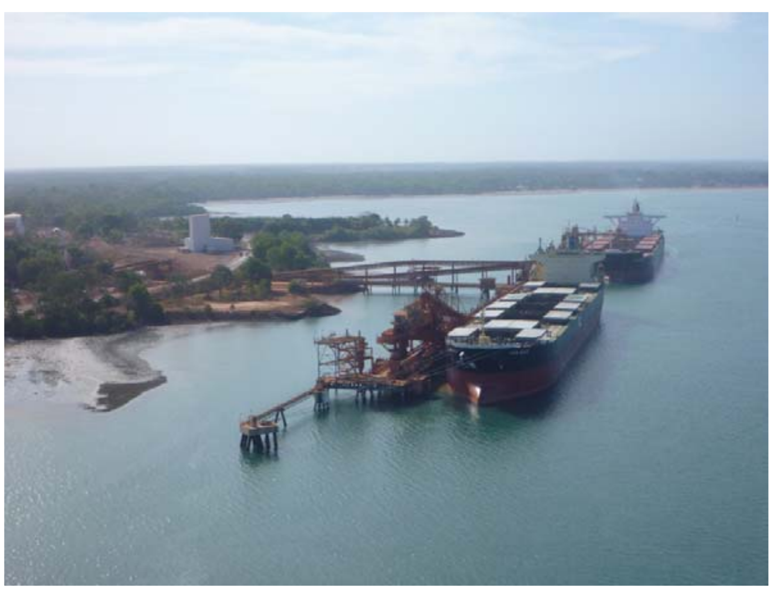
Centre for Tropical Water and Aquatic Ecosystem Research

PORT OF WEIPA LONG-TERM SEAGRASS MONITORING: AUGUST 2012

Carter AB, McKenna SA & Rasheed MA

Report No. 13/05

March 2013



PORT OF WEIPA LONG-TERM SEAGRASS MONITORING:

AUGUST 2012

A Report for North Queensland Bulk Ports Corporation (NQBP)

Report No. 13/05

March 2013

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EXECUTIVE SUMMARY

This report details the results of the Port of Weipa seagrass monitoring program including the most recent survey in August 2012. Seagrasses in the Port of Weipa were in a reasonable condition in 2012, with the biomass of monitoring meadows remaining similar to or increasing from the previous year. However there were some reductions in area of meadows and there is still an overall declining trend in seagrass biomass for some meadows over the 13 years of monitoring, indicating seagrasses may remain vulnerable to further natural or anthropogenic stress. Importantly, however, the key meadow on the western bank of the Embley River that is closest to maintenance dredging activity has shown a significant increase in biomass and is likely to be resilient to planned maintenance dredging activities in 2013.

Changes in seagrass biomass between 2011 and 2012 varied for the core monitoring meadows. Biomass increased significantly in the *Enhalus acoroides* dominated meadow on the western bank of the Embley River (A2), the largest monitoring meadow, but did not change in the smaller *E. acoroides* dominated and *Halodule uninervis* dominated meadows. Biomass in A2 in 2012 was similar to other high biomass years such as 2002 and 2010, and coincided with the re-appearance of moderate/dense biomass hotspots similar to those recorded in 2010. Biomass in two of the smaller monitoring meadows (A3 and A6) more than doubled between 2011 and 2012 although the highly variable nature of these meadows meant that this change was outside the ability of statistical analysis to detect change.

Biomass for the core monitoring meadows has varied considerably between years, with an overall trend of decline in three (A2, A6, A7) of the five meadows in the 13 years of monitoring. These declines are likely associated with natural shifts in tidal exposure and changes in light and temperature associated with local climate conditions. These changes were significantly correlated with the amount of daytime tidal exposure in the month prior to the survey as well as the amount of solar radiation in the twelve months prior to monitoring.

In 2012, meadow area around the major port operations (IMA) was below the thirteen-year average of 1035 ± 66 ha. Total meadow area within the IMA reduced by 5.8% between August 2011 and 2012 reversing a 3 year trend of increasing area. While the declines were recorded for all of the meadows, all but meadow A2 remained within the range of previously recorded values.

The 12 months prior to the 2012 survey were characterised by above-average rainfall and below-average tidal exposure. Preliminary results from light and temperature loggers deployed since September 2010 indicate a strong influence of tidal cycles on photosynthetically active radiation (PAR) and water temperature, with the highest PAR recorded during midday low tides, particularly in the shallower intertidal meadows. The PAR data set obtained so far also indicates PAR is reduced between October and March each year, coinciding with increased rainfall. Continued collection of fine-scale light and temperature data within the monitoring meadows will enhance the ability of the program to pinpoint some of the causes of seagrass changes.

Seagrasses have been resilient to the impacts associated with regular port maintenance dredging during the life of the monitoring program. However, the continued low biomass of some of the meadows in Weipa may leave them vulnerable to additional stresses including those associated with dredging. Ongoing monitoring will provide the information necessary to inform the management of maintenance and capital dredging programs in Weipa to ensure the protection of these seagrasses. It forms an integral component of the Dredge Technical Advisory Consultative Committee's assessment of potential dredge mitigation strategies that may need to be applied to continue to protect seagrasses within the port. Results from 2012 monitoring show the large meadow on the western bank of the Embley River (A2) that is closest to the majority of maintenance dredging in the port was in a relatively robust condition. The relatively high biomass of this meadow indicates that it should remain resilient to planned maintenance dredging activities in 2013, provided the duration of dredging remains relatively short and that there are no major loses associated with climate or other impacts leading up to the 2013 dredging campaign.

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 (Costanza et al., 1997; Hemminga and Duarte, 2000). Seagrass meadows show measurable responses to changes in water quality, making them ideal candidates for monitoring the long-term health of marine environments (Abal and Dennison, 1996; Dennison et al., 1993; Orth et al., 2006). A network of long-term seagrass monitoring sites has been established at various port locations throughout Queensland to assist port managers in planning and management to ensure port activities have minimal impact on the marine environment and fish habitats. The program is also used to help separate natural from anthropogenic change to seagrass meadows.

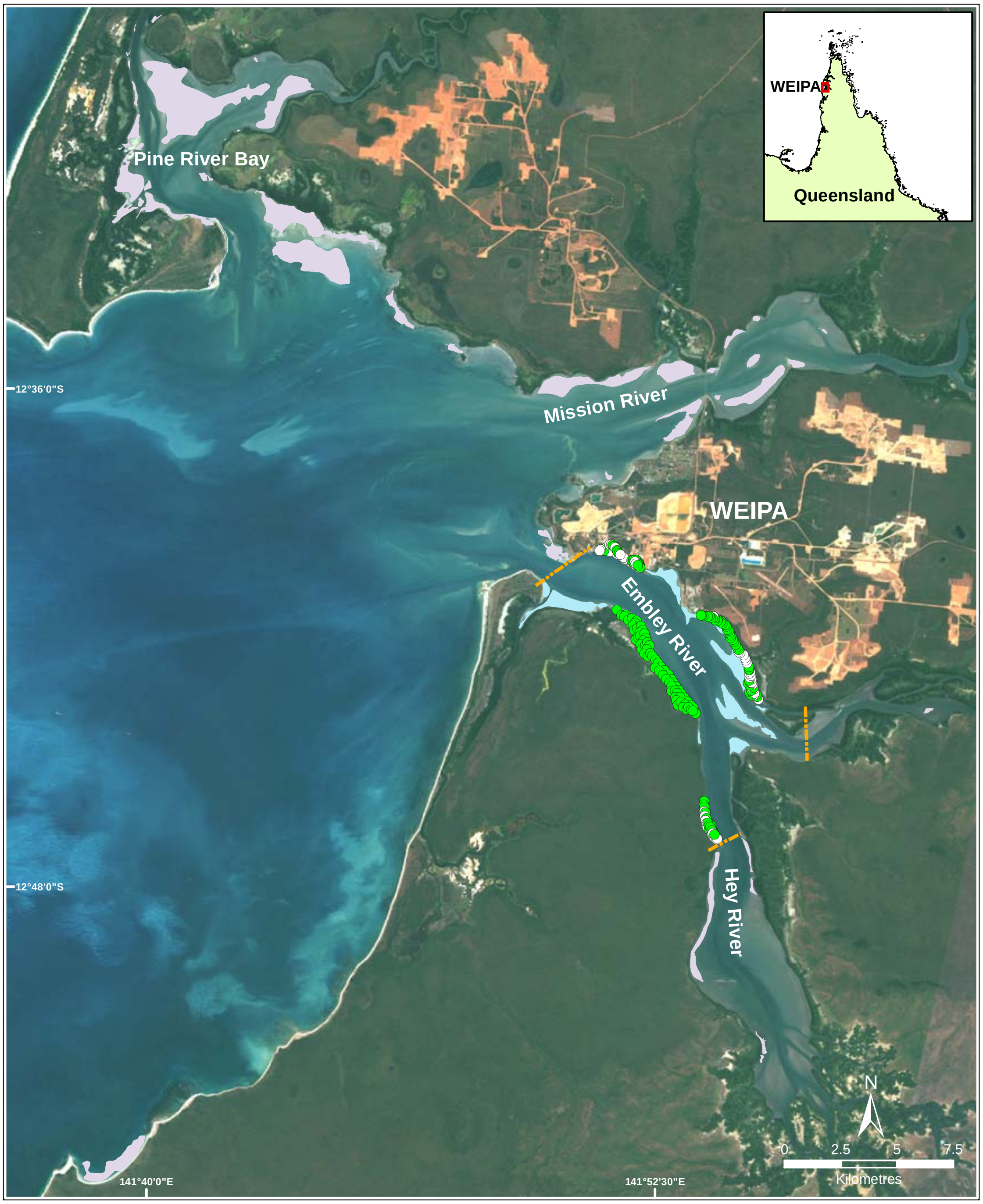
North Queensland Bulk Ports Corporation (NQBP) is responsible for managing and monitoring Weipa's port environment. NQBP has recognised that seagrasses form a key ecological habitat in the Weipa region and commissioned the James Cook University Centre for Tropical Water and Aquatic Ecosystem Research (JCU-TropWATER) (formally the Marine Ecology Group in DAFF) to established a long-term seagrass monitoring program for Weipa's port in 2000 (Roelofs et al., 2005, 2001, 2003). 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 2012 the combined dredge campaign commenced mid-July and was completed in 47 days, with 598 658 m^3 of maintenance dredge material and 328 399 m^3 capital dredge material removed. 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 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 1). 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 (Map 1).

This report presents the results of the long-term seagrass monitoring and conducted in August 2012. The objectives of the 2012 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 the Intensive Monitoring Area (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 1. Location of 2012 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: Carter, AB, McKenna, SA, Rasheed, MA (2013) 'Port of Weipa long-term seagrass monitoring – August 2012'. 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 August 29 – 31, 2012. Annual monitoring over the past 13 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 1, 2; Appendix 2).
2. Map seagrass distribution and confirm species composition in non-core monitoring meadows within the IMA (Maps 1 & 2).

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.

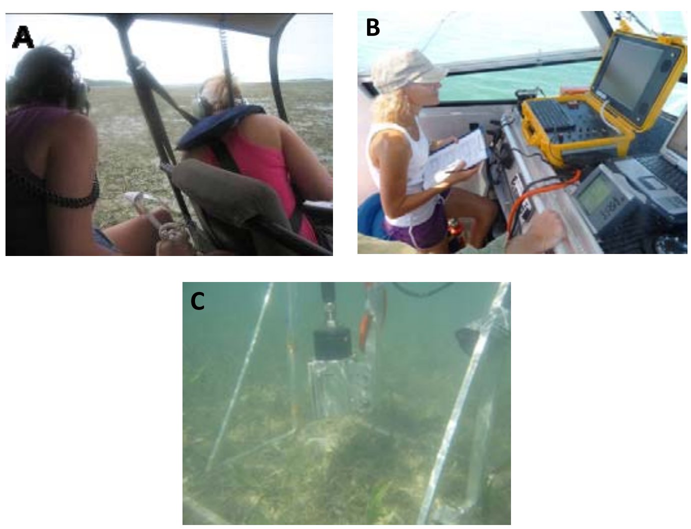


Plate 1. Seagrass methodology utilising (A) helicopter aerial surveillance, and (B,C) boat-based CCTV surveillance.

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 2012 as *E. acoroides* was absent from the A3 and A5 meadows.

2.2 Geographic Information System

Spatial data from the August 2012 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 2012.

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 2012.

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 second 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 divided 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 using a one-way ANOVA for three of the core monitoring meadows (Meadows A2, A5 and A7). Post hoc analysis using Fisher's unprotected least significant difference test was used for pair wise comparison of years. Data was square root-transformed (A2 and A7) and $\log_{(x+1)}$-transformed (A5) to improve the assumptions of normality and homogeneity of variance. A Kruskall-Wallis one-way ANOVA on ranks with Dunn's post hoc comparison was used to compare median above-ground biomass in the A3 and A6 core monitoring meadows. Detailed statistical results are presented in Appendix 1.

3 RESULTS

3.1 Seagrass species, distribution and abundance

A total of 240 seagrass habitat characterisation sites were surveyed in the Weipa monitoring meadows in August 2012, with seagrass present in 70% 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., 2001, 2003).

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 within the Intensive Monitoring Area (IMA) that encompasses the region of port activity in August 2012 (Maps 1 – 2). The total combined seagrass meadow area was 975 ± 51 ha, a 5.8% reduction in area from August 2011. Meadow area was also below the 13-year average of 1035 ± 66 ha (Figure 2). Individual meadow area ranged from 0.2 ha to 233 ha. As in all previous years the largest meadow, A2, stretched along the western bank of the Embley River (Map 2).

The dominant seagrass species in each of the core monitoring meadows remained unchanged from 2011. *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 sub tidal 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 2).

The condition known as burning, i.e. the browning and subsequent death of seagrass blades, was observed at 17.5% of sites surveyed within the IMA in 2012, an increase from 11% of sites in 2011 and 7.5% of sites in 2010. The prevalence of burning indicates that a higher level of exposure-related stress was experienced by intertidal seagrasses leading up to the survey. Dugong feeding trails, which were present in the A2, A4 and A5 meadows in 2010, were not observed within the IMA in 2011 or 2012.

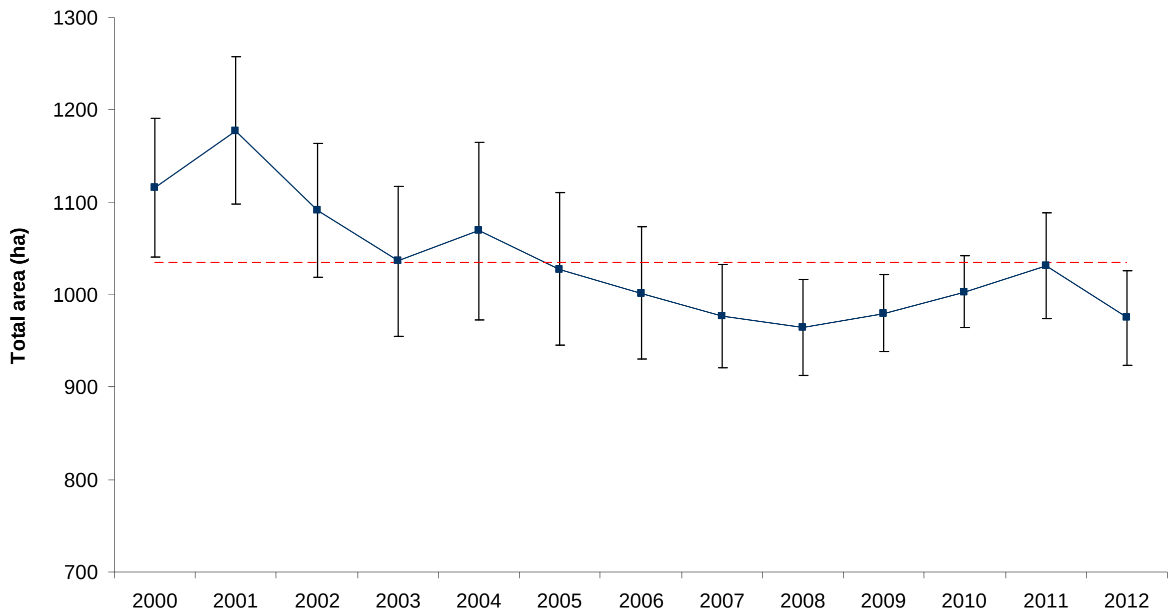
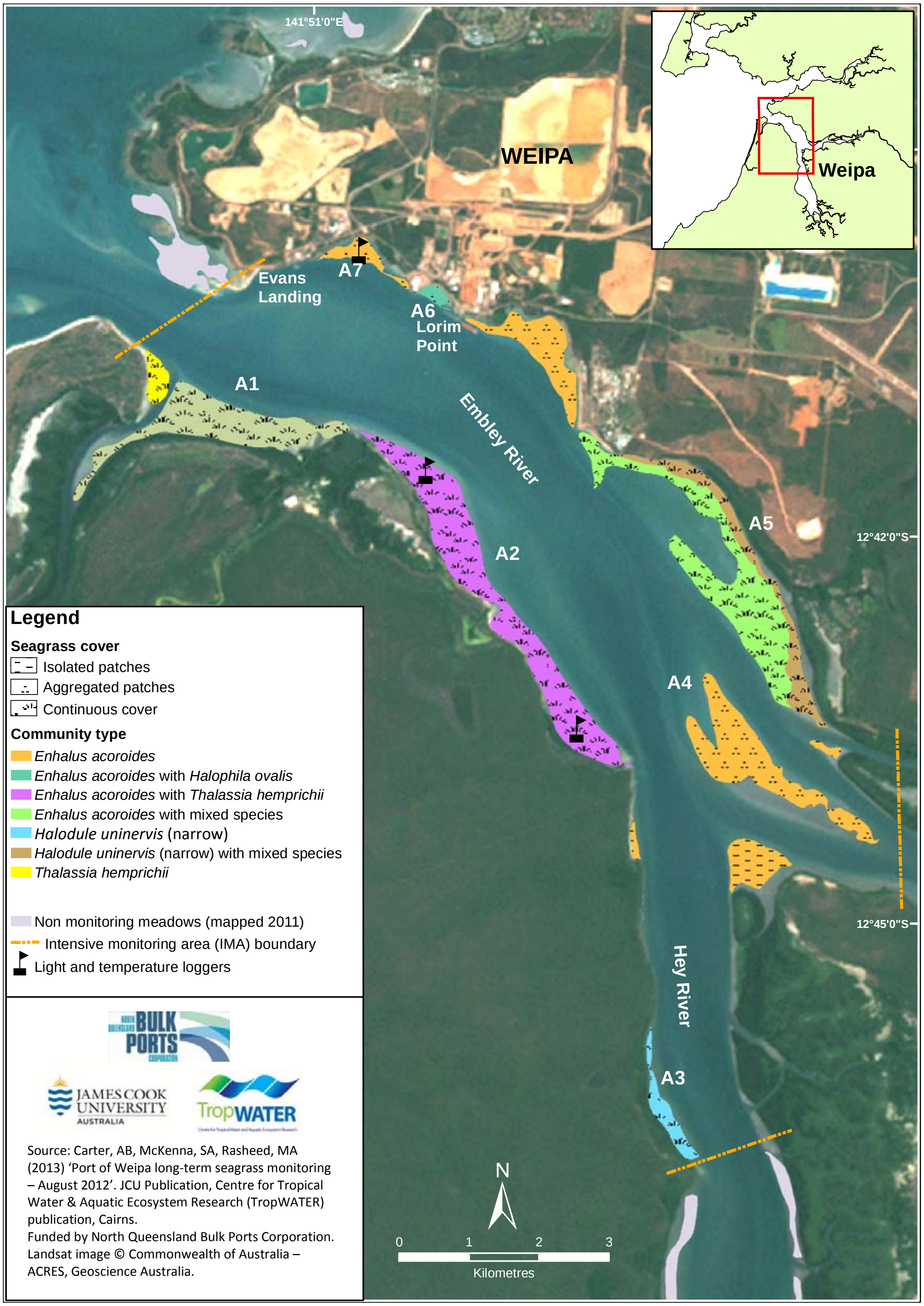


Figure 2 Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2012 (error bars = "R" reliability estimate). Red dashed line indicates 13-year mean of total meadow area.

Map 2. Meadow type and cover for seagrass meadows within the Intensive Monitoring Area 2012



3.3 Comparison of core monitoring meadows

Total meadow area for all core monitoring meadows decreased 9% from 399 $\pm$ 18 ha in 2011 to 363 $\pm$ 25 ha in 2012. Meadow area decreases occurred in each of the monitoring meadows, but were greatest in A2 in terms of area (decrease of 21 ha or 8.3%) and greatest in A5 in terms of per cent decrease (10 ha or 12.0%) (Figure 3). Despite these decreases meadow area generally remained within the range of previously recorded values, apart from meadow A2 which had the lowest area recorded for the 13 year monitoring program.

Changes in seagrass biomass between August 2011 and August 2012 varied for the core monitoring meadows. Biomass increased significantly in the *E. acoroides* dominated A2 meadow, while meadow biomass did not differ between 2011 and 2012 in the *E. acoroides* dominated A7 and *H. uninervis* dominated A5 meadows (Figure 3; see Appendix for detailed statistical results). Mean meadow biomass increased approximately 300% from 2011 to 2012 in the *H. uninervis* dominated A3 meadow and *E. acoroides* dominated A6 meadows. However, due to the patchiness of meadows with large variations in biomass between sites and a large number of sites with zero biomass, this increase was beyond the power of the statistical analysis to detect significance.

Significant variation in biomass across multiple years was observed in Weipa's *E. acoroides*-dominated seagrass meadows A2 and A7 (see Appendix 1). The large A2 meadow experienced the greatest fluctuations in biomass over 13 years of monitoring, from a peak of 33.6 $\pm$ 5.8 g DW m^{-2} in 2000 followed by a declining trend to a low of 4.7 ± 0.6 g DW m^{-2} in 2008 (Figure 3a). Since 2009 biomass has fluctuated between years, with biomass in 2012 (14.6 ± 1.3 g DW m^{-2}) statistically similar to other medium-high biomass years such as 2002 and 2010. The increase in seagrass density coincides with the re-appearance in 2012 of moderate/dense biomass hotspots similar to those recorded in 2000-2004 and 2010, this time in the northern section of the meadow (Map 3). Despite long-term fluctuations in A2 meadow biomass, meadow area has remained relatively stable, ranging from 255 $\pm$ 19 ha in 2002 and 2005, to 233 $\pm$ 7 ha in 2012 (Figure 3a).

Biomass in the small *E. acoroides*-dominated A7 meadow on the northern banks of the Embley River has also experienced a declining trend since 2001. For the first time since monitoring began, A7 had the lowest biomass of all core monitoring meadows at 1.7 ± 0.5 g DW m^{-2}. Meadow biomass was statistically similar to previous low biomass years for A7 (2005 – 2006, 2010 – 2011) (Figure 3a). Despite a 1 ha reduction in meadow size between 2011 and 2012, the area of A7 at 21 $\pm$ 7 ha was still the third highest recorded since monitoring began in 2000.

Biomass in the intertidal *H. uninervis*-dominated A3 and A5 meadows has also been variable between years over the course of the monitoring program (Figure 3b). Biomass in A5 was 4.2 $\pm$ 0.9 g DW m^{-2} in 2012, statistically similar to previous high biomass years such as 2007 and 2009-2011. Biomass in A3 was 2.4 $\pm$ 0.6 g DW m^{-2} in 2012, the second highest biomass recorded in this meadow since monitoring began (Figure 3b).

The species composition of seagrass in monitoring meadows continued to shift in 2012. There was increased dominance of *T. hemprichii* in meadows A2 and A5. In meadow A2 *T. hemprichii* increased from 10% to 30% of seagrass biomass between 2011 and 2012, at the expense of *E. acoroides* (Figure 3a). In meadow A5 *T. hemprichii* increased in dominance from 11% to 25% between 2011 and 2012, at the expense of *H. uninervis* (Figure 3b). Species composition also shifted in A6 with a decline in dominance of *E. acoroides*, from 99.5% of biomass in 2011 to 89.5% in 2012, with increases in *H. uninervis* and *H. ovalis* accounting for 10% (Figure 3a). Meadow A7 in 2012 returned to total dominance of *E. acoroides*, a similar species composition to that observed from 2001 – 2009, following the loss of *H. ovalis* and *H. decipiens* recorded in the meadow in 2011 (Figure 3a). Meadow A3 remained characteristically dominated by *H. uninervis*, although there was a small re-emergence of *H. ovalis* (<1%), the first time this species has been recorded in A3 since 2006 (Figure 3b).

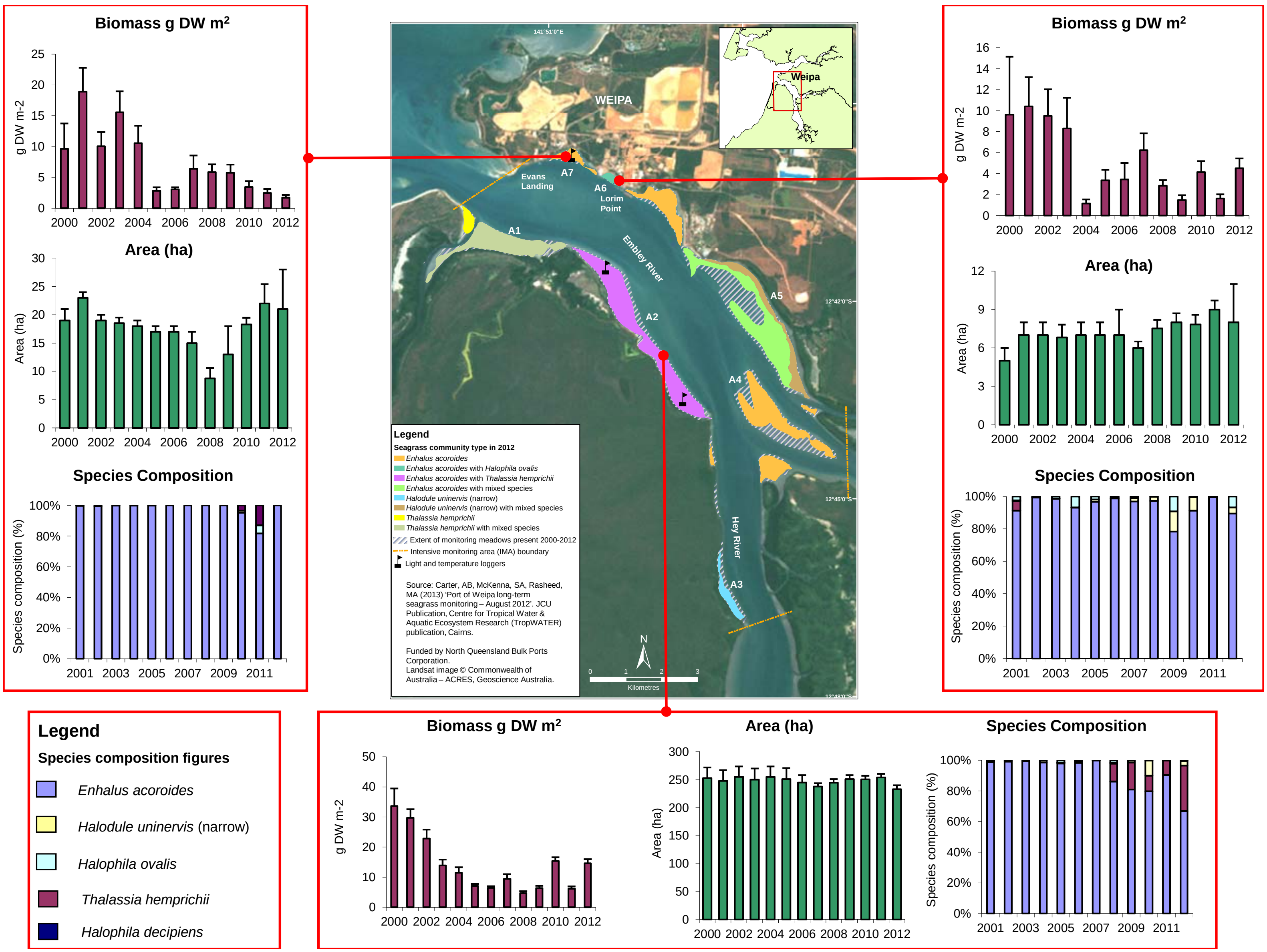


Figure 3a. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated core monitoring meadows A2, A6 and A7 in Weipa from 2000 to 2012 (biomass error bars = SE; area error bars = "R" reliability estimate).

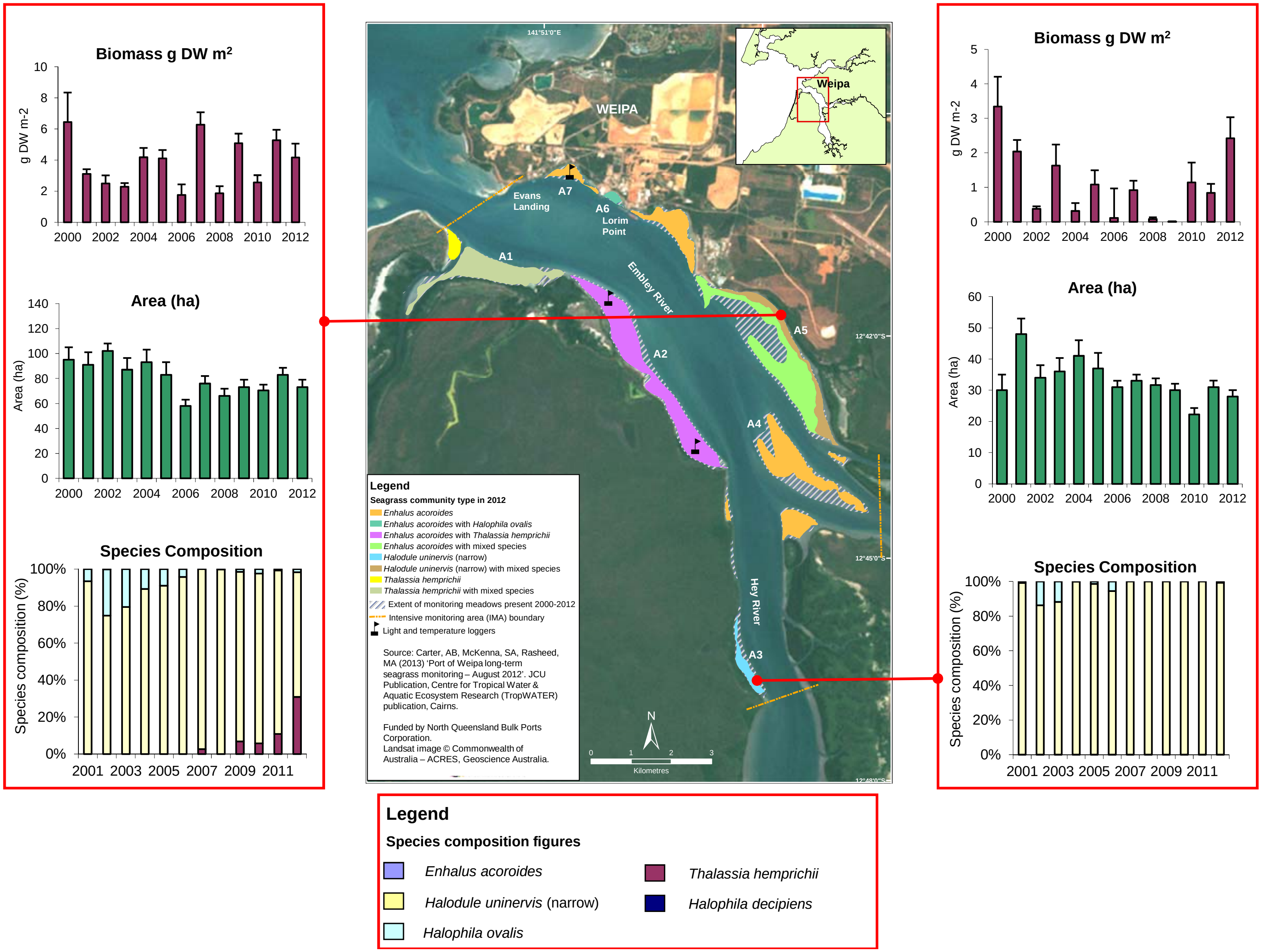
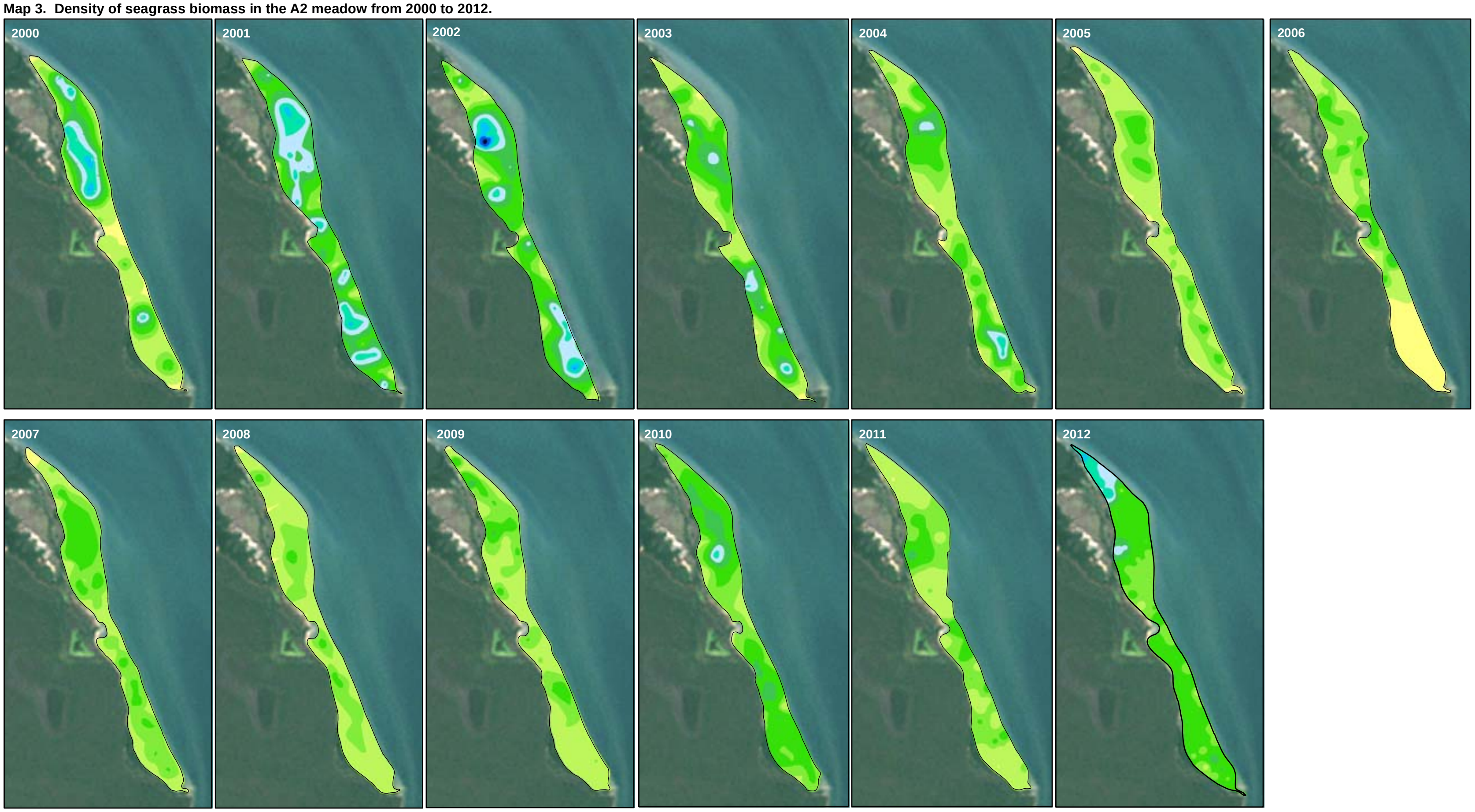


Figure 3b. Changes in biomass, area and species composition for the *Halodule uninervis* dominated core monitoring meadows A3 and A5 in Weipa from 2000 to 2012 (biomass error bars = SE; area error bars = "R" reliability estimate).

Map 3. Density of seagrass biomass in the A2 meadow from 2000 to 2012.



Legend

Biomass (g DW m-2)

- 0-0.1
- 0.11-5
- 5.1-10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - 60
- 60.1 - 80
- 80.1 - 105

N

0 1 2 3

Kilometres

Source: Carter, AB, McKenna, SA, Rasheed, MA (2013) 'Port of Weipa long-term seagrass monitoring – August 2012'. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) publication, Cairns.

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3.4 Weipa climate data and seagrass change

3.4.1 Rainfall

Total annual rainfall in Weipa in the 12 months preceding the 2012 survey was 2175 mm. Rainfall in 2012 was 223 mm above the long-term average, but 568 mm less than in 2011 when rainfall was at the highest level since seagrass monitoring began in 2000 (Figure 4 inset). Rainfall was highly variable between days, but followed a general trend of summer peaks, particularly between late January and late March, and winter lows (Figure 4).

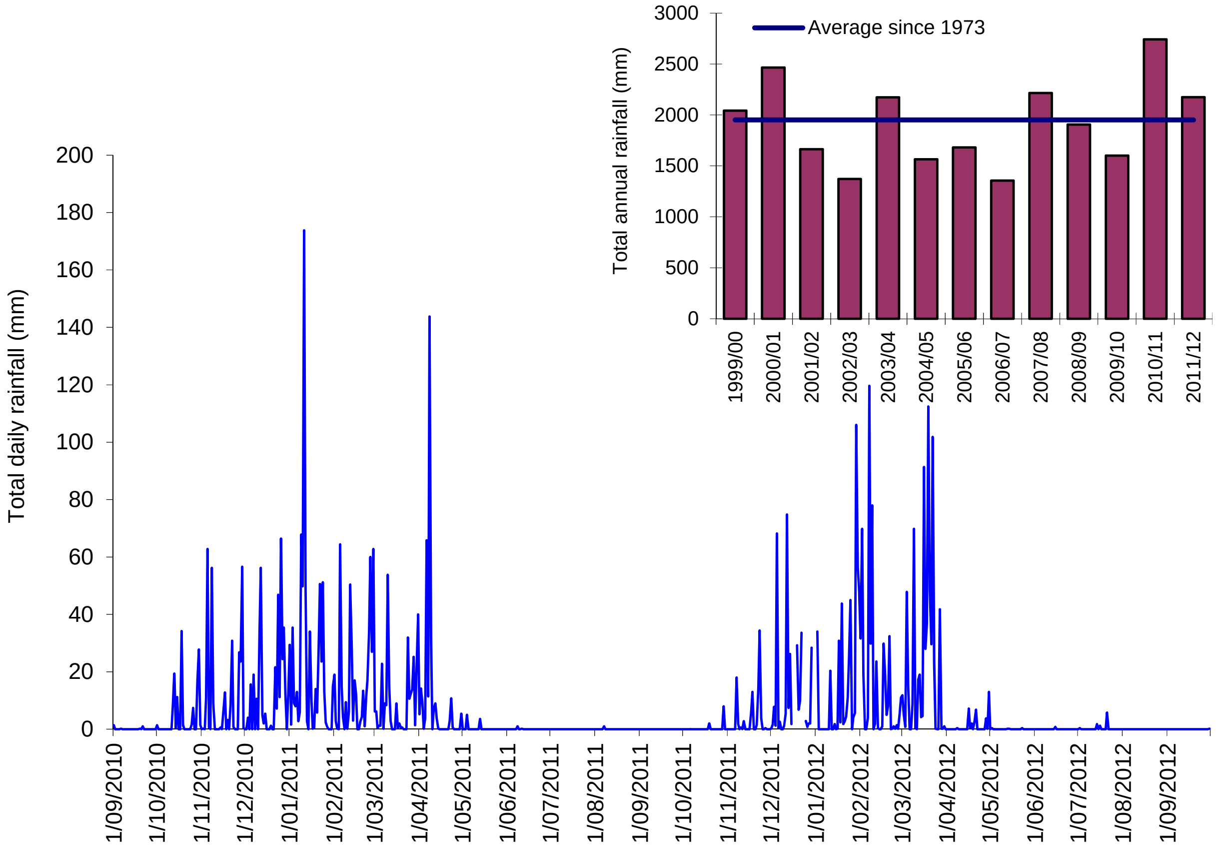


Figure 4. Total daily rainfall (mm) from September 1 2010 – September 30 2012 and (Inset) total annual rainfall for the 12 months preceding each survey from 1999/2000 – 2011/2012 recorded at Weipa airport (Bureau of Meteorology, Station 027045). Black arrow indicates when 2012 survey was conducted.

3.4.2 Tidal exposure

Intertidal banks at Weipa were exposed for a total of 346 hours during the 12 months prior to the August 2012 monitoring survey. Total daytime tidal exposure has been below the total annual 420 hour average for the last four years (Figure 5). Prior to 2008, exposure was above average for seven years. The number of hours intertidal seagrass banks were exposed during the day was generally higher over the winter period, peaking in July at 104 hours average exposure, and lower in summer where intertidal banks rarely expose (Figure 6). Exposure was below average every month in the 12 months preceding the 2012 survey (Figure 6). In 2012 total hours exposed three months prior to the survey was 56 hours below the average 269 hours exposure, continuing the trend of relatively low exposure in the three months prior to each survey seen from 2008-2011. In 2012 intertidal meadows were exposed for 88 hours one month prior to the monitoring survey, close to the average 89 hours measured between 2000 and 2012 (Figure 7).

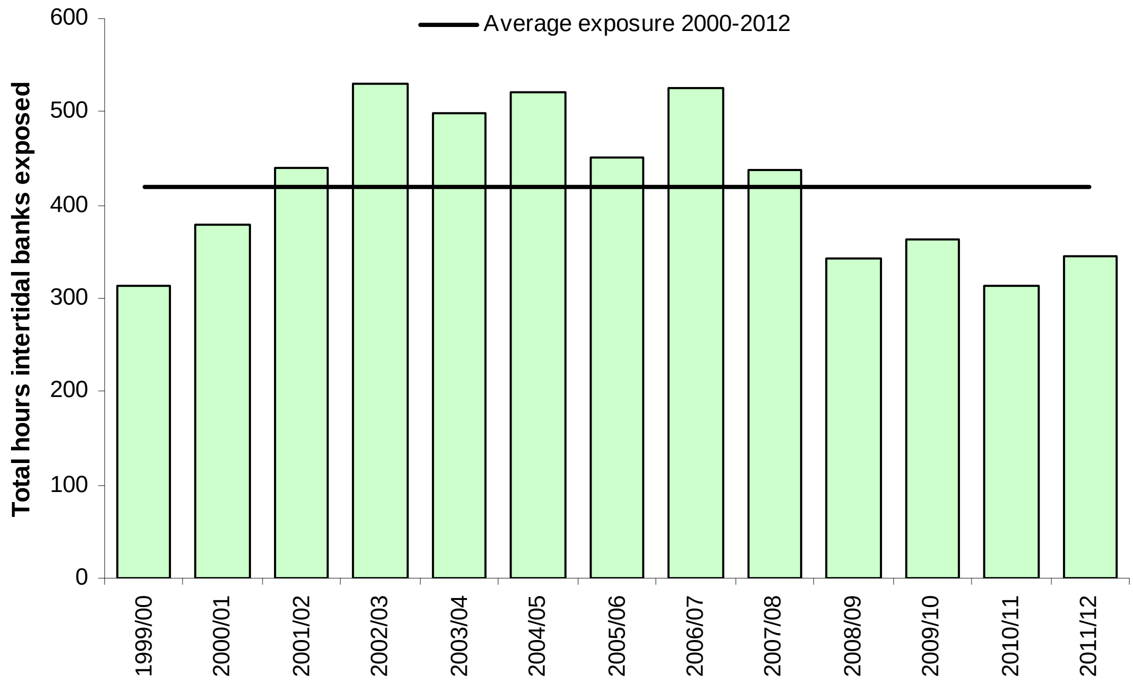


Figure 5. Total number of daytime hours intertidal banks are exposed (<0.9m tidal height) in Weipa in the 12 months preceding each monitoring survey from 2000 – 2012. Tidal data © The State of Queensland (Department of Transport and Main Roads) 2012, Tidal Data.

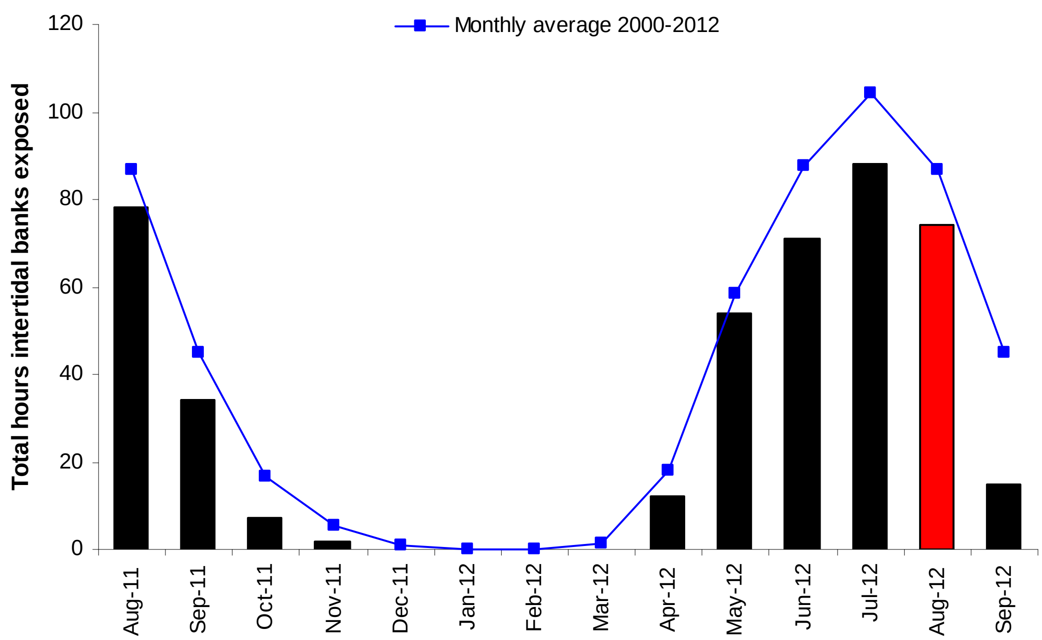


Figure 6. Monthly total number of daytime hours intertidal banks are exposed (<0.9m tidal height) in Weipa in the 12 months preceding the 2012 monitoring survey. Red bar indicates month when monitoring survey occurred. Tidal data © The State of Queensland (Department of Transport and Main Roads) 2012, Tidal Data.

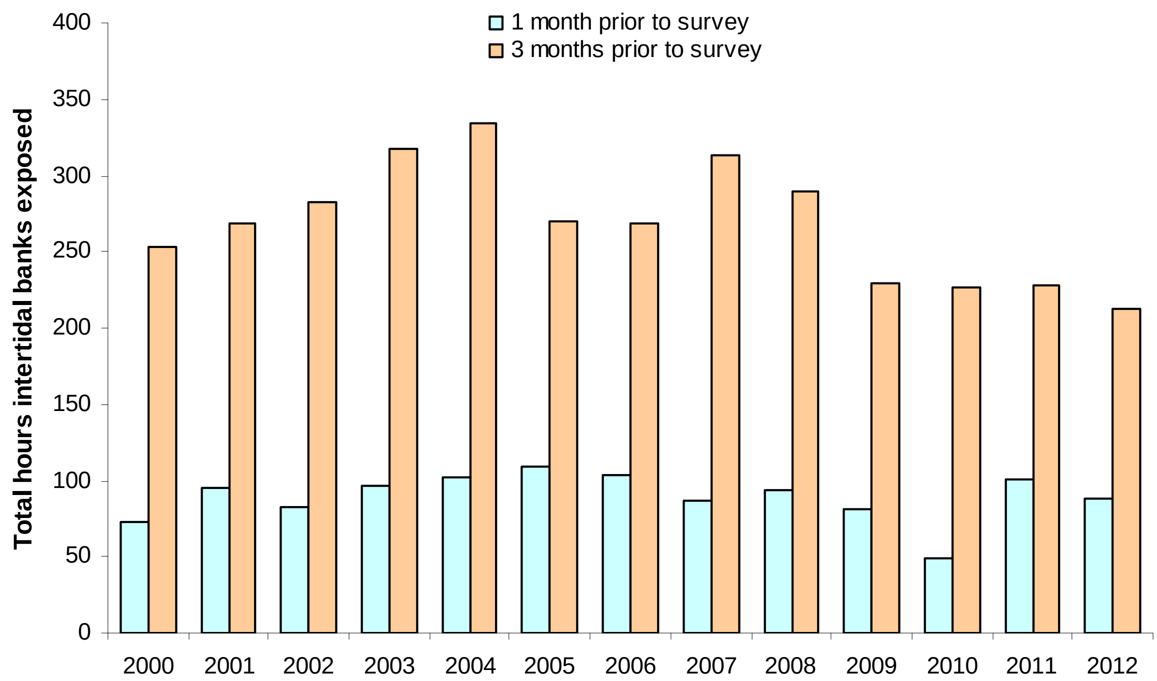


Figure 7. Total number of daytime hours intertidal banks are exposed (<0.9m tidal height) in Weipa in the 1 and 3 months preceding each monitoring survey from 2000-2012. Tidal data © The State of Queensland (Department of Transport and Main Roads) 2012, Tidal Data.

3.4.3 Light

Total daily PAR in the shallower intertidal A2 meadow was greater and more variable than in the deeper intertidal A7 meadow. Mean daily PAR at meadow A7 was 6.1 $\pm$ 0.2 mol m^{-2} day^{-1} compared with 11.7 $\pm$ 0.4 and 10.9 $\pm$ 0.4 mol m^{-2} day^{-1} in the intertidal sites at A2-1 (north) and A2-2 (south), respectively (Figure 8a-c). Total daily PAR ranged from less than 0.003 mol m^{-2} day^{-1} at all three sites, to a maximum daily PAR of 19.6 mol m^{-2} day^{-1} in A7, and 40.7 and 31.3 mol m^{-2} day^{-1} at sites A2-1 and A2-2, respectively (Figure 8a-c). Variation in PAR within the A2 meadow is likely due to loggers deployed approximately 4km apart experiencing slightly different exposure periods.

The relationship between rainfall and PAR could not be definitively determined due to logger failure over the 2010-2011 summer wet season and partial logger failure over the 2011-2012 wet season. However, the PAR data set obtained so far indicates a decrease in PAR between October and March each year, coinciding with increased rainfall (Figures 4, 8a-c). Tidal cycles accounted for much of the 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 8d). 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.

The data set over the 25 months the loggers were deployed was incomplete (Figures 8a-c). The most common cause of data loss was due to wiper unit malfunction. Malfunctions were most commonly a result of a water leak damaging the electronics. As more data is collected and the causes of malfunctions are rectified, a more complete data set will become available.

3.4.4 Water temperature

The average maximum daily water temperature in the shallow intertidal A2 meadow was 31.5 ± 0.1°C (at both A2-1 and A2-2 sites), approximately 1.5°C greater than in the deeper intertidal A7 meadow (Figure 8a-c). Within-meadow average daily water temperature was highly variable, ranging from approximately 20°C to 32°C. Peaks in maximum water temperature at the A2 meadow coincided with peaks in PAR (Figure 8b-c). These peaks coincided with midday low tides when shallow water over the seagrass meadow became heated.

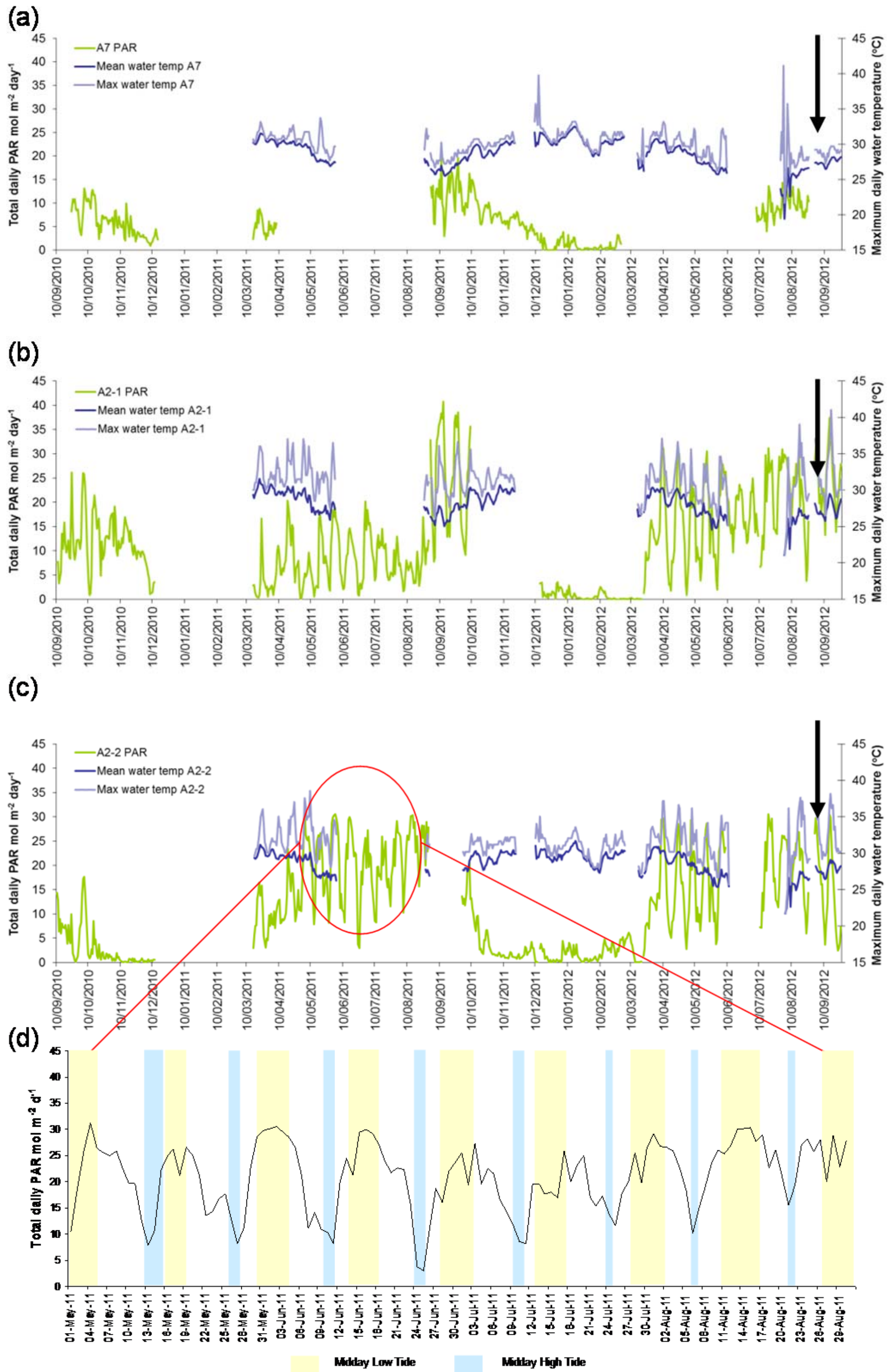


Figure 8. Daily photosynthetically active radiation (PAR mol m^{-2} day^{-1}) and maximum daily water temperature (°C) at Weipa, September 2010 – September 2012, at (a) meadow A7; (b) northern meadow A2-1; (c) southern meadow A2-2; with (d) detail of PAR data with tidal cycles for A2-2, May 1 to Aug 30 2011. Black arrow indicates when 2012 seagrass monitoring survey was conducted.

4 DISCUSSION

Seagrasses in the Port of Weipa remained in a reasonable condition in 2012. Within the Intensive Monitoring Area (IMA) and close to major port operations seagrass biomass generally increased or remained constant between 2011 and 2012. However the combined seagrass meadow area in this region decreased 6% between 2011 and 2012.

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). These declines occur because tidal exposure coupled with high daytime temperatures can lead to high levels of photosynthetic active radiation and ultra violet radiation as well as desiccation and temperature stress which leads to physiological stress to the leaf structure and photosystems (Bjork et al., 1999; Kahn and Durako, 2009; Rasheed and Unsworth, 2011; Stapel, 1997). In 2012 tidal exposure was 88 hours in the month preceding the monitoring survey, 13 hours less than the 101 hours meadows were exposed during the month prior to the 2011 survey. Below average daytime tidal exposure in July and August 2012 is likely to have facilitated increases in seagrass biomass within the monitoring meadows. However, the increase in "burning" of seagrass leaves, reported at 17.5% of sites within the IMA in 2012, indicates Weipa's intertidal seagrasses continue to experience exposure-related stress despite the reduction in hours of tidal exposure between 2011 and 2012.

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 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. Preliminary data indicates PAR is also 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). A thorough analysis of the relationship between PAR and rainfall in Weipa will be conducted as a more complete and longer term data set that includes all loggers deployed over the summer wet season becomes available.

Light and temperature are two of the major factors that have been linked to changes in seagrasses, and 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, 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.

Despite annual fluctuations in seagrass biomass the general trend of long-term decline in several of the core monitoring meadows indicates that Weipa's seagrasses may still remain vulnerable to further natural and anthropogenic impacts. Continued care should be taken when conducting activities in the Weipa region that could further stress these meadows. The seagrass monitoring program provides information to inform the management of maintenance and capital dredging programs in Weipa, and forms an integral component of the Dredge Technical Advisory Consultative Committee's assessment of potential dredge mitigation strategies that may need to be applied to continue to protect seagrasses within the Port. The large meadow on the western bank of the Embley River (A2) that is closest to the majority of maintenance dredging in the port was in a relatively robust condition in 2012. The relatively high biomass of this meadow indicates that it should remain resilient to planned maintenance dredging activities in 2013, provided the duration of dredging remains relatively short and that there are no major loses associated with climate impacts leading up to the 2013 dredging campaign.

In summary, results of the 2012 monitoring indicate:

1. Seagrass habitat in the Port of Weipa was in a reasonable condition, although some meadows remain vulnerable to further impacts.
2. Biomass in the large *E. acoroides* meadow (A2) on the western bank of the Embley River increased significantly between 2011 and 2012, and should remain resilient to planned maintenance dredging activities in 2013.
3. Tidal exposure and solar radiation explain a significant component of the long-term decline in biomass for some intertidal meadows; however, they are not the only factors that could be contributing to changes in seagrass.
4. The deployment of PAR and temperature loggers at Weipa in 2010 has enhanced the monitoring program and will continue to improve interpretations of meadow-scale change and the ability of the program to pinpoint the causes of seagrass declines.

5 APPENDICES

Appendix 1. (A) Results of one-way ANOVA comparing mean biomass between years (2001 – 2012) for the Weipa core monitoring meadows A2, A5 and A7. Post hoc analysis using Fisher's unprotected least significant difference test was used for pair wise comparison of years. Years that share the same letter are not significantly different (*P*<0.05).

Meadow A2		
Year	**Mean biomass (sqrt-transformed)**	
2001	4.944	e
2002	4.084	d
2003	2.993	c
2004	2.746	bc
2005	2.398	abc
2006	2.004	a
2007	2.746	bc
2008	1.829	a
2009	2.172	ab
2010	3.720	d
2011	2.164	ab
2012	3.618	d

Meadow A5		
Year	**Mean biomass ($\log_{(x+1)}$transformed)**	
2001	1.361	bcd
2002	1.120	ab
2003	1.173	abc
2004	1.442	cd
2005	1.385	bcd
2006	0.912	a
2007	1.975	f
2008	1.124	abc
2009	2.053	f
2010	1.594	de
2011	2.154	f
2012	1.932	ef

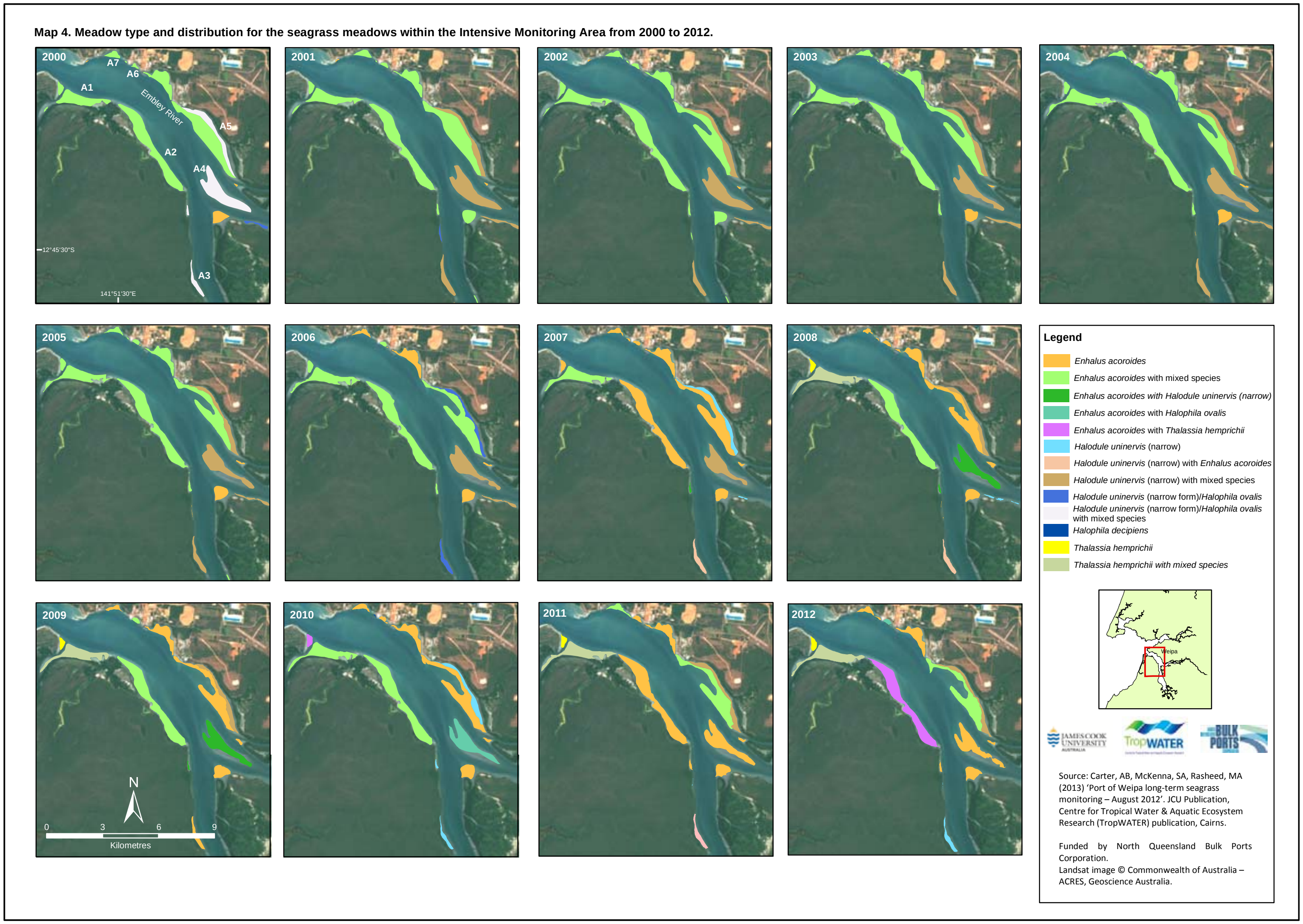
Meadow A7		
Year	**Mean biomass (sqrt-transformed)**	
2001	3.177	g
2002	2.317	efg
2003	2.878	fg
2004	2.209	def
2005	1.279	abcd
2006	1.212	abc
2007	2.108	cdef
2008	2.033	bcdef
2009	1.929	bcdef
2010	1.367	abcde
2011	1.075	ab
2012	0.794	a

(B) Results of Kruskall-Wallace ANOVA in ranks with Dunn's post hoc comparison comparing median above-ground seagrass biomass in the core monitoring meadow A3 and A6 at Weipa. Cells marked with a "Yes" indicates a significant difference in biomass of the meadow between comparison years and cells marked "No" indicates no significant difference in meadow biomass between years. Significance was set at *P*<0.05.

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

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

Appendix 2. Meadow type and distribution for the seagrass meadows within the Intensive Monitoring Area, 2000 – 2012.



Appendix 3. Mean above-ground seagrass biomass (g DW m^{-2}) and number of biomass sampling sites for each core monitoring meadow within the Port of Weipa, 2000 – 2012.

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**
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)
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)
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)
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)
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)

Appendix 4. Total meadow area for each core monitoring meadow within the Port of Weipa, 2000 – 2012.

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**
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
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
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
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
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
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

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