No	Yes	No	Yes	No	No	No							
2008	No	Yes	No	Yes	No	No	No	No						
2009	No	Yes	No	Yes	No	No	No	No	No					
2010	No	Yes	No	Yes	No	No	No	No	No	No				
2011	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No			
2012	No	Yes	No	Yes	No	No	No	No	No	No	No	No		
2013	No	Yes	No	No	No	No	No	No	No	No	No	Yes	No	

(D) Results of Pearson's product-moment correlations comparing the proportion of sites with seagrass present with mean seagrass biomass, 2000-2013.Correlation coefficients (*r*) and significance values ($p < 0.05$).

Meadow	*r*	*p*-value
A2	0.44	0.12
A3	**0.55**	**0.04**
A5	0.29	0.31
A6	-0.15	0.61
A7	0.33	0.25

Appendix 2. Meadow type and distribution for the seagrass meadows within the Intensive Monitoring Area, 2000 – 2013.



Appendix 3. 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 – 2013.

Monitoring Meadow	Mean Biomass ± SE (g DW m^{-2}) (no. of sites)													
	September 2000	**September 2001**	**September 2002**	**September 2003**	**August 2004**	**August 2005**	**August 2006**	**September 2007**	**September 2008**	**September 2009**	**September 2010**	**August 2011**	**August 2012**	**September 2013**
A2 Intertidal *Enhalus* dominated	33.63 ± 5.82 (17)	29.73 ± 2.88 (51)	22.84 ± 2.99 (50)	13.91 ± 1.96 (54)	11.47 ± 1.77 (51)	7.04 ± 0.72 (51)	6.43 ± 1.03 (55)	9.40 ± 1.55 (46)	4.66 ± 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 ± 2.57 (76)
A3 Intertidal *Halodule* dominated	3.34 ± 0.87 (11)	2.04 ± 0.33 (26)	0.37 ± 0.07 (30)	1.63 ± 0.61 (26)	0.31 ± 0.23 (26)	1.08 ± 0.41 (25)	0.11 ± 0.05 (31)	0.92 ± 0.27 (31)	0.24 ± 0.13 (29)	0.00004 ± 0.00004 (31)	1.14 ± 0.57 (24)	0.84 ± 0.26 (44)	2.42 ± 0.61 (34)	1.37 ± 0.26 (68)
A5 Intertidal *Halodule* dominated	6.45 ± 1.90 (9)	3.11 ± 0.31 (51)	2.49 ± 0.52 (51)	2.29 ± 0.23 (50)	4.18 ± 0.61 (50)	4.11 ± 0.54 (50)	1.75 ± 0.38 (56)	6.27 ± 0.80 (54)	1.94 ± 0.45 (48)	5.09 ± 0.61 (76)	2.56 ± 0.47 (61)	5.28 ± 0.66 (77)	4.17 ± 0.88 (60)	3.94 ± 0.66 (70)
A6 Intertidal *Enhalus* dominated	9.63 ± 5.52 (9)	10.4 ± 2.79 (26)	9.5 ± 2.54 (25)	8.31 ± 2.91 (24)	1.14 ± 0.40 (26)	3.37 ± 1.00 (26)	3.45 ± 1.58 (26)	6.22 ± 1.62 (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)	13.85 ± 4.83 (32)
A7 Shallow subtidal *Enhalus* dominated	9.63 ± 4.12 (14)	18.89 ± 3.88 (30)	10.03 ± 2.34 (33)	15.57 ± 3.39 (31)	10.56 ± 2.82 (30)	2.84 ± 0.58 (30)	3.06 ± 0.76 (33)	6.41 ± 2.12 (34)	5.85 ± 1.28 (21)	5.75 ± 1.32 (21)	3.46 ± 0.92 (21)	2.47 ± 0.65 (35)	1.70 ± 0.45 (33)	6.58 ± 2.63 (45)

Appendix 4. Total meadow area ± R (ha) for each core monitoring meadow within the Port of Weipa, 2000 – 2013.

Monitoring Meadow	Total meadow area ± R (ha)													
	September 2000	September 2001	September 2002	September 2003	August 2004	August 2005	August 2006	September 2007	September 2008	September 2009	September 2010	August 2011	August 2012	September 2013
A2 Intertidal *Enhalus* dominated	253 ± 19	248 ± 19	255 ± 19	250 ± 20	255 ± 19	251 ± 20	245 ± 13	238 ± 6	244 ± 6	251 ± 7	251 ± 7	254 ± 7	233 ± 7	257 ± 7
A3 Intertidal *Halodule* dominated	30 ± 5	48 ± 5	34 ± 4	36 ± 4	41 ± 5	37 ± 5	31 ± 2	33 ± 2	32 ± 2	30 ± 2	22 ± 2	31 ± 2	28 ± 2	25 ± 2
A5 Intertidal *Halodule* dominated	95 ± 10	91 ± 10	102 ± 6	87 ± 9	93 ± 10	86 ± 10	58 ± 5	76 ± 6	66 ± 6	73 ± 6	70 ± 5	83 ± 6	73 ± 6	73 ± 6
A6 Intertidal *Enhalus* dominated	5 ± 1	7 ± 1	7 ± 1	7 ± 1	7 ± 1	7 ± 1	7 ± 2	6 ± 0.5	7 ± 0.7	8 ± 0.7	8 ± 0.8	9 ± 1	8 ± 3	9 ± 2
A7 Shallow subtidal *Enhalus* dominated	19 ± 2	23 ± 1	19 ± 1	19 ± 1	18 ± 1	17 ± 1	17 ± 1	15 ± 2	9 ± 2	13 ± 5	18 ± 1	22 ± 3	21 ± 7	21 ± 3
Total	402 ± 37	417 ± 36	417 ± 31	399 ± 35	414 ± 36	398 ± 37	358 ± 23	368 ± 17	358 ± 17	345 ± 19	369 ±15	399 ± 18	363 ± 25	385 ± 19

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