Centre for Tropical Water and Aquatic Ecosystem Research

PORT OF WEIPA LONG-TERM SEAGRASS MONITORING: 2000 - 2014

Taylor HA, Rasheed MA, Carter AB

Report No. 15/02

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Prepared by
Helen Taylor, Michael Rasheed, Alex Carter

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

Seagrass Condition 2014

Good

1. Seagrasses in the Port of Weipa were in a good condition with biomass, area and species composition of monitoring meadows all close to or above the long-term average.

2. The 4,741 ha of seagrass mapped in the broader port limit extent was the second highest recorded since monitoring began in 2000.

3. Results of the seagrass and light monitoring indicate that Weipa's marine environment was in a healthy condition.

4. The good condition of seagrasses, including the large *Enhalus acoroides* meadow (A2) on the western bank of the Embley River, means seagrasses should continue to be resilient to planned maintenance dredging activities in 2015 without the requirement for additional mitigation measures.

5. Monitoring of light (Photosynthetically Active Radiation (PAR)) at key seagrass locations indicates that the light environment remained favourable for seagrass growth during the majority of 2013-2014. The light environment naturally fell below the likely light requirements for seagrass for a short period of time during the peak of the wet season.

6. Tidal exposure and solar radiation explain a significant component of previous declines in some intertidal meadows. More frequent (quarterly) assessments of seagrass change coupled to the PAR monitoring would enable a better understanding of the actual light requirements for seagrasses in Weipa and help to develop relevant light thresholds for management.

7. The good condition of seagrasses in Weipa and other monitoring locations in the Gulf of Carpentaria and Torres Strait contrast with many of the seagrass meadows on Queensland's east coast that were significantly impacted by major climate events and are yet to fully recover.

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 sections 2.5 and 3.3 of this report for further details). Every 3 years all seagrasses within the port limits are remapped (conducted in 2014).

Seagrasses in the Port of Weipa were in a good condition in 2014, with biomass, area and species composition of monitoring meadows all close to or above the long-term average (Map 1). The total area of all seagrasses within the IMA has been relatively stable over the past decade and was higher in 2014 than in 2013 (Figure 1). The only meadow classified as being in “fair” condition was the light biomass *Halodule uninervis* meadow (A5) in the Hey River, which was greater than 10% below the 10 year fixed average in area, however biomass of seagrass remained high compared with the average for this meadow.

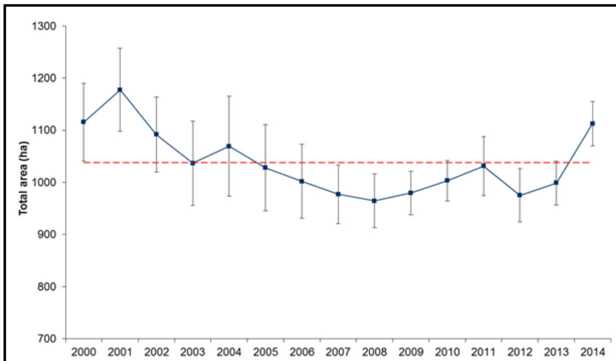
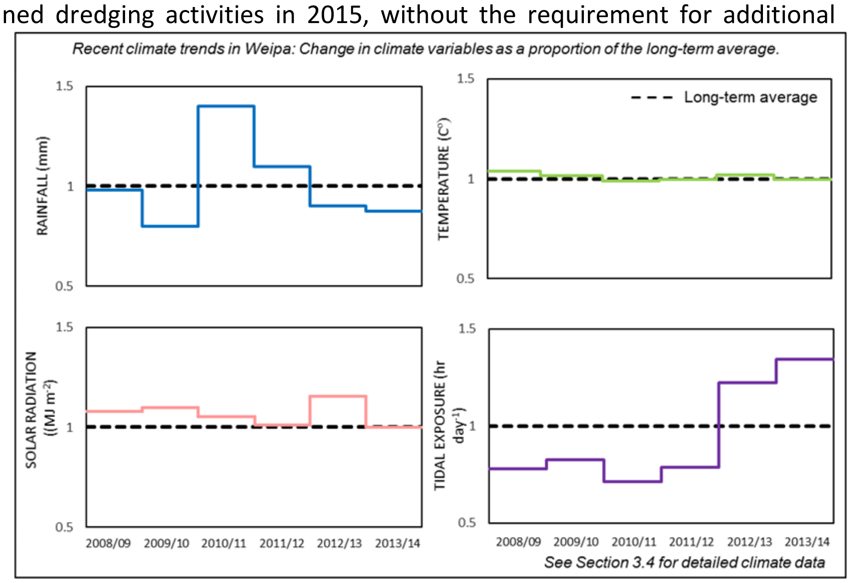


Figure 1. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2014. (error bars = “R” reliability estimate). Red dashed line indicates 15-year mean of total meadow

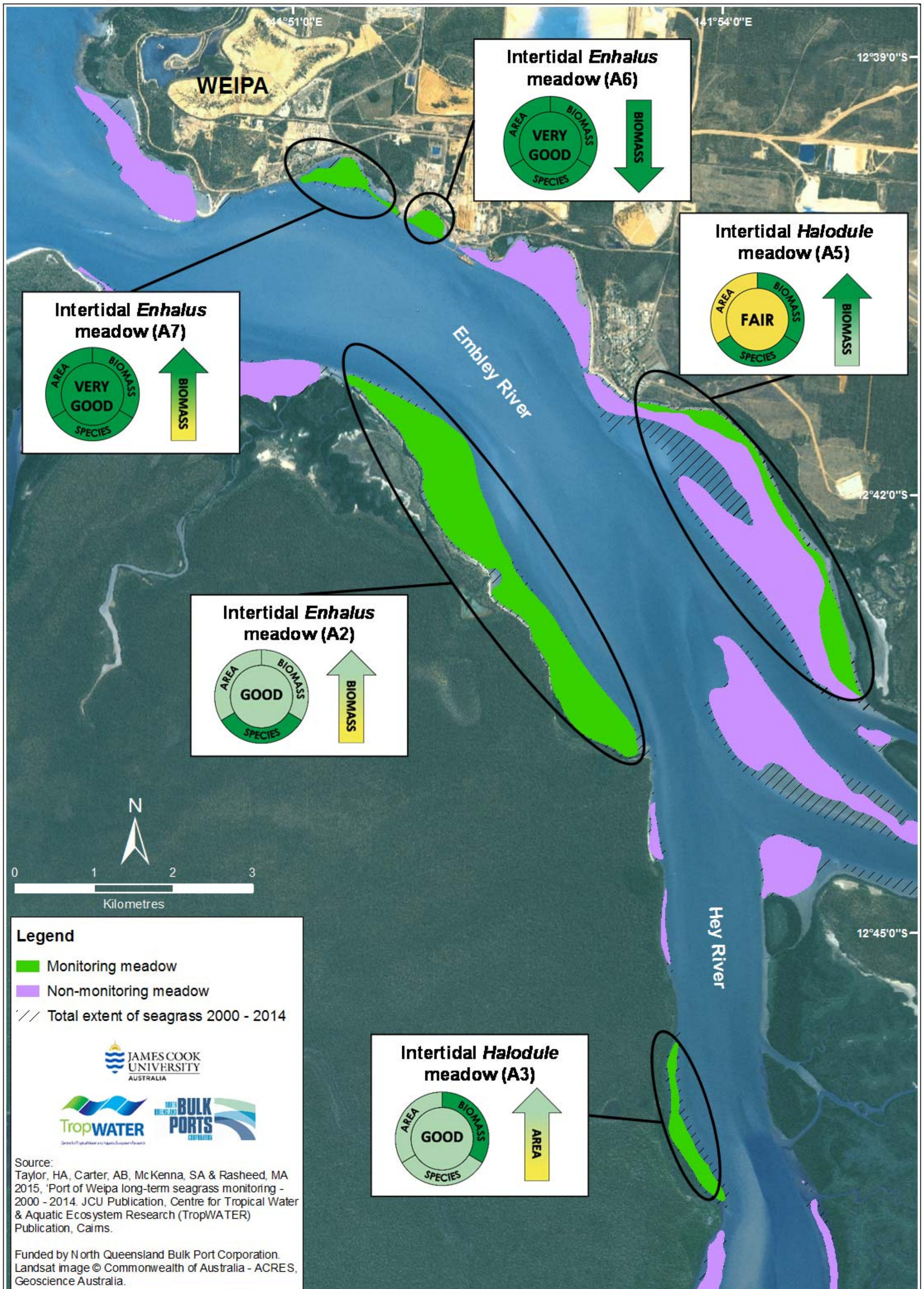
Natural shifts in the amount of daytime tidal exposure of intertidal banks between years has previously led to significant die off and declines in the large and dense *Enhalus acoroides* seagrass meadow opposite Lorim Point (meadow A2) (Unsworth et al. 2012). In 2014 area and biomass of this meadow had increased since 2013 and was above the 10 year fixed average despite a relatively high amount of air exposure of these banks prior to the survey.

Monitoring of light available to seagrasses in Weipa during 2014 indicates that light availability was likely to be favourable for seagrass growth during most of the year. During the peak of the wet season light levels were recorded well below likely seagrass minimum requirements, and for one extended 10 day period were recorded at levels which have been shown to cause deleterious effects on some seagrass species. In order to determine the specific light requirements for the local species in Weipa additional monitoring of seagrass condition during the year at the light monitoring sites, ideally quarterly, would be required. Seagrass meadows appeared resilient to maintenance dredging activities in 2014 and should continue to be resilient to planned dredging activities in 2015, without the requirement for additional mitigation measures, provided the duration of dredging remains relatively short and there are no major losses associated with climate or other impacts leading up to dredging in 2015.



The Weipa seagrass monitoring program forms part of James Cook University’s seagrass assessment and research program that examines condition of seagrasses in the majority of Queensland commercial ports. Seagrasses on western Cape York, Torres Strait and the Gulf of Carpentaria were generally in a good condition, in contrast to seagrasses on the east coast of Queensland that were severely impacted by climate events and cyclones and were yet to fully recover in 2014. For full details of the Queensland ports seagrass monitoring program see www.jcu.edu.au/PortSeagrassQld.

Map 1. Seagrass condition index for Weipa seagrass monitoring meadows in 2014



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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) 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 (Map 2).

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

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

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 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

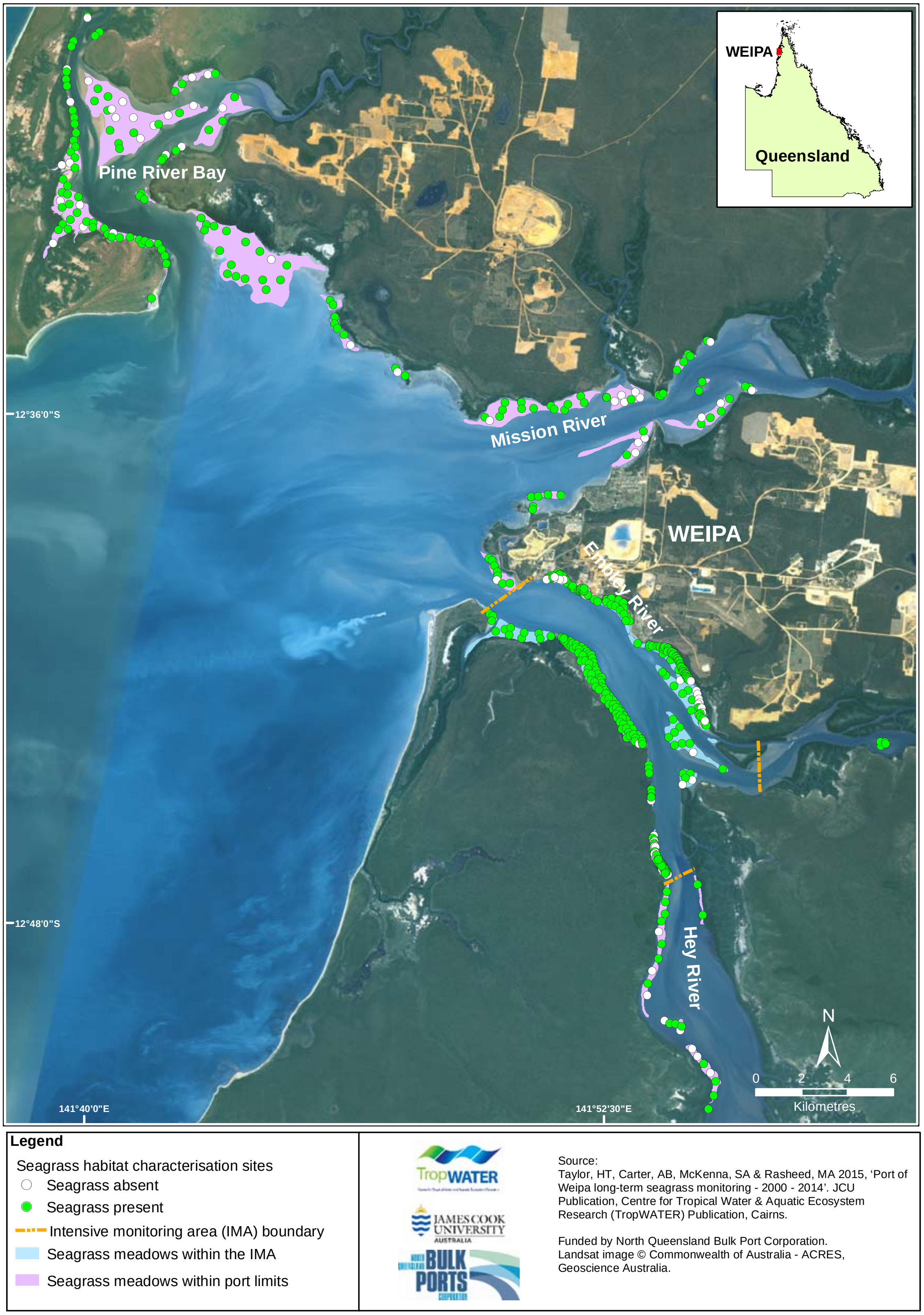
North Queensland Bulk Ports (NQBP) Corporation is responsible for managing and monitoring Weipa's port environment. NQBP has recognised that seagrasses form a key ecological habitat in the Weipa region and commissioned TropWATER to establish a long-term seagrass monitoring program for Weipa's port in 2000 (Roelofs et al. 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 2014 the annual maintenance dredge campaign commenced on July 17 and was completed in 28 days, with 394,524m^3 of dredge material removed. This was a relatively small scale dredge compared with the previous two year's volumes of between 600,000-645,000m^3. 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; 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, 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 (Map 3).

This report presents the results of the long-term seagrass monitoring and whole of port mapping survey conducted in August 2014. The objectives were:

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 and greater port limits;
3. Assess changes in seagrass meadows with previous monitoring surveys;
4. Incorporate the results into the Geographic Information System (GIS) database for the Port of Weipa.

Map 3. Location of 2014 seagrass monitoring 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 9-14, 2014. Annual monitoring over the past 15 years has focused on five core monitoring 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.

Three levels of sampling were used in the August 2014 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 and 4; Appendix 2).
2. Map seagrass distribution and species composition in non-core monitoring meadows within the IMA (Maps 3 and 4).
3. Map seagrass distribution and species composition in seagrass meadows within the greater Weipa port limits and compare with previous whole of port surveys (Maps 3, 6-8).

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, percent 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).

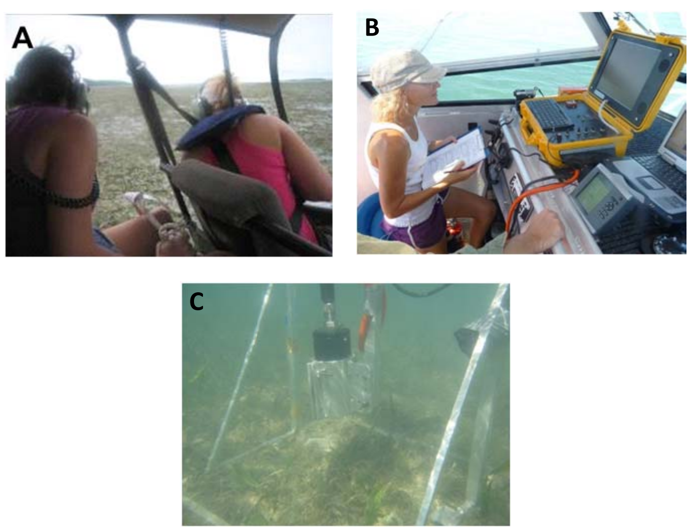


Plate 1. Seagrass methods using (A) helicopter aerial surveillance, and (B,C) boat-based CCTV surveillance.

Results from previous baseline surveys suggested the analysis of biomass for meadows where the large growing species *Enhalus 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 *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 2014 in A3 as *E. acoroides* was absent from the meadow. There was one biomass site for A5 that was excluded.

2.2 Geographic Information System

Spatial data from the August 2014 survey were entered into the Port of Weipa GIS. Three seagrass GIS layers were created in ArcGIS® version 10.1 - site information, seagrass meadow characteristics and seagrass landscape category.

2.2.1 Site information

This includes site data containing seagrass 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 Queensland seagrass meadows (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 and 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 2014.

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 2014.

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 contain 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 contains 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 fifth 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 4) 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 stages. First, a binary generalised linear model 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 among 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 assumptions of ANOVA. Each meadow's data was examined for normality and homogeneous variance and square-root transformations applied to meet these assumptions. Tukey's post hoc analysis was used to test for significant differences in biomass among all combinations of years. Third, a correlation analysis was run on the proportion of sites with seagrass present and the mean biomass for that year. This analysis indicated whether seagrass meadow patchiness and seagrass biomass within each meadow were related. Detailed statistical results are presented in Appendix 1. Statistical analysis was conducted using R (R Development Core Team 2013)

2.5 Seagrass meadow condition index

This is the second year of applying and testing the seagrass meadow condition index. This index was developed for the monitoring meadows and is based on the mean above ground biomass, total meadow area and species composition of each seagrass meadow. We have modified the classifications of the initial index that was rolled out and tested across ports in 2013/2014 by expanding the number of categories from three to five. The previous classifications of seagrass meadow condition: "good", "moderate" or "poor" has been expanded to five classifications: "very good", "good", "fair", "poor" and "very poor" to more closely match other report card programs in Queensland that apply condition indices (i.e. Reef Rescue Marine Monitoring Program, Gladstone Healthy Harbour Program). The index provides a means of comparing current meadow condition and likely resilience to impacts with the known long-term average.

Two different threshold ranges for biomass and three different threshold ranges for area were developed to recognise that some seagrass meadows are historically more stable and others are expected to fluctuate substantially from year to year (highly variable). These differences reflect growth characteristics of species that comprise different meadows, as well as the meadow setting. There are also regional differences within a meadow that reflect the natural growing conditions. This resulted in four classes of monitoring meadow for reporting purposes.

- **Class 1 Meadows -** stable biomass, stable distribution
- **Class 2 Meadows -** variable biomass, stable distribution
- **Class 3 Meadows -** variable biomass, variable distribution (intertidal)
- **Class 4 Meadows -** variable biomass, variable distribution (subtidal)

For biomass and area the current value for each meadow was compared with the average for the meadow from the first 10 years of the program and categorised into a range that corresponded to the five condition categories (Table 3). Ranges for each level of the condition index were selected based on the historical variability of the monitoring meadow representing seagrass condition.

Species composition was assessed qualitatively as "very good" when the species composition remained stable; "good" when there had been minor loss of the climax species; "moderate" when there had been a substantial shift in species toward colonising species indicating disturbance or stress; "poor" when the meadow had shifted to become clearly dominated by colonising species; and "very poor" where there was a complete loss of the climax species. Species shifts are relative and determined on a meadow by meadow basis taking into account both the current years' species composition and historical trends.

It is important to note that tropical seagrass communities vary in condition naturally due to a number of factors including climate. Some monitoring meadows being classified as "poor" condition can be part of the natural range of expected conditions and not necessarily a result of anthropogenic impacts. The index provides a means of comparing current meadow condition and likely resilience to impacts with the known long-term average.

The final condition of each monitoring meadow was 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.

A trend indicator was also added where there has been a substantial increase or decrease in any of the three criteria (biomass, area, species composition) from the previous year. In the condition index this is represented as either an upwards or downwards arrow for the criteria where the change has occurred (Table 3).

Table 3. Threshold levels for grading seagrass indicators for various seagrass meadow classes in the Port of Weipa 2014.

Seagrass indicators/class		Very Good	Good	Fair	Poor	Very Poor
Biomass	Stable	More than 20% above the baseline	Within 20% of the baseline (above or below)	Between 20% and 50% below the baseline	Between 50% and 80% below the baseline	More than 80% below the baseline
	Highly variable	More than 40% above the baseline	Within 40% of the baseline (above or below)	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline
Area	Stable	More than 10% above the baseline	Within 10% of the baseline (above or below)	Between 10% and 30% below the baseline	Between 30% and 50% below the baseline	More than 50% below the baseline
	Highly variable intertidal	More than 20% above the baseline	Within 20% of the baseline (above or below)	Between 20% and 50% below the baseline	Between 50% and 80% below the baseline	More than 80% below the baseline
	Highly variable subtidal	More than 40% above the baseline	Within 40% of the baseline (above or below)	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline
Species composition		Composition remains stable	Some loss of climax species	Shift towards colonising species	Colonising species dominant	Complete loss of climax species
Trend Indicators			Substantial increase from previous year			Substantial decrease from previous year

3 RESULTS

3.1 Seagrass species, distribution and abundance

A total of 567 seagrass habitat characterisation sites were surveyed in the Weipa port limits in August 2014, with seagrass present in 82% of sites (Map 3). Five seagrass species (from two families) were identified. A full list of species present in Weipa is available in previous reports (Roelofs et al. 2003; 2001).

CYMODOCEACEAE TAYLOR		***Halodule uninervis*** (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 August 2014 within the Intensive Monitoring Area (IMA) (Map 4). The total combined seagrass meadow area was 1113 ± 43 ha, a 1% increase in area from September 2013. Seagrass area was above the 14 year average of 1038 ± 66 ha for the first time since 2004 (Figure 2). Individual meadow area ranged from 6 ha to 268 ha.

The dominant seagrass species in each of the core monitoring meadows remained unchanged from 2013. *E. acoroides* dominated seagrass communities in nine of the fourteen meadows within the IMA, including the core monitoring meadows A2, A6 and A7 (Map 4). 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 three 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 24% of sites surveyed within the IMA in 2014, an increase from 4% in 2013 and 17% in 2012. The increase in burning indicates that exposure-related stress was at higher levels for intertidal seagrasses leading up to the survey than in 2013. Dugong feeding trails were observed at a few sites in meadow A5 and were recorded in dense numbers in the meadow closest to the western mouth of the Embley River. Prior to 2014, dugong feeding trails had not been observed between 2011 - 2013 in the IMA.

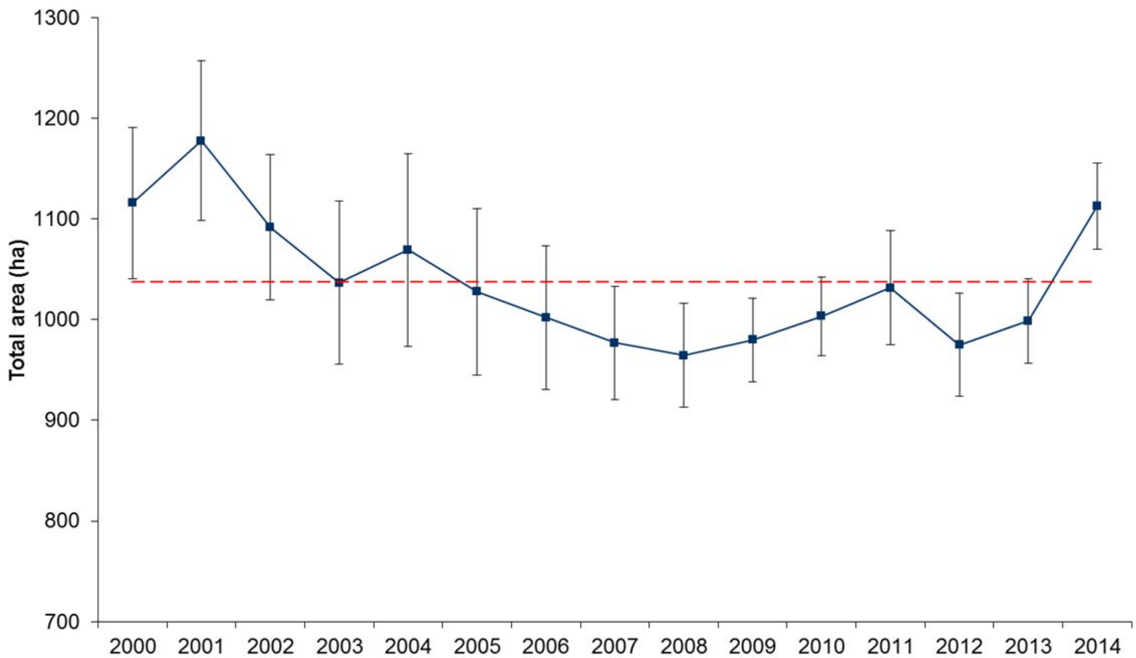
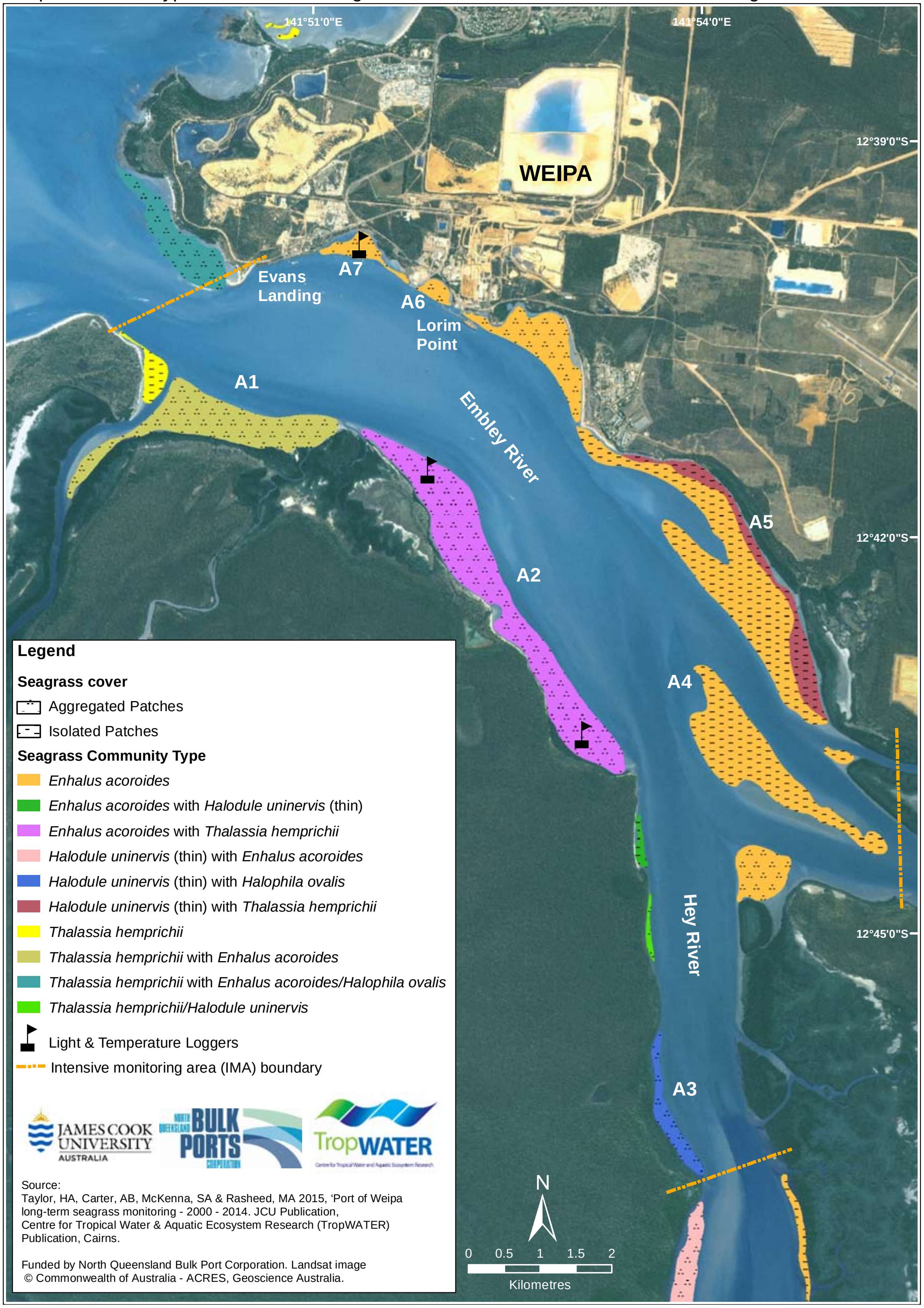


Figure 2 Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2014 (error bars = “R” reliability estimate). Red dashed line indicates 14-year mean of total meadow area.

Map 4. Meadow type and cover for seagrass meadows within the Intensive Monitoring Area 2014



3.3 Comparison of core monitoring meadows

Seagrasses in the five core monitoring meadows in the Port of Weipa were in a good or very good condition in 2014. Seagrass biomass and meadow area was above the long-term average for most monitoring meadows. The exceptions were the *E. acoroides* dominated A2 meadow where biomass was <20% below the baseline (but similar to 2012 and 2013 biomass values), and the *H. uninervis* dominated A5 meadow where meadow area 10-30% below baseline (Figures 3 and 5). There was no evidence of substantial shifts in species composition towards colonising species that would cause concern in meadow condition in any of the monitoring meadows (Figures 3-7). *H. ovalis* has increased in the past three years from 0% to 15% in Meadow A3. This meadow is, traditionally dominated by *H. uninervis*, therefore A3 was rated as being in "good" rather than "very good" condition (Figure 4).

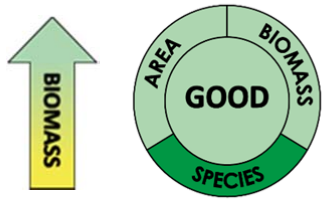
Monitoring meadows dominated by *E. acoroides* (A2, A6 and A7), the largest growing species found in Weipa, were all in good condition in 2014. The area of all three of these meadows was above the long-term averages (Figures 3, 6, 7). Biomass for the two meadows on the port infrastructure side of the Embley River (A6 and A7) was similar to previous medium and high biomass years including 2000-2003 and 2013 (Figures 6 and 7; Appendix 1 and 3). Biomass at meadow A7 between Evans Landing and Humbug Wharves was at the highest level recorded in a decade (Figure 7; Appendix 3), and biomass of meadow A6 adjacent to the Lorim Point wharves was the second highest recorded in a decade (Figure 6; Appendix 3).

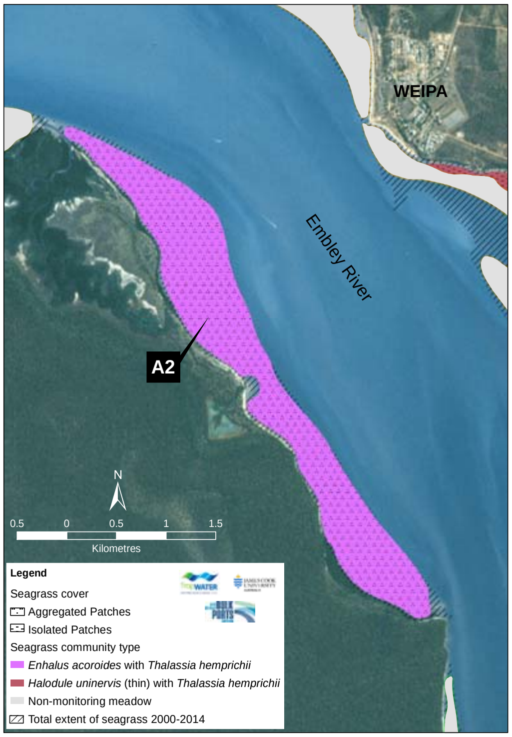
Concerns have been raised previously regarding the resilience of meadow A2 due to declining biomass between 2000 and 2006 (Figure 3). Biomass of this meadow appears to have stabilised in recent years. An analysis of biomass hotspots within this meadow over time indicates that biomass was more evenly distributed with less obvious areas of low biomass as well as fewer dense hotspots compared with previous years (Map 5). Area of this meadow remains relatively stable, with meadow area in 2014 the highest recorded since monitoring began in 2000.

Biomass in the intertidal *H. uninervis* dominated meadows (A3 and A5) has been relatively stable between 2010 and 2014, and above the long-term averages for these meadows (Figures 4 and 5). Meadow A5 was the only meadow in Weipa listed as being in fair condition - due to meadow area declines of between 10 and 30% below the baseline (Map 4; Figure 5). This was the third consecutive year there was a decline in A5 meadow area.

Meadow patchiness varied significantly between years in the *E. acoroides* dominated A2 meadow and in the *H. uninervis* dominated A3 and A5 meadows ($p < 0.05$; see Appendix 1). Approximately 15% of sites in meadow A2 had no seagrass present compared with the 2000-2014 average of 10% of sites. Patchiness was slightly lower in 2014 than the 2000-2014 average in the *H. uninervis m*eadows; meadow A3 had 46% of sites with no seagrass (2000-2014 average of 56%), and meadow A5 had 24% of sites with no seagrass (2000-2014 average of 28%). There was a positive correlation between the proportion of sites with seagrass present and meadow biomass only in meadow A3 (Pearson's product-moment correlation, $p < 0.05$) (Appendix 1).

Intertidal *Enhalus* meadow - A2





Biomass and area condition index

	Very Good	Good	Fair	Poor	Very Poor
Biomass	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Area	> 10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	> 50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Species composition figures

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

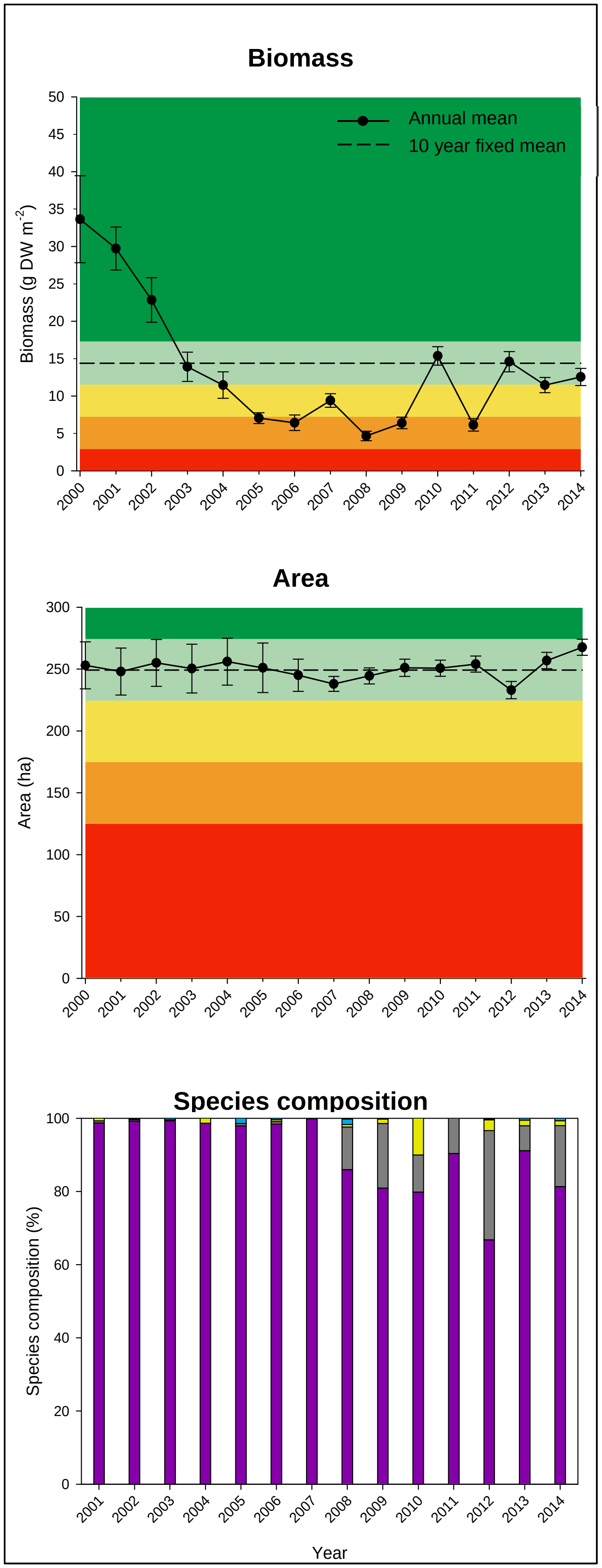
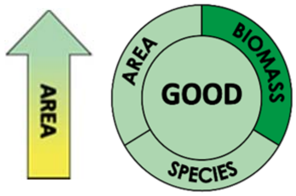
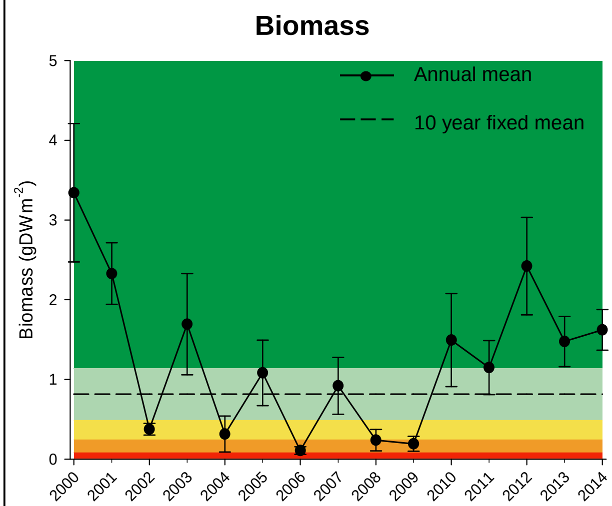
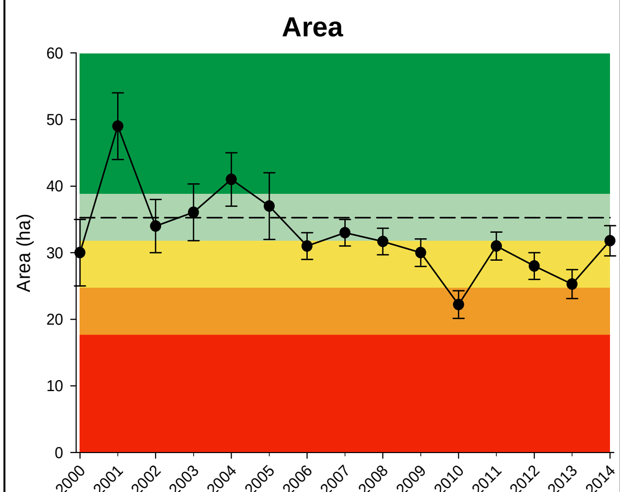


Figure 3. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated core monitoring meadow A2 in Weipa from 2000 to 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

Intertidal *Halodule* meadow - A3

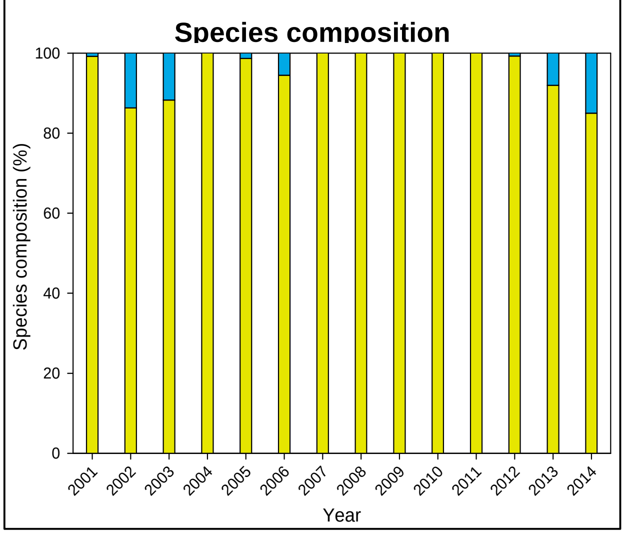






Biomass and area condition index

	Very Good	Good	Fair	Poor	Very Poor
Biomass	> 40% above baseline	Within 40 % of baseline	40% to 70% below baseline	70% to 90% below baseline	> 90% below baseline
Area	> 10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	> 50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

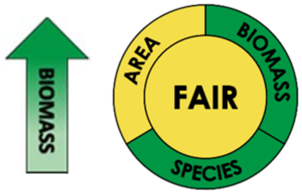


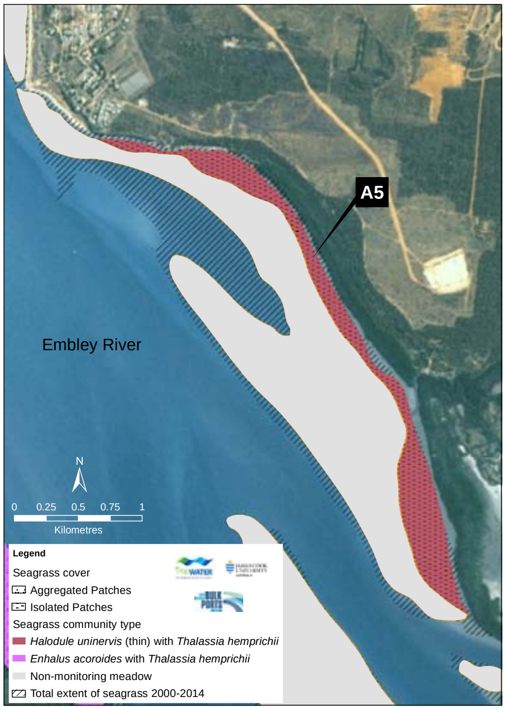
Species composition figures

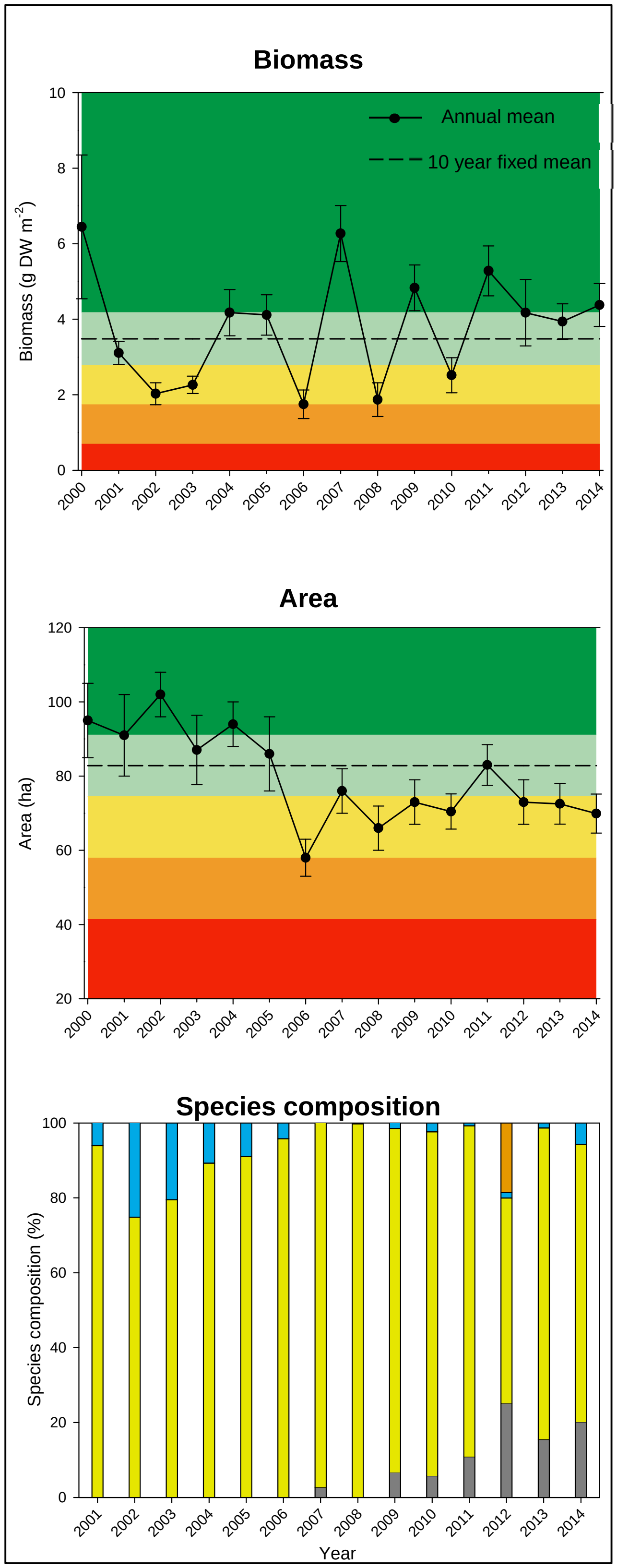
- *Halodule uninervis* (narrow)
- *Halophila ovalis*

Figure 4. Changes in biomass, area and species composition for the *Halodule uninervis* dominated core monitoring meadow A3 in Weipa from 2000 to 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

Intertidal *Halodule* meadow - A5







Biomass and area condition index

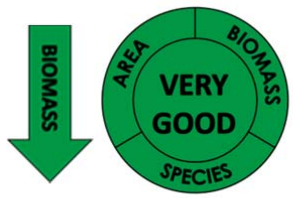
	Very Good	Good	Fair	Poor	Very Poor
Biomass	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Area	> 10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	> 50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Species composition figures

- *Halodule uninervis* (narrow)
- *Halophila ovalis*
- *Thalassia hemprichii*
- *Halodule uninervis* (wide)

Figure 5. Changes in biomass, area and species composition for the *Halodule uninervis* dominated core monitoring meadow A5 in Weipa from 2000 to 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

Intertidal *Enhalus* meadow - A6



Biomass and area condition index

	Very Good	Good	Fair	Poor	Very Poor
Biomass	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Area	> 10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	> 50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Species composition figures

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

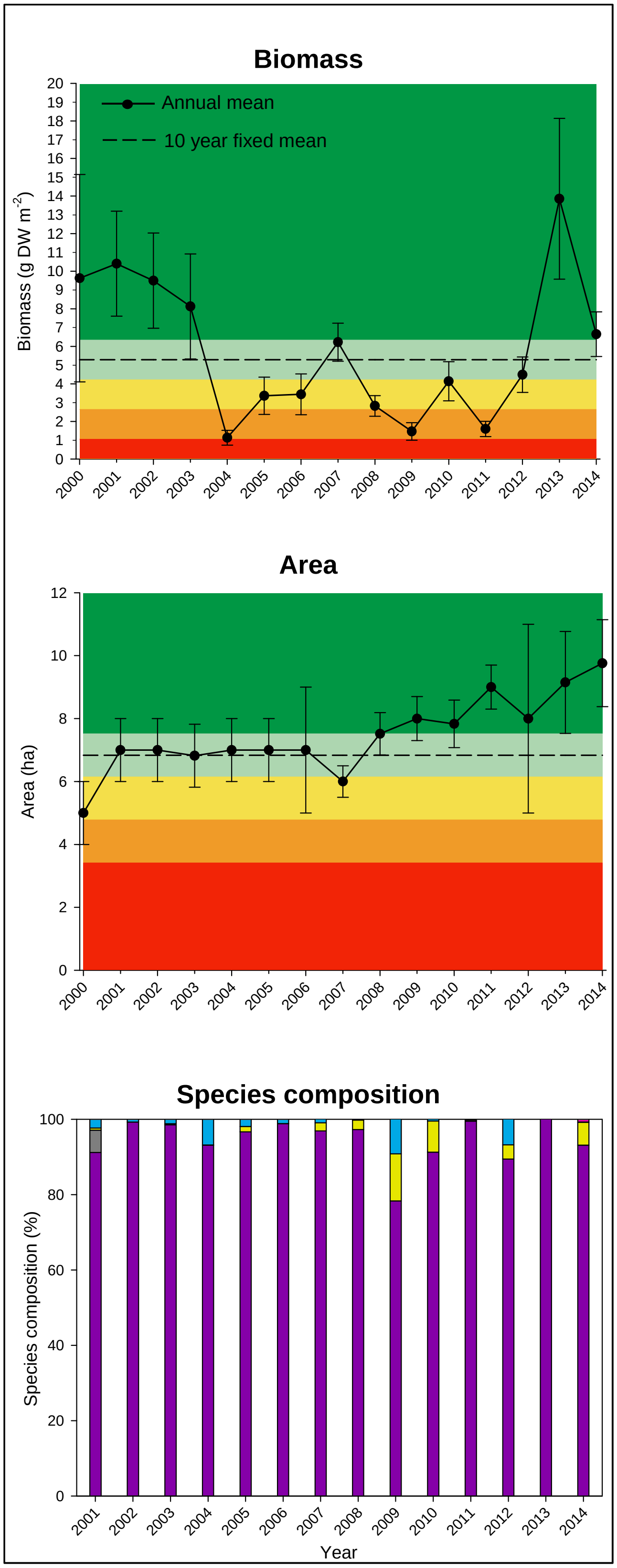
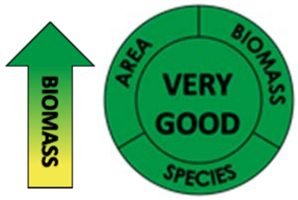
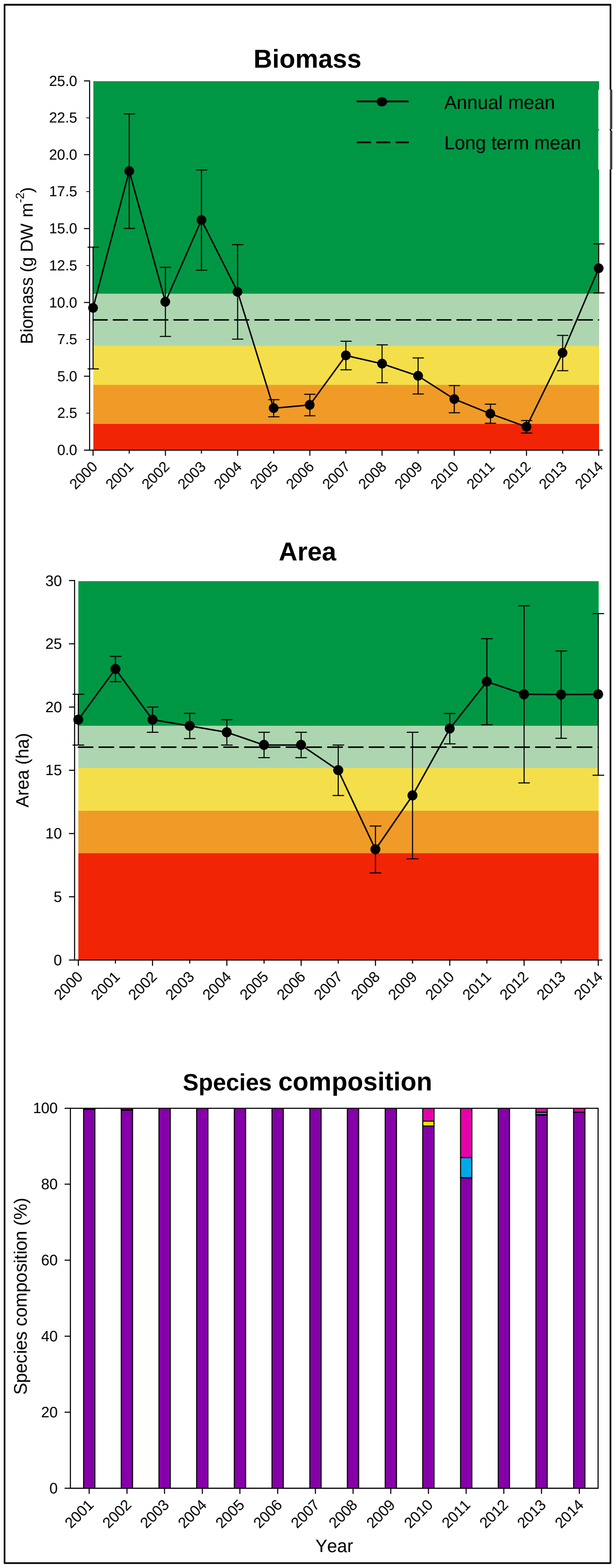


Figure 6. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated core monitoring meadow A6 in Weipa from 2000 to 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

Intertidal *Enhalus* meadow - A7





Biomass and area condition index

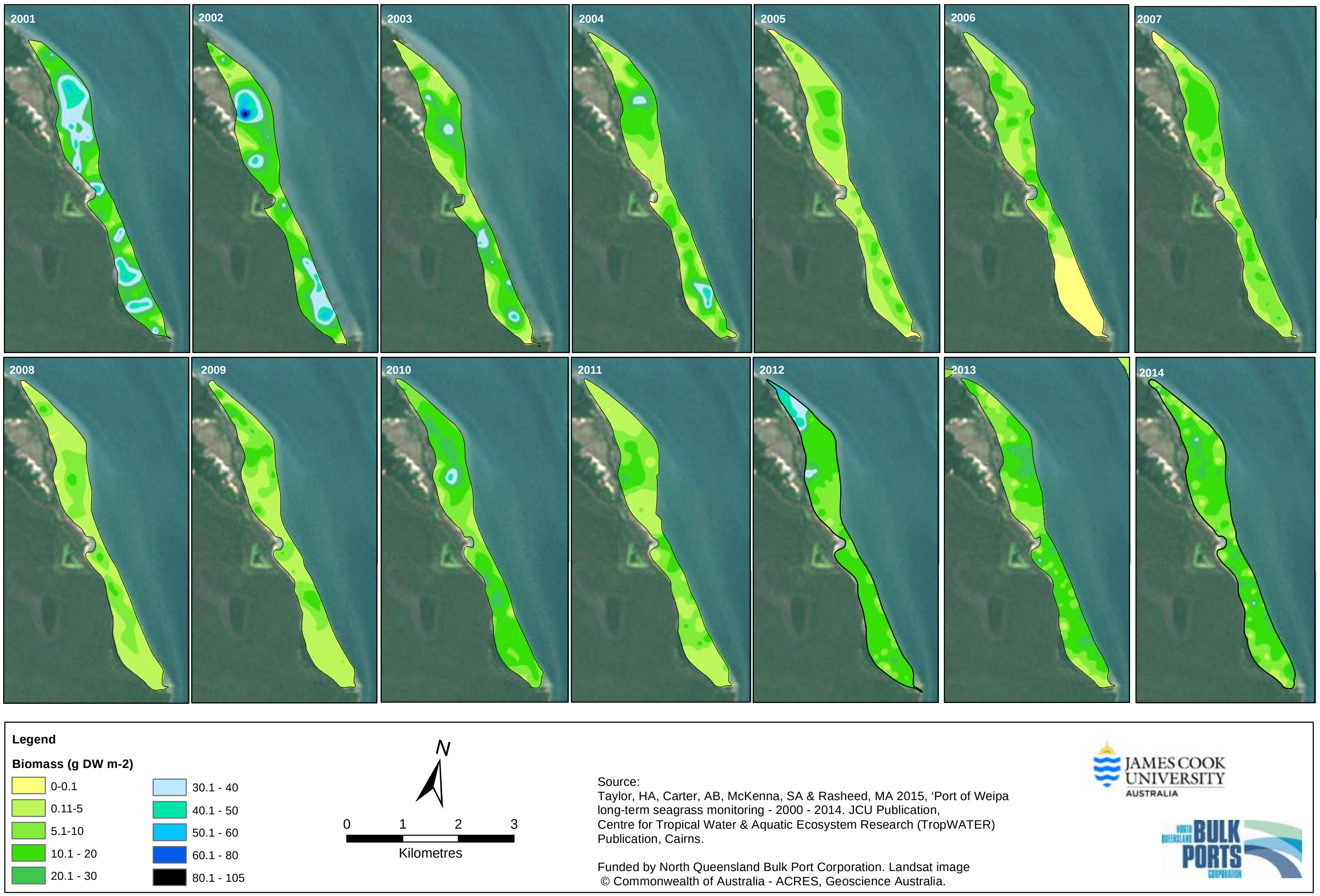
	Very Good	Good	Fair	Poor	Very Poor
Biomass	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Area	> 10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	> 50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

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 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

Map 5. Seagrass biomass in the A2 meadow from 2001 to 2014.



3.4 Seagrass in the broader Weipa port area

In 2014, seagrass distribution and community type within the entire port limits was mapped to enable a comparison with previous whole of port mapping conducted from 2000 – 2002, 2005, 2008 and 2011 (Figure 8, Maps 6 - 8). Total seagrass meadow area (4741 ± 132 ha) was the second highest level recorded since monitoring began, an increase of 18% since 2011 (Figure 8). Aggregated patches of seagrass continued to be the dominant landscape category and described 59% of meadows. It was the first year that no meadows were classed as having continuous seagrass cover, and the first time since 2005 that very isolated patches of seagrass were not recorded. Burning of *E. acoroides* plant leaves was recorded in 4% of sites in the broader Weipa port area.

Area increases occurred in several Hey River meadows, particularly in the southernmost section of the river. Several Hey River meadows remained fragmented, similar to 2011. Cover type in the largest, *H. uninervis* dominated meadow on the western bank changed from isolated patches in 2011 to aggregated patches in 2014, with *E. acoroides* recorded in the highest biomass to date. *E. acoroides* dominated meadows with isolated patches were present on the eastern bank of the Hey River (Map 6).

Meadow area in the Mission River had increased in nearly all meadows since 2011. One new meadow was also recorded between Wallaby Island and the foreshore in front of the Albatross Hotel, and was dominated by *H. uninervis* and *H. ovalis*. Seagrass community type remained a combination of isolated and aggregated patches in Mission River (Map 7). In most meadows the dominant seagrass species remained unchanged from 2011. There were three exceptions: the dominant species changed from *E. acoroides* to *H. uninervis* in two meadows (one in the northern Mission River and one in the south), and the meadow at Kerr Point (where the Embley meets the Mission River) changed from *H. ovalis* to *T. hemprichii* dominated (Map 7). The largest meadows on the southern bank of Mission River remained dominated by isolated patches of *E. acoroides*.

Seagrass meadows along the western banks of Pine River Bay covered the largest area since monitoring began in 2000. Between 2011 and 2014 many small fragmented meadows merged to form continuous meadows (Map 8). The presence of *T. hemprichii* in the bay had increased since 2011 and *S. isoetifolium* was recorded for the first time since 2005. *E. acoroides* had decreased in abundance; this was evident in the largest meadow at the top of the bay which changed from an *E. acoroides dominated meadow* to a mixed *H. ovalis/E. acoroides* meadow.

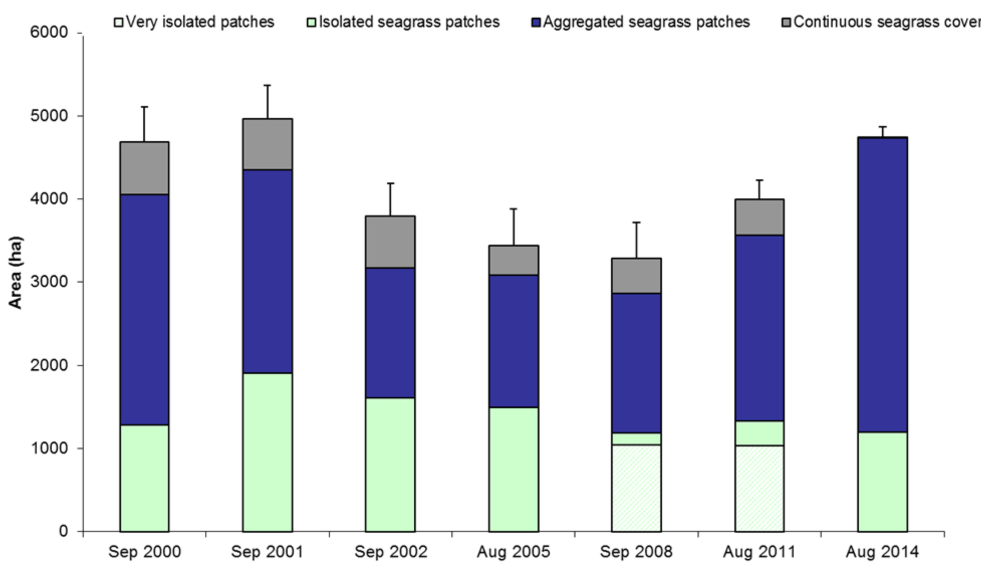
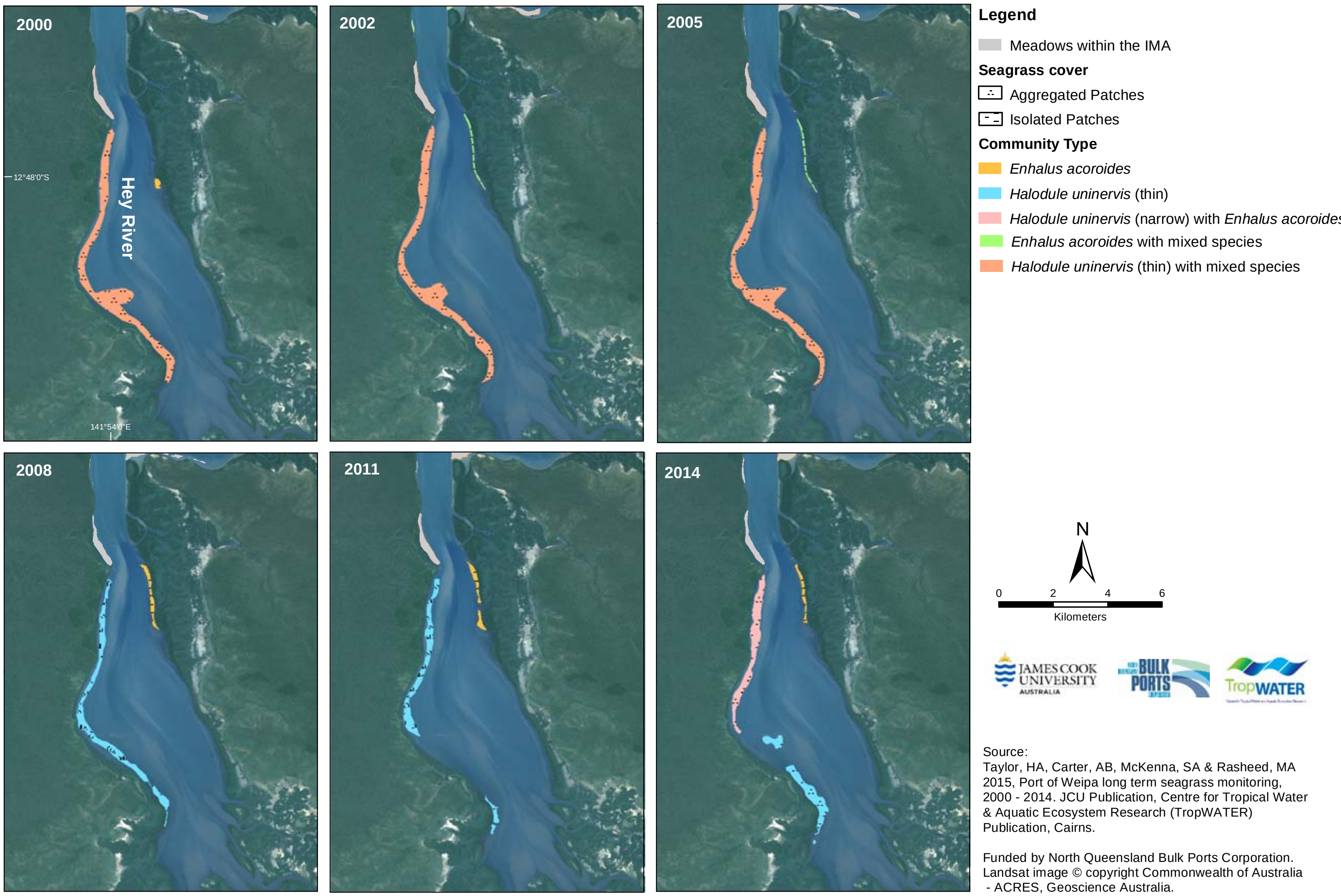


Figure 8. Total seagrass area (hectares) and the landscape cover within the Weipa port limits, 2000 - 2014. Error bars = "R" reliability estimate.

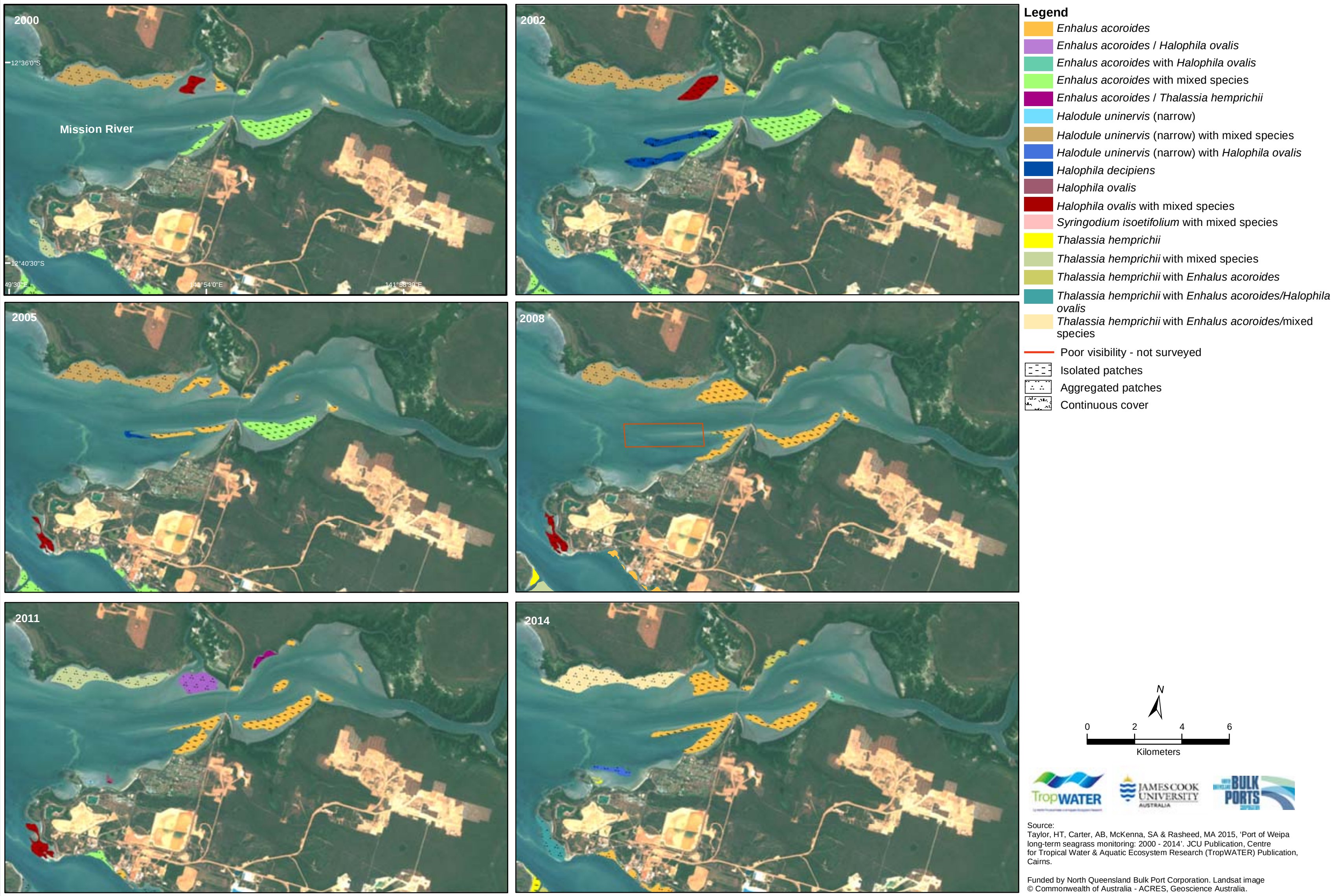
Map 6. Community type for seagrass meadows in the Hey River, 2000 - 2014.



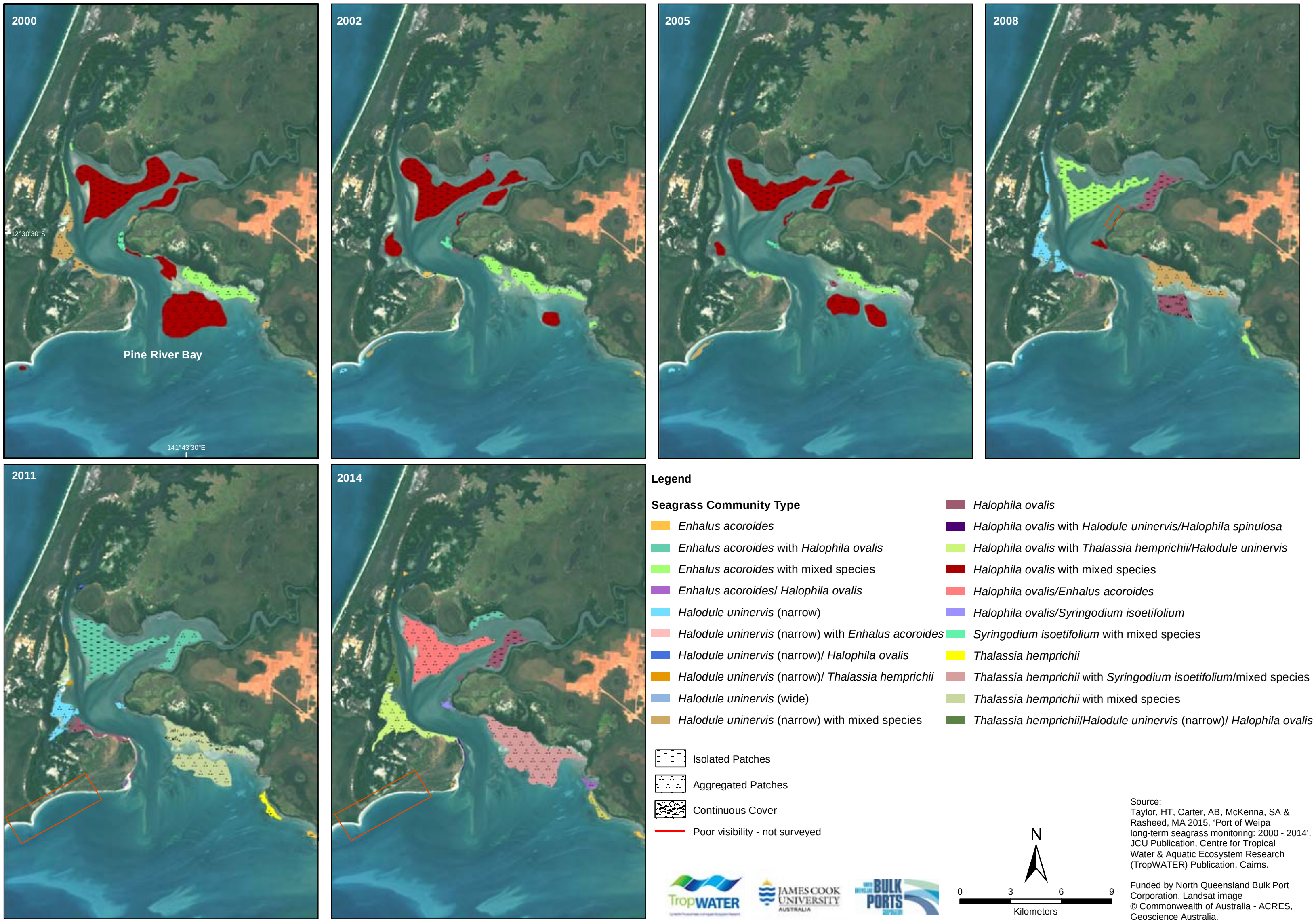
Source:
Taylor, HA, Carter, AB, McKenna, SA & Rasheed, MA 2015, Port of Weipa long term seagrass monitoring, 2000 - 2014. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, Cairns.

Funded by North Queensland Bulk Ports Corporation.
Landsat image © copyright Commonwealth of Australia - ACRES, Geoscience Australia.

Map 7. Seagrass meadows in Mission River, 2000 to 2014.



Map 8. Seagrass meadows in Pine River Bay, 2000 to 2014.



3.5 Weipa climate data and seagrass change

3.5.1 Rainfall

Total annual rainfall in Weipa in the 12 months preceding the 2014 survey was 1706 mm. Rainfall in 2013-2014 was 240 mm below the long-term average and much reduced from the high rainfall years of 2011 and 2012 (Figure 9). Rainfall was highly variable between months, and showed a typical tropical wet and dry season pattern. In 2014 over 53% of the annual rainfall fell during the month of February (Figure 10).

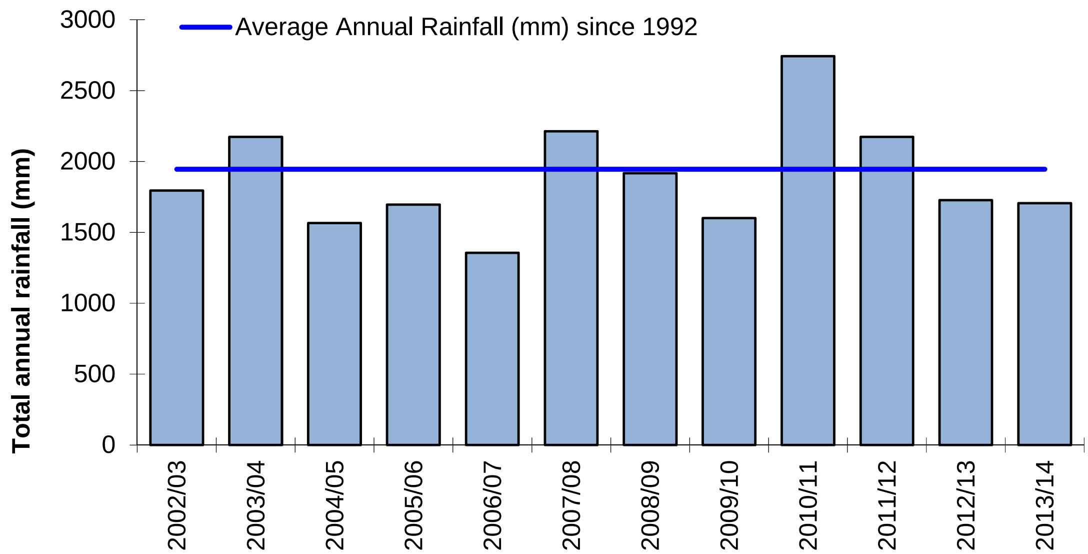


Figure 9. Total annual rainfall for the 12 months preceding each survey from 1999/2000 – 2013/2014. Solid line indicates annual average since 1992/1993. Data recorded at Weipa airport (Bureau of Meteorology, Station 027045).

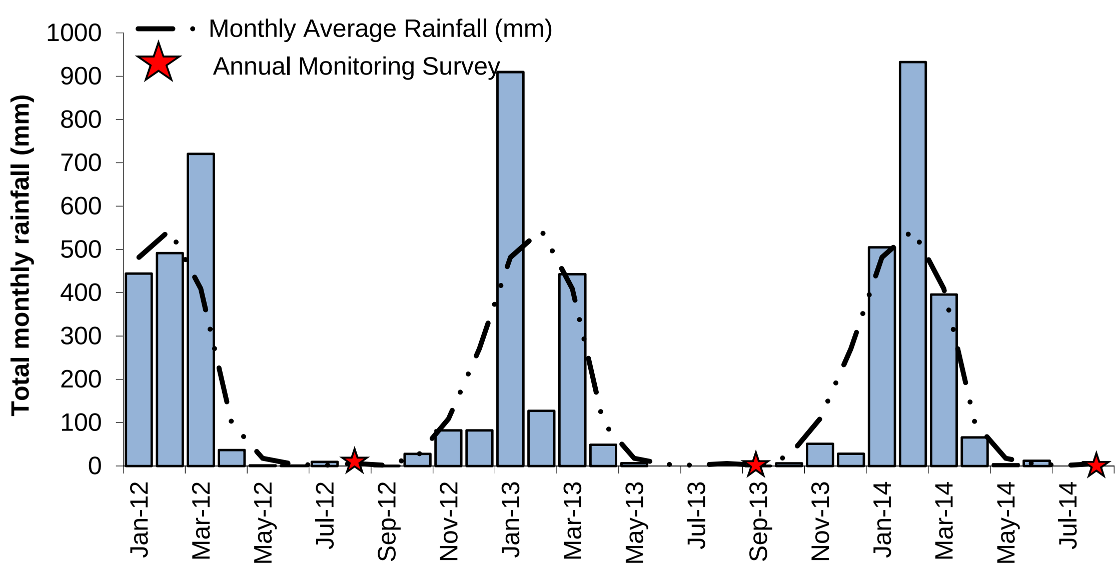


Figure 10. Total monthly rainfall (mm), January 1 2012 – August 31 2014. Dashed line indicates monthly average since 1992; red stars indicate timing of annual surveys. Data recorded at Weipa airport (Bureau of Meteorology, Station 027045).

3.5.2 Daytime tidal exposure

Intertidal banks at Weipa were exposed for 589 hours during the 12 months prior to the August 2014 monitoring survey, a 10% increase from 2013 and the highest number of hours recorded since monitoring began in 2000 (Figure 11). Intertidal seagrass meadows generally experienced a greater number of hours exposure during winter, peaking at 165 hours in July, one month prior to the seagrass survey (Figure 12). Intertidal meadows rarely exposed in summer. Exposure exceeded 100 hours per month for the three months preceding the 2014 survey (Figure 12). Daytime tidal exposure times in both the one and three months prior to the 2014 survey were the highest recorded since monitoring began, at 75% and 52% above the average exposure respectively. This contrasts with relatively low exposure in the three months prior to each survey between 2009-2012 (Figure 13).

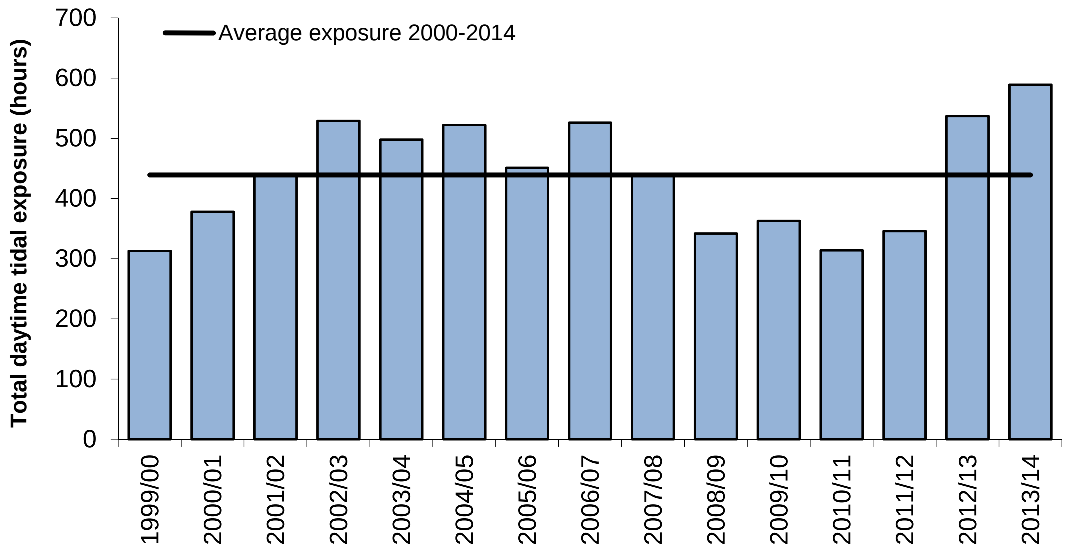


Figure 11. Annual total daytime tidal exposure (hours; <0.9m tidal height) in Weipa in the 12 months preceding each monitoring survey, 2000 – 2014. 2014 tidal data © State of Queensland (Department of Transport and Main Roads).

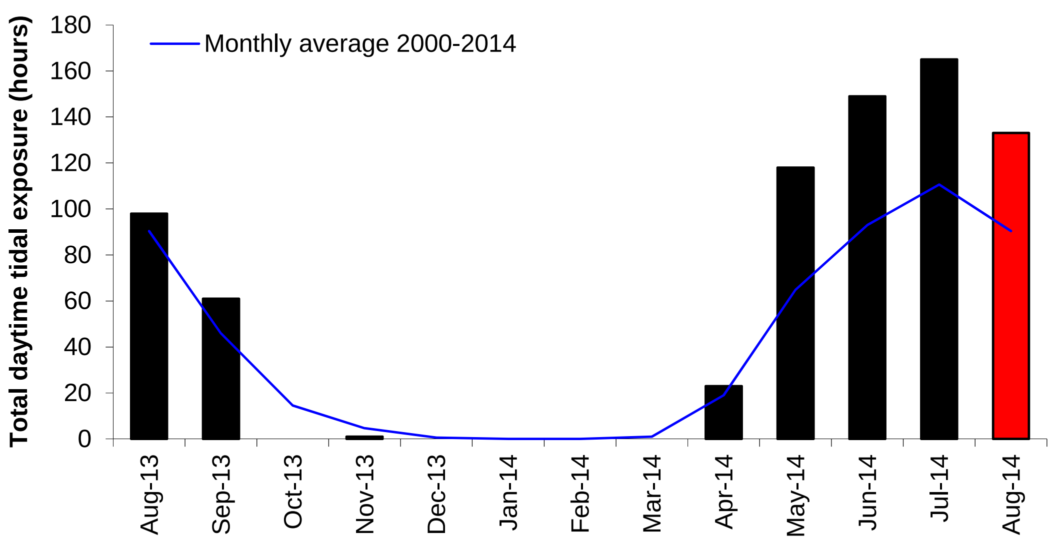


Figure 12. Monthly total daytime tidal exposure (hours; <0.9m tidal height) in Weipa in the 12 months preceding the 2014 monitoring survey. Red bar indicates month when monitoring survey occurred. 2014 tidal data © State of Queensland (Department of Transport and Main Roads).

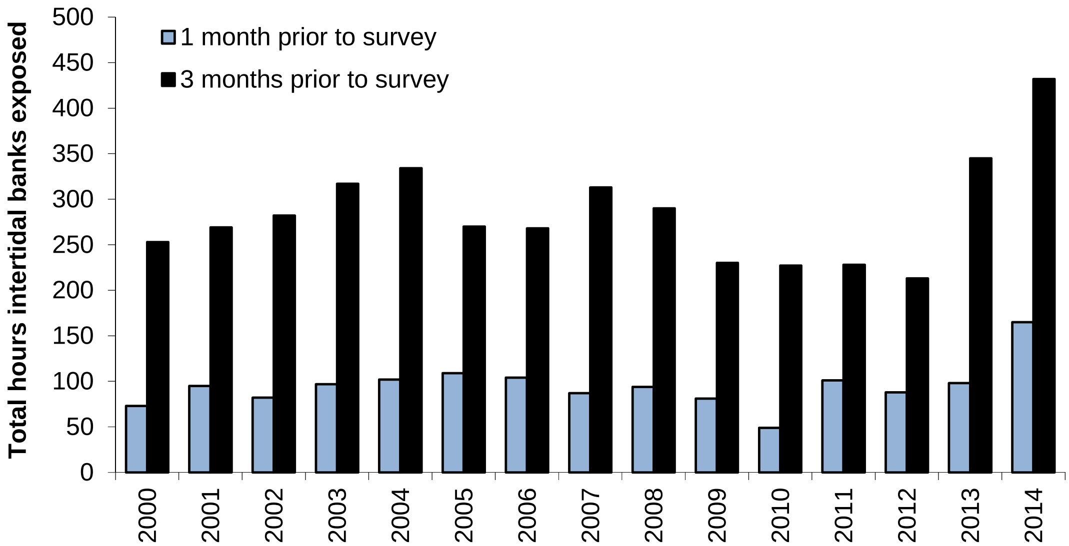


Figure 13. Total daytime tidal exposure (hours; <0.9m tidal height) in Weipa in the 1 and 3 months preceding each monitoring survey, 2000-2014. 2014 tidal data © State of Queensland (Department of Transport and Main Roads).

3.5.3 Solar Radiation

Mean daily solar radiation (global solar exposure) was similar to the long-term average in Weipa in the 12 months preceding the 2014 survey (Figure 14). Solar radiation was 15% lower in 2013/2014 than the record high levels recorded for 2012/2013. It was the first time since 2005/2006 that solar radiation was at or below the long-term average.

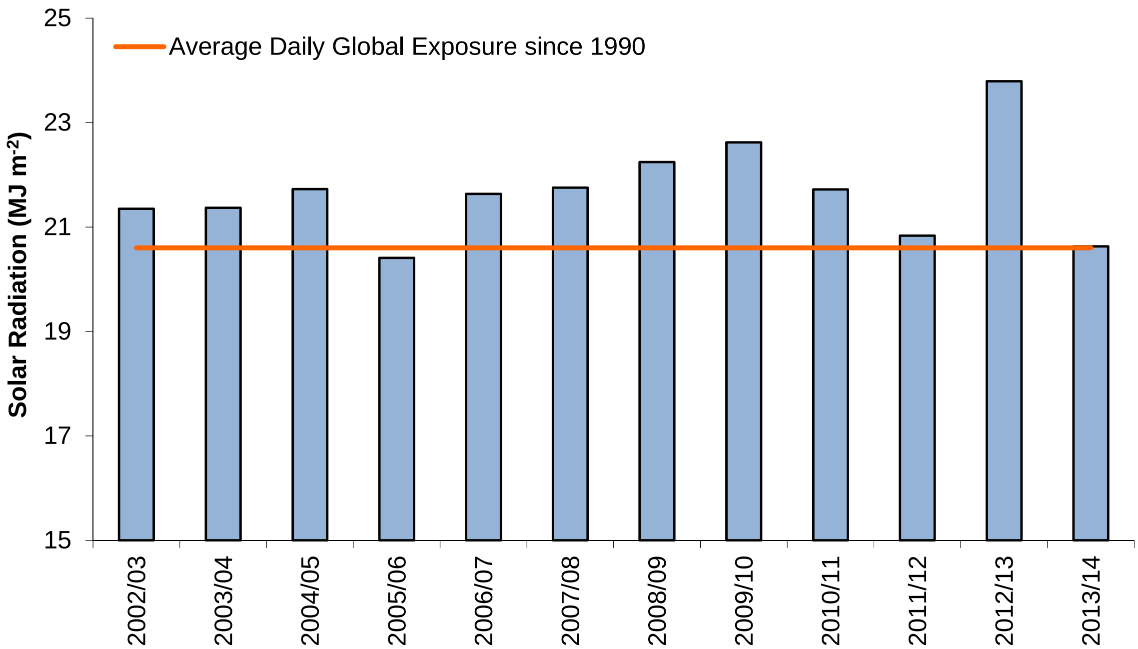


Figure 14. Average annual solar radiation (mJ m^{-2}) for the 12 months preceding each survey, 2002/2003 – 2013/2014. Data recorded at Weipa airport (Bureau of Meteorology, Station 027045).

3.5.4 Daily photosynthetically active radiation (light)

Mean total daily photosynthetically active radiation (PAR) in 2014 was similar to 2013 levels, with less than 1% difference between years across all three sites. Total daily PAR in the shallower intertidal A2 meadow was greater and more variable than in the deeper intertidal A7 meadow. Mean total daily PAR in the 12 months prior to the August 2014 survey was 9.26 $\pm$ 0.4 mol m^{-2} day^{-1} in meadow A7, compared with 15.3 $\pm$ 0.5 and 12.1 $\pm$ 0.6 mol m^{-2} day^{-1} in the meadow A2 north and south, respectively (Figure 15). Total daily PAR ranged from less than 0.002 mol m^{-2} day^{-1} at all three sites, to 30.6 mol m^{-2} day^{-1} in A7, and 39.8 and 40.4 mol m^{-2} day^{-1} at the north and south A2 sites (Figure 15). Par was lowest in February 2014 which coincided with maximum rainfall levels (Figure 10). Variation in PAR within the A2 meadow is likely due to loggers deployed approximately 4km apart experiencing slightly different air exposure periods.

PAR decreased between November 2013 and March 2014, coinciding with peak rainfall (Figure 16). Mean daily PAR during this period ranged between 4.8 – 7.1 mol m^{-2} day^{-1} at all three sites and was approximately 60-65% less than PAR during the dry season. During peak rainfall in February 2014 there were 10 consecutive days during which PAR fell below 1.0 mol m^{-2} day^{-1} at all three sites. In previous years logger failures occurred during the wet season, making it difficult to determine the relationship between PAR and rainfall. The deployment of more robust equipment has reduced data loss significantly. Continued monitoring of PAR levels over the next few wet seasons will further strengthen the relationship between rainfall and PAR.

3.5.5 Water temperature

Mean daily water temperature in the A2 meadow was 28.6°C (at both north and south sites) and 28.5°C in meadow A7 (Figure 15). Maximum daily water temperature peaked at a much higher temperature in the shallow A2 meadow (39.7°C) than in the deeper A7 meadow (32.9°C). Within-meadow mean daily water temperature was highly variable, ranging from approximately 25°C to 31°C. Mean daily water temperature was greatest in December 2013 and January 2014 and lowest in July and August 2014. Peaks in maximum water temperature coincided with peaks in PAR in the A2 meadow (Figure 15). These peaks occurred with low tides in the middle of the day when shallow water pooling over the seagrass meadow became heated.

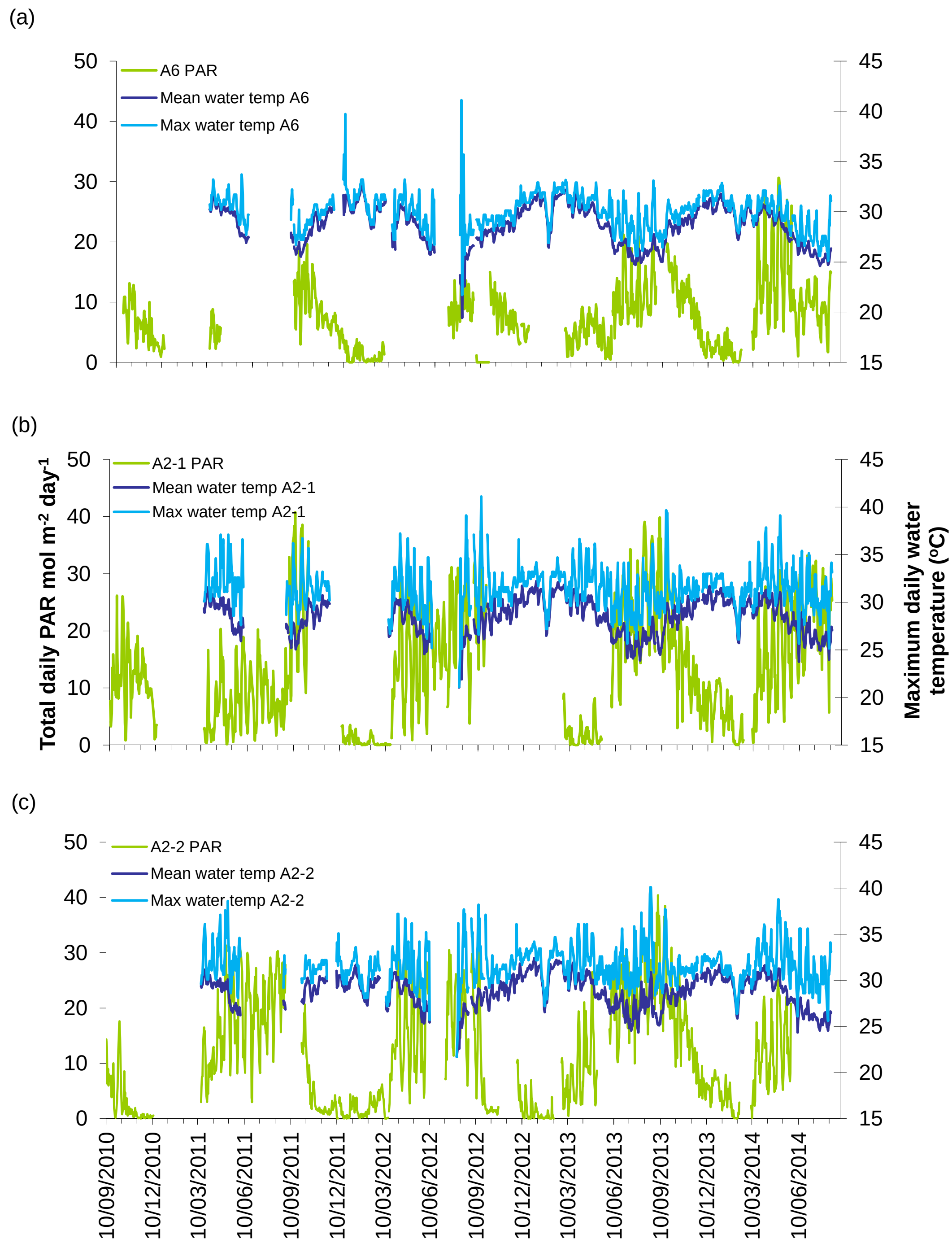


Figure 15. Daily photosynthetically active radiation (PAR mol m^{-2} day^{-1}) and mean and maximum daily water temperature (°C) at Weipa, September 2010 – August 2014, at (a) meadow A7; (b) northern meadow A2-1; and (c) southern meadow A2-2..

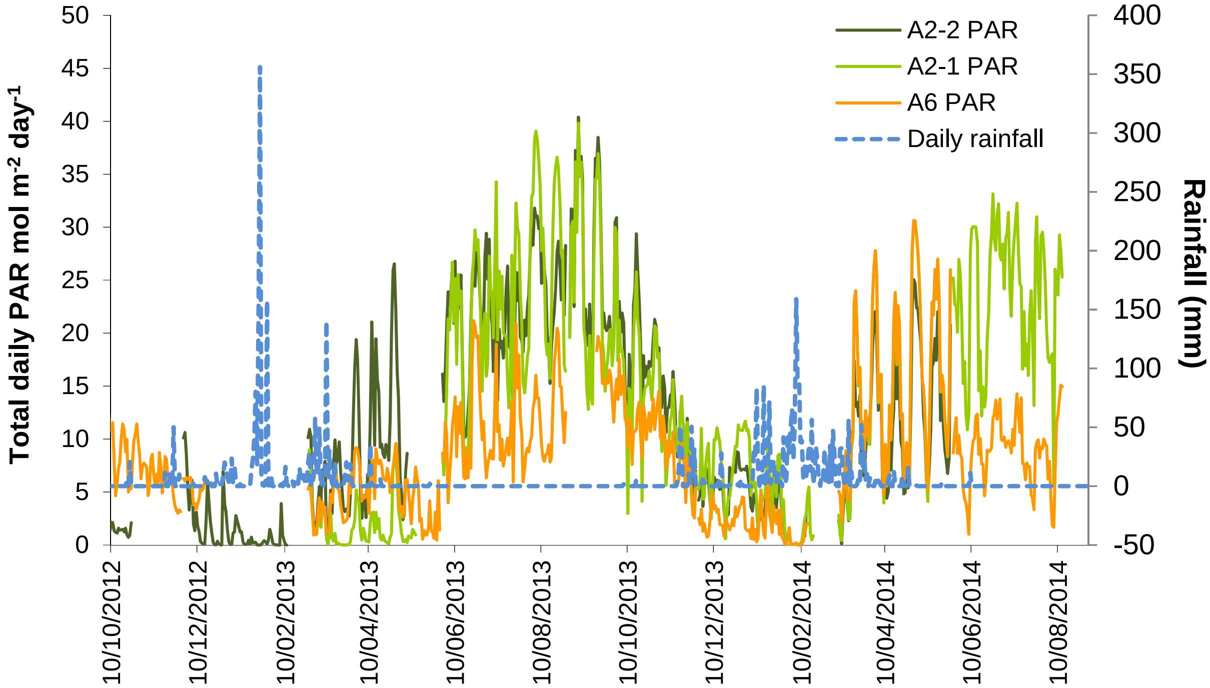


Figure 16. Daily photosynthetically active radiation (PAR; mol m^{-2} day^{-1}) and total daily rainfall (mm) at Weipa, October 2012 – August 2014, at Meadow A7 and Meadow A2 northern (A2-1) and southern (A2-2).

4 DISCUSSION

Seagrasses in the Port of Weipa were in a good condition in 2014. In the area closest to major port operations (Intensive Monitoring Area (IMA)), seagrass biomass and meadow area were similar to or above the long-term average, and species composition remained stable. Total seagrass meadow area within the IMA increased 10% between 2013 and 2014. The two meadows closest to port facilities were also in very good condition with the *E. acoroides* dominated meadow between Humbug Wharf port facility and Evans Landing recording its highest biomass for 10 years and the adjacent meadow next to the Lorim Point facilities had its second highest biomass in 10 years. Outside of the IMA the area of seagrasses in the broader port limits was the second highest ever recorded.

Maintenance dredging activities in 2014 appeared to have no significant negative impact on Weipa's seagrasses. We expect that Weipa's seagrasses should display similar resilience to planned maintenance dredging activities in 2015, without the requirement for additional mitigation measures. This expectation assumes the duration of dredging remains relatively short and that there are no major seagrass losses associated with climate or other impacts leading up to the 2015 dredging campaign.

Annual fluctuations in meadow biomass and area in Weipa have been associated with regional and local climate conditions. Seagrass biomass in Weipa is negatively correlated with tidal exposure during the preceding month and solar radiation in the preceding year (Unsworth et al. 2012). Long and frequent periods of daytime tidal exposure can result in desiccation, temperature stress and light stress, leading to permanent morphological and physiological damage to the plant (Jiang et al. 2014; Unsworth et al. 2012; York et al. 2008; Stapel 1997; Erftemeijer and Herman 1994). In 2014 tidal exposure reached a record high of 165 hours in the month preceding the monitoring survey, much higher than in years like 2004 where the greatest declines in biomass were recorded. Prominent burning of seagrass leaves observed in 2014 suggests that Weipa's intertidal meadows experienced more exposure-related stress than in 2013, yet seagrass biomass and area were at high-levels throughout the port area. This may indicate that seagrass biomass was particularly high prior to the exposure period or that other factors mitigated some of the exposure related stresses. Perhaps the below average solar radiation in 2014 meant Weipa's seagrasses did not experience the same level of physiological stress during exposure as in previous years. Jiang et al. (2014) demonstrated that *E. acoroides* is more resistant to the deleterious effects of desiccation during exposure relative to another common Weipa seagrass species, *T. hemprichii,* owing to *E. acoroides'* thick waxy leaves. However, this resilience is diminished in *E. acoroides* when periods of exposure coincide with periods of high temperature and desiccation occurred faster and critical threshold limits were reached sooner relative to other species.

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. Light levels in the Port of Weipa were typical of the naturally turbid environment in which seagrasses grow in that region. PAR varied with location, weather patterns and tidal exposure as expected. PAR was lowest during periods when high tides occurred around midday, when a high proportion of PAR is dispersed in the water column. PAR was also lower in the deeper of the monitoring locations (intertidal A7 meadow) which remained submerged for longer during low tides compared with the shallower sites in the A2 meadow. PAR was also reduced during the wet season, likely in response to a combination of rainfall, a high percentage of cloud cover lowering total atmospheric PAR, and higher turbidity levels in the water due to an influx of sediment-laden freshwater runoff (Chartrand et al. 2010).

The local light environment plays an important role in seagrass dynamics. Collier et al. (2012) reported that *H. uninervis* at three island locations in the northern Great Barrier Reef required between 5 and 8.4 mol m^{-2} d^{-1} for growth, and found a strong correlation between seagrass loss and repeated exposure to light levels below 3 mol m^{-2} d^{-1}. Similarly, Chartrand et al. (2012) reported deleterious effects of light levels below its minimum requirements after 21 days for *Zostera muelleri* . The specific light levels required to sustain the important *Enhalus acoroides* meadows in Weipa are unknown. Intertidal light levels at Weipa were highly variable and results indicate that average light levels during the wet season were within the likely range for other seagrass species. There was a continuous 10 day period in February 2014 where light was <1.0 mol m^{-2} d^{-1} which is far below accepted minimum levels needed for growth of most seagrass species but this was not sustained in the longer term. A better understanding of the actual light thresholds for seagrasses in Weipa could be obtained by adding regular assessments of seagrass change at the three PAR monitoring sites. Quarterly seagrass sampling (conducted when PAR instruments are exchanged) would enable a better understanding of the relationships between seagrass, temperature, exposure and light which could be used to develop actual light thresholds for management applicable to the local species.

The good condition of meadow A2, the largest seagrass meadow in Weipa and the meadow closest to the majority of dredging indicates that port maintenance dredging did not having a significant negative effect on seagrass in Weipa during 2014. In 2012 there was a capital dredging campaign that occurred where > 900,000m^3 of material was removed, followed by annual maintenance dredging of > 600,000m^3 in July 2013 and 395,000m^3 in July/August 2014. In addition the overall good condition of seagrasses in the area is a strong indicator of good water quality and a healthy marine environment (Dennison et al. 1994).

The management of seagrass resources in Weipa should remain focused on ensuring the resilience of local seagrasses remains high enough to withstand expected anthropogenic impacts and risks. Currently the resilience of seagrasses in Weipa was likely to be at high levels. This is in 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) and Mourilyan (York et al. 2014) and coastal meadows at Abbot Point (McKenna and Rasheed 2014) where climate impacts have led to major declines that have yet to fully recover (Rasheed et al. 2014). Under these circumstances seagrasses may struggle to withstand stresses they have previously been able to cope with. In summary, results of the 2014 monitoring indicate:

1. Seagrasses in the Port of Weipa were in a good condition with biomass, area and species composition of monitoring meadows all close to or above the long-term average.
2. Results of the seagrass and light monitoring indicate that Weipa's marine environment was in a healthy condition.
3. The good condition of seagrass meadows indicates meadows should continue to be resilient to planned maintenance dredging activities in 2015, without the requirement for additional mitigation measures.
4. Results from light monitoring (photosynthetically active radiation) indicates that the light environment remained favourable for seagrass growth during the majority of 2013-2014, but fell below the likely minimum light requirements for a short time periods during the wet season.
5. Tidal exposure and solar radiation explain a significant component of previous declines in some intertidal meadows. More frequent (quarterly) assessments of seagrass change coupled to the PAR monitoring would enable a better understanding of the actual light requirements for seagrasses in Weipa and help to develop relevant light thresholds for management.
6. The good condition of seagrasses in Weipa and other monitoring locations in the Gulf of Carpentaria and Torres Strait contrast with many of the seagrass meadows on Queensland's east coast that were significantly impacted by major climate events and are yet to fully recover.

5 APPENDICES

Appendix 1. (A) Likelihood ratio test (LRT) results for binary generalised linear models comparing seagrass presence/absence among years (2000 – 2014) for the Weipa core monitoring meadows A2, A3, A5, A6 and A7. *** Significant difference at Pr(>Chi) < 0.001.

	A2					A3				
	Df	**Deviance**	**AIC**	**LRT**	**Pr(>Chi)**	**Df**	**Deviance**	**AIC**	**LRT**	**Pr(>Chi)**
None		470.66	500.66				574.27	604.27		
Year	14	514.74	516.74	44.08	***	14	688.73	690.73	114.46	***

	A5					A6				
	Df	**Deviance**	**AIC**	**LRT**	**Pr(>Chi)**	**Df**	**Deviance**	**AIC**	**LRT**	**Pr(>Chi)**
None		883.35	913.35				519.33	549.33		
Year	14	982.13	984.13	98.78	***	14	528.41	530.41	9.08	0.83

	A7				
	Df	**Deviance**	**AIC**	**LRT**	**Pr(>Chi)**
None		539.81	569.81		
Year	14	561.90	563.90	22.09	0.08

(B) Results of one-way ANOVA comparing mean biomass between years (2000 – 2014) for the Weipa core monitoring meadows A2, A3, A5, A6 and A7. Biomass was compared only for sites where seagrass was present. All biomass data were square-root transformed. *** 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	14	614.1	43.86	20.5	***	14	66.05	4.72	10.2	***
Residuals	724	1549.4	2.14			206	95.31	0.46		

Source of variation	A5					A6				
	DF	**SS**	**MS**	**F**	**Pr(>F)**	**DF**	**SS**	**MS**	**F**	**Pr(>F)**
Year	14	145.0	10.36	12.68	***	14	223.7	15.98	7.71	***
Residuals	577	471.4	0.82			260	538.6	207		

Source of variation	A7				
	DF	**SS**	**MS**	**F**	**Pr(>F)**
Year	14	272.3	19.45	8.76	***
Residuals	291	646.2	2.22		

(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	2014
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		
2014	YES	YES	YES	NO	NO	YES	YES	NO	YES	YES	NO	YES	NO	NO	

A3	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
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		
2014	NO	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	

A5	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
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		
2014	NO	NO	YES	YES	NO	NO	YES	NO	YES	NO	NO	NO	NO	NO	

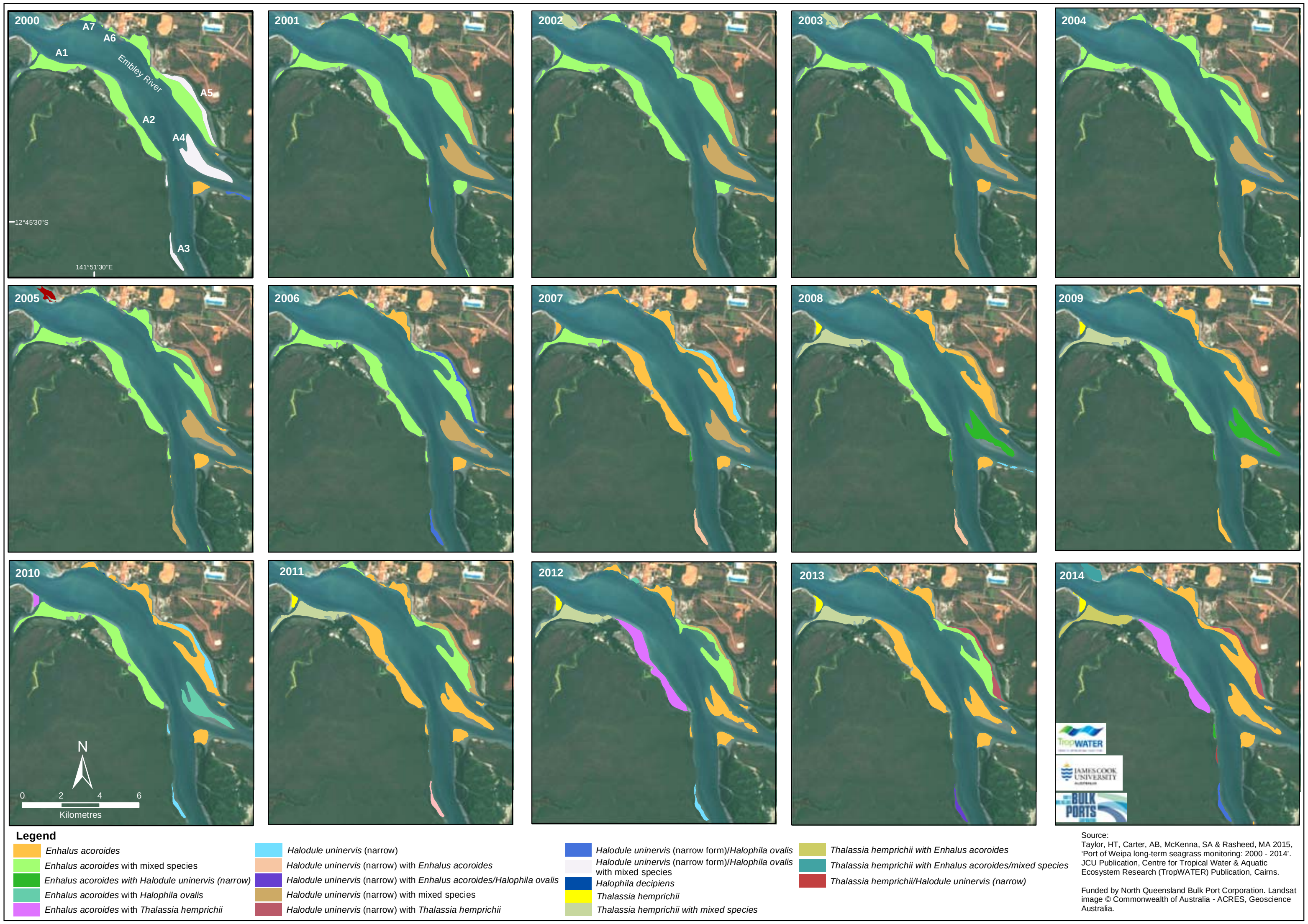
A6	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2000															
2001	NO														
2002	NO	NO													
2003	NO	NO	NO												
2004	NO	YES	YES	YES											
2005	NO	YES	YES	NO	NO										
2006	NO	NO	NO	NO	NO	NO									
2007	NO	NO	NO	NO	YES	NO	NO								
2008	NO	NO	NO	NO	NO	NO	NO	NO							
2009	NO	YES	YES	NO	NO	NO	NO	NO	NO						
2010	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO					
2011	NO	YES	YES	YES	NO	NO	NO	YES	NO	NO	NO				
2012	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO			
2013	NO	NO	NO	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES		
2014	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO	NO	YES	NO	NO	

A7	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
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		
2014	NO	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO	YES	YES	NO	

(D) Results of Pearson's product-moment correlations comparing the proportion of sites with seagrass present with mean seagrass biomass, 2000-2014. Correlation coefficients (*r*) and significance values where * indicates a significant correlation at $p < 0.05$.

Meadow	*r*	*p*-value
A2	0.35	0.20
A3	**0.56**	**0.03**
A5	0.20	0.48
A6	-0.14	0.61
A7	0.19	0.49

Appendix 2. Meadow type and distribution for the seagrass meadows within the Intensive Monitoring Area, 2000 – 2014.



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 – 2014.

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**
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 (66)	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)	12.55 ± 2.56 (81)
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)	1.62 ± 0.48 (71)
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)	4.38 ± 0.69 (67)
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)	7.3 ± 1.76 (33)
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)	12.31 ± 4.09 (39)

Appendix 4. Total meadow area ± R (ha) for each core monitoring meadow within the Port of Weipa, 2000 – 2014.

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**
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	267 ± 6
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	32 ± 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	70 ± 5
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	10 ± 1
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	12 ± 6
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	391 ± 20

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