Department of **Employment, Economic Development and Innovation**

# Port of Weipa Long-term Seagrass Monitoring

## 2000 - 2011

**Carter, AB, McKenna, SA & Rasheed, MA.**

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# EXECUTIVE SUMMARY

This report details the results of the August 2011 monitoring program in the Port of Weipa. Seagrasses in the Port of Weipa remained in a reasonable but vulnerable condition. Several meadows have shown a long-term decline in biomass since monitoring began in 2000. These declines are likely associated with natural shifts in tidal exposure and changes in light and temperature associated with local climate conditions. The long-term nature of these declines may have left some meadows in a vulnerable state with a low resilience to further natural or anthropogenic impacts.

In 2011, meadow area within the Intensive Monitoring Area (IMA) around the major port operations was approximately equal to the twelve-year average of 1039 ± 67 ha following three consecutive years of modest increases in meadow area of ~20 ha per year. Seagrass biomass within four of the five core monitoring meadows declined between 2010 and 2011 and biomass values were statistically similar to other low biomass years over the 12 years of monitoring. The most significant biomass decline was recorded in the large intertidal *Enhalus acoroides* dominated A2 meadow opposite Lorim Point, where the 2011 biomass value of 6.13 ± 0.8 g DW $m^{-2}$ was less than half of the biomass reported in 2010. In contrast, biomass in the *Halodule* dominated intertidal A5 meadow on the eastern bank of the Embley River more than doubled between 2010 and 2011. Changes in biomass for these meadows over the course of the monitoring program are 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. Preliminary results from light and temperature loggers deployed in September 2010 indicate a negative correlation between photosynthetically active radiation (PAR) with rainfall and meadow depth, and high within- and between-meadow variation in average and peak water temperatures and PAR. 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 declines.

Seagrass distribution and species composition were also mapped within the broader Weipa port limits as occurs every three years. Total seagrass meadow area was 3996 ± 231 ha, its highest level since 2001 and an increase of 21% since 2008 monitoring. Aggregated patches of seagrass continued to be the dominant landscape category and described 55% of meadows. Species composition in many of the individual meadows had changed since 2008, which is characteristic of the dynamic nature of seagrass meadows.

Seagrasses appear to have been resilient to the impacts associated with regular port maintenance dredging during the life of the current monitoring program. However, Fisheries North remain concerned that the continued low biomass of some of the meadows in Weipa leaves them vulnerable to additional stresses including those associated with dredging. Seagrass monitoring will continue to provide information necessary to inform the management of maintenance and capital dredging programs in Weipa, and forms an integral component of the Dredge Technical Review Panel's assessment of potential dredge mitigation strategies that may need to be applied to continue to protect seagrasses within the Port.

# 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 & 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 & 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.

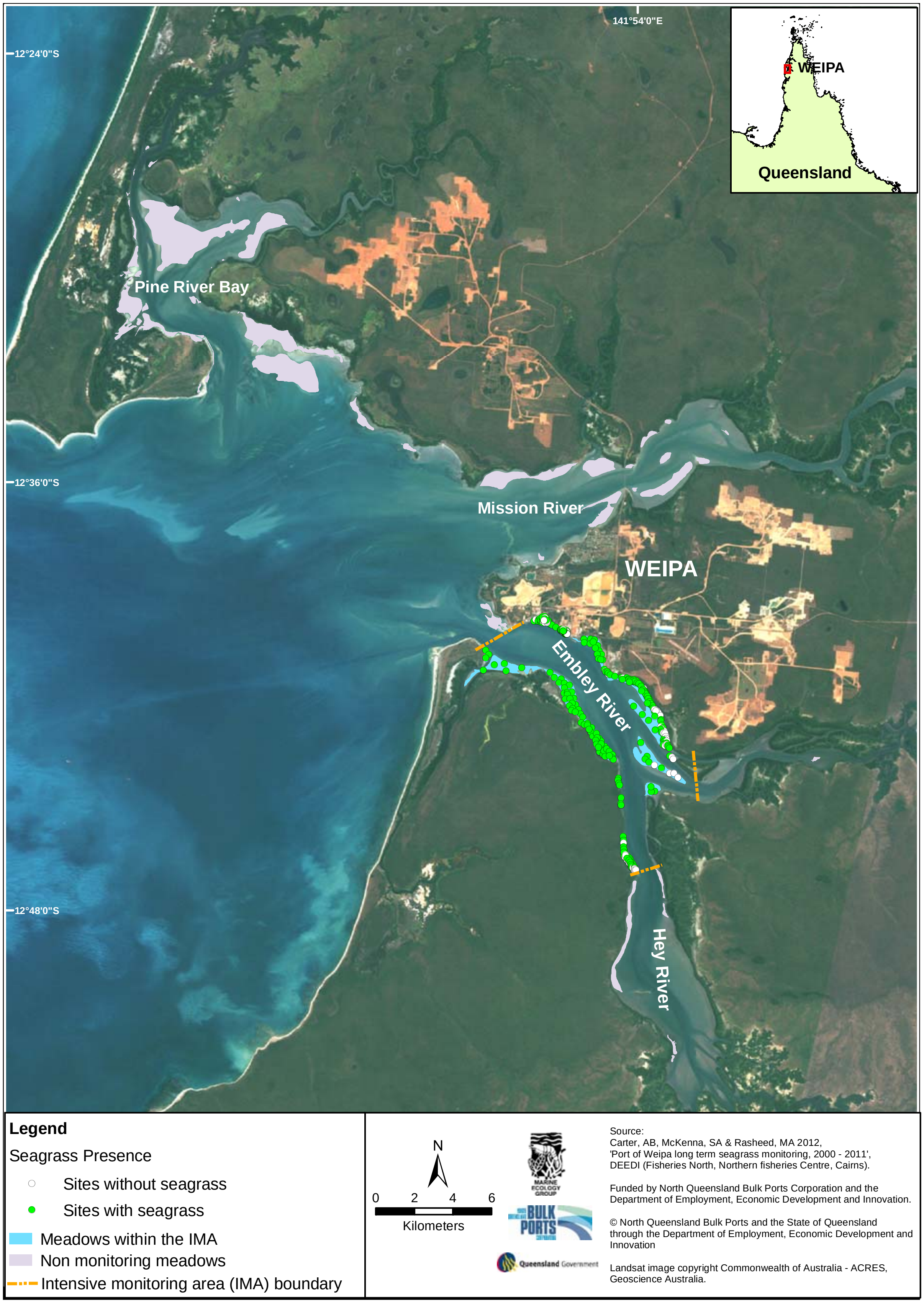
North Queensland Bulk Ports Corporation (NQBP) is the organisation responsible for managing and monitoring Weipa's port environment. The NQBP has recognised that seagrasses form a key ecological habitat in the Weipa region and established a long-term seagrass monitoring program for the Port in 2000 (Roelofs et al. 2001; Roelofs et al. 2003; Roelofs et al. 2005). The goals of the program are to minimise impacts of port activities on seagrass habitats and to periodically assess the health of Weipa's port environment. Results from seagrass monitoring surveys are used by NQBP to assess the health of the port marine environment, and help identify any possible detrimental effects of port operations (e.g. dredging) on seagrass meadows. These surveys also 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 Fisheries North's network of long-term monitoring sites for important fish habitats.

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 whole of port mapping survey conducted in August 2011. The objectives of the 2011 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) and the greater port limits;
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 2011 seagrass monitoring sites and seagrass meadows in the Port of Weipa



# METHODS

The 2011 annual seagrass monitoring within the Port of Weipa was conducted August 26 – 30 2011. This included the annual assessment of seagrasses within the Intensive Monitoring Area (IMA) as well as mapping all seagrasses within the greater port limits that is conducted every three years. Annual monitoring over the past 12 years has focused on five core seagrass meadows selected from baseline surveys (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.

There were three levels of sampling intensity used in the August 2011 surveys:

1. Map seagrass distribution and confirm species composition in seagrass meadows within the greater Weipa port limits and compare to those previously mapped in the 2008 whole of port survey (Maps 1, 4 – 6)
2. 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).
3. 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 surveillance 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, depth below mean sea level (dbMSL) for subtidal meadows, sediment type, time and position fixes (GPS; ±5m). 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 surveillance) as only the core monitoring meadows were assessed specifically for biomass and species composition.

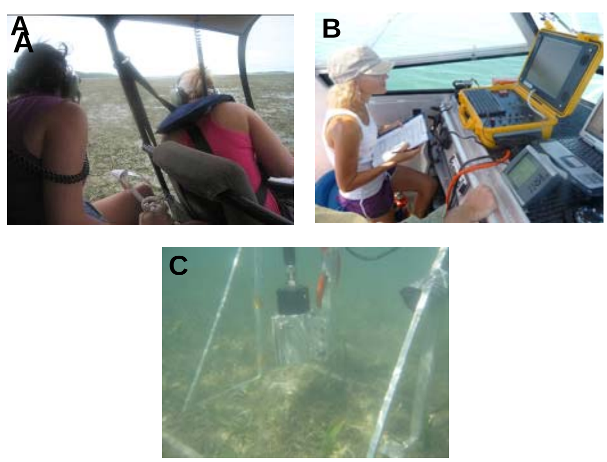



**Plate 1.** Seagrass methodology utilising helicopter aerial surveillance (A); and boat based CCTV surveillance (B & C).

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 *Enhalus acoroides* was dominant (Roelofs et al. 2003).The dry weight biomass for *Enhalus* is many orders of magnitude higher than other tropical seagrass species and dominates the average biomass of a meadow where it is present. Therefore, isolated *Enhalus acoroides* plants occurring within the *Halodule*/*Halophila* dominated meadows (A3, A5) were excluded from all biomass and species analyses in order to track the dynamics of the morphologically distinct *Halodule*/*Halophila* within the IMA.

***Geographic Information System***

Spatial data from the August 2011 survey were entered into the Port of Weipa Geographic Information System (GIS). Three seagrass GIS layers were created in ArcGIS®:

**(1) Site information** - site data containing seagrass percent cover and above-ground biomass (for each species), dbMSL, sediment type, time, latitude and longitude from GPS fixes, sampling method and any comments.

**(2) Seagrass meadow characteristics** – area data for seagrass meadows with summary information on meadow characteristics. Seagrass meadows were assigned a meadow identification number which were 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 methodology used for that meadow (Table 2). Mapping precision estimates ranged from $\leq$ 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 basemaps 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 2011.

| 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 methodology for seagrass meadows in the Port of Weipa 2011.

| Mapping precision | Mapping methodology |
|---|---|
| 1-5m | Meadow boundaries mapped in detail by GPS from helicopter;<br>Intertidal meadows completely exposed or visible at low tide;<br>Relatively high density of mapping and survey sites;<br>Recent aerial photography aided in mapping. |
| 10-50m | Meadow boundaries determined from helicopter and camera/grab surveys;<br>Inshore boundaries mapped from helicopter;<br>Offshore boundaries interpreted from survey sites and aerial photography;<br>Relatively high density of mapping and survey sites. |

**(3) Seagrass landscape category** – 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.

## Light and Temperature Assessments

Temperature and light (photosynthetically active radiation or PAR) conditions on the seagrass meadows were assessed in 2011 for the first time in the Port of Weipa. PAR and temperature were monitored within two seagrass meadows (A2 & A7; Map 2) in the port using custom built benthic data logging stations. Each logging station consists of a stainless steel frame which holds a PAR logger (Odyssey Integrated Light loggers Model Z412) and its supporting electronic wiper unit, and an autonomous iBTag temperature logger (Figure 1).

Logging stations are located at two sites within the intertidal A2 meadow and at one site in the subtidal A7 meadow (Map 2). PAR and temperature within the seagrass canopy was recorded every 15 minutes. The PAR readers were fitted with automatic wiper brushes to clean the optical surface of the sensor every 15 minutes to prevent marine organisms fouling the sensor. Loggers were exchanged and downloaded approximately every 90 days.

The Odyssey PAR loggers log a cumulative reading at 15 minute intervals, which is calibrated and summed to gain total PAR per day (mol/m$^2$/day) at each site. The raw data captured by the Odyssey 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.

## Statistical analysis

Seagrass above-ground biomass was compared between years using a one-way ANOVA for four of the core monitoring meadows (Meadows A2, A5, A6 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 to improve the assumptions of normality and homogeneity of variance. A Kruskall-Wallace one way ANOVA on ranks with Dunn's post hoc comparison was used to compare median above-ground biomass in the A3 core monitoring meadow. Detailed statistical results are presented in Appendix 1.

# RESULTS

## Seagrass species

A total of 270 seagrass habitat characterisation sites were surveyed in the Weipa port limits in August 2011, with seagrass present in 80% of sites (Map 1). Five seagrass species (from two families) were identified:

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

## Seagrass in the Intensive Monitoring Area

Fifteen seagrass meadows were mapped within the Intensive Monitoring Area (IMA) in August 2011 (Maps 1 – 2; Appendix 2). The total combined seagrass meadow area was 1031 ± 57 ha, marking the third consecutive year of modest increases in meadow area (~ 20 ha per year). In 2011, meadow area within the IMA was approximately equal to the twelve-year average of 1039 ± 67 ha (Figure 2; Appendix 2 & 4). Individual meadow area ranged from 0.01 ha to 255 ha (Appendix 2 & 4). The largest meadow stretched along the western bank of the Embley River (Map 2).

*Enhalus acoroides* dominated the seagrass communities in ten of the fifteen meadows within the IMA, including the core monitoring meadows A2, A6 and A7 (Map 2). Large *Enhalus* 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, while *Thalassia hemprichii* was the dominant species in meadow A1 (Map 2).

The condition known as burning, i.e. the browning and subsequent death of seagrass blades, was observed at 11% of sites surveyed within the IMA, an increase of 3.5% of sites surveyed 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.

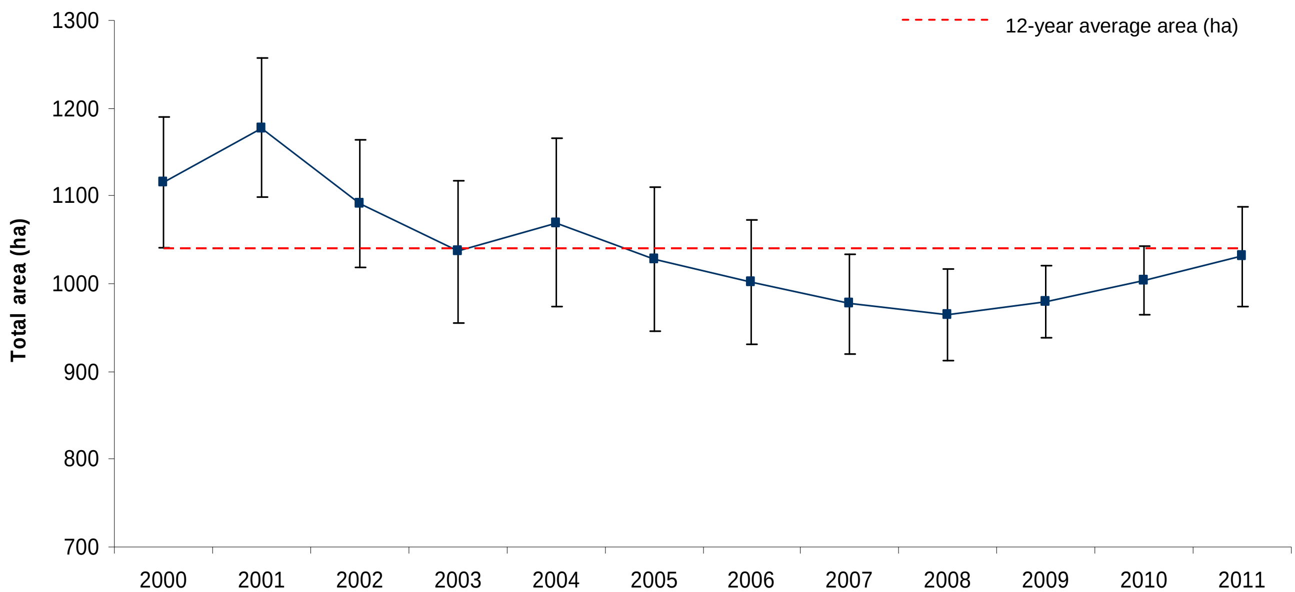
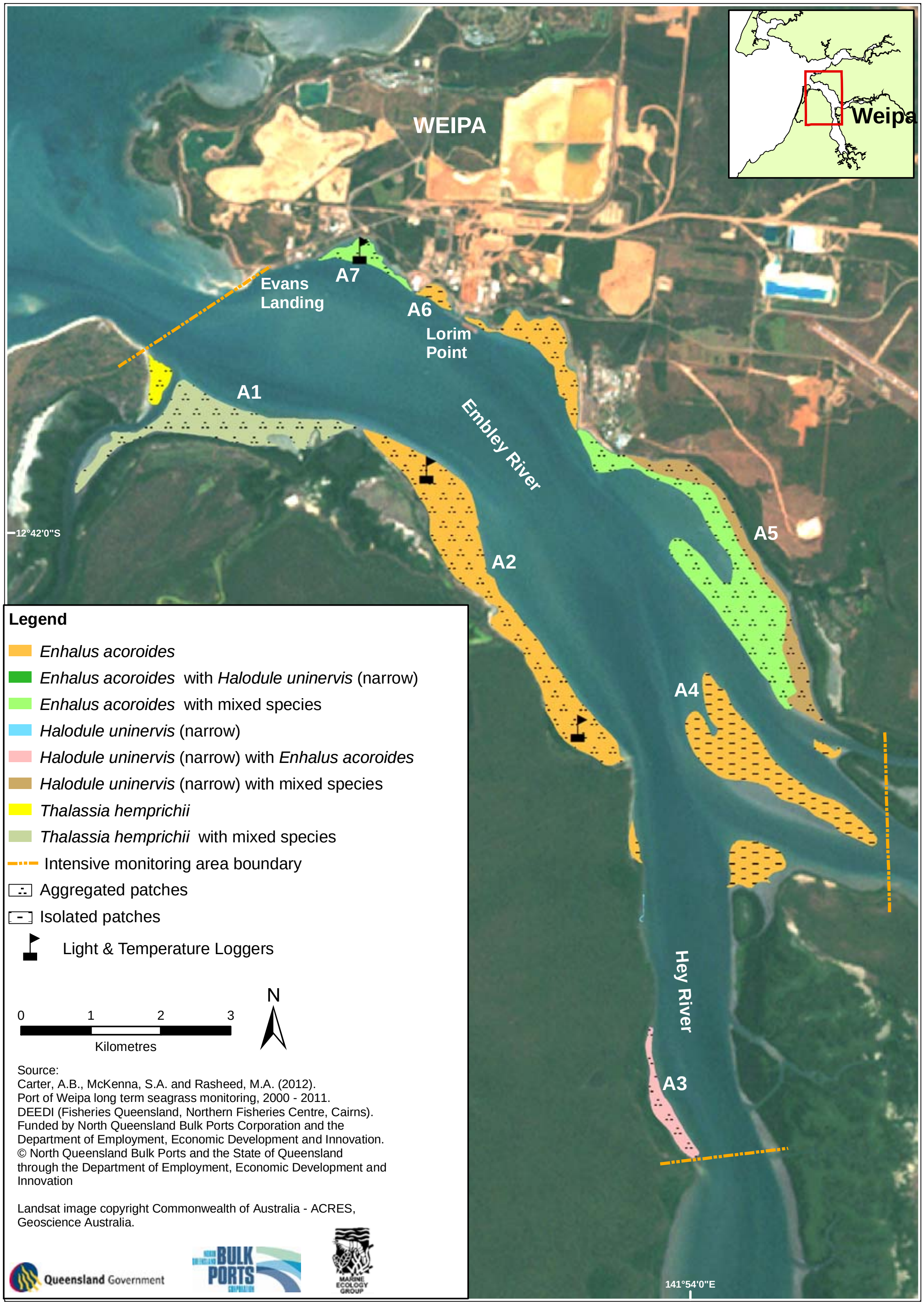



**Figure 2** Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2011 (error bars = “R” reliability estimate). Red dashed line indicates 12-year mean of total meadow area.

Map 2. Meadow type and cover for seagrass meadows within the Intensive Monitoring Area, 2011



## Comparison of Core Monitoring Meadows

Seagrass biomass within the core monitoring meadows had generally declined between monitoring in September 2010 and August 2011. In contrast, total meadow area for all core monitoring meadows in August 2011 was 399 ± 18 ha, the highest recorded value since 2004. Increases in meadow area were greatest in the *Halodule* dominated meadows (+13 ha in A5; +9 ha in A3), and modest increases of 1 – 4 ha were recorded in the *Enhalus* dominated A2, A6 and A7 meadows (Figure 3).

Biomass declined significantly in the *Enhalus* dominated core monitoring meadow A2, and slight but not statistically significant declines were observed in the *Enhalus* dominated A6 and A7 and *Halodule* dominated A3 meadows (Figure 3; see Appendix for detailed statistical results). The only exception to the declining trend was the *Halodule* dominated A5 meadow where biomass increased significantly.

As is typical for Weipa's seagrass meadows, significant annual variation in biomass across multiple years was observed (see Appendix 1). Biomass ranged from 0.84 ± 0.3 g DW $m^{-2}$ for the intertidal *Halodule* dominated A3 meadow to 6.13 ± 0.8 g DW $m^{-2}$ for the intertidal *Enhalus* dominated A2 meadow (Figure 3). The greatest fluctuations in biomass over twelve years of monitoring have occurred in this A2 meadow (Maps 2 – 4). While the total area of this meadow has remained relatively stable, mean above-ground biomass had trended downward from 33.63 ± 5.8 g DW $m^{-2}$ in 2000, to a low of 4.66 ± 0.6 g DW $m^{-2}$ in 2008 (Figure 3a; Map 3). Biomass was low in 2011 (6.13 ± 0.8 g DW $m^{-2}$) which was statistically similar to other low biomass years recorded from 2003 - 2009. Seagrass density in the A2 meadow has consistently been 'light' across the A2 meadow following the disappearance of moderate/dense biomass hotspots recorded in 2000-2004 and 2010 (Map 4).

The smaller *Enhalus* meadows near Lorim Point and Evans Landing (A6 & A7) on the northern banks of the Embley River have also displayed considerable declines in biomass over the course of the monitoring program. Above-ground biomass in the mostly intertidal to subtidal A6 meadow was statistically similar to previous low-biomass years such as 2004 – 2006 and 2008 – 2010 (1.61 ± 0.4 g DW $m^{-2}$), despite a one hectare increase in meadow area (Figure 3a). Similarly, the low biomass recorded in A7 (2.47 ± 0.7 g DW $m^{-2}$) in 2011 was statistically similar to previous low biomass years (2005 – 2006, 2008 – 2010) despite a 4 ha increase in meadow area (Figure 3a).

Density of the intertidal *Halodule uninervis* dominated A3 and A5 meadows has shown high inter-annual variability over the course of the monitoring program with declines and increases in biomass over multiple years (Figure 3b). These changes are considered within the normal scope for this low biomass, patchy and naturally dynamic species. *Enhalus acoroides* was excluded from all biomass and species composition analyses in the A3 and A5 meadows in order to track the dynamics of the *Halodule* component. Biomass had increased significantly in A5 since 2010 from 2.56 ± 0.5 g DW $m^{-2}$ to 5.33 ± 0.7 g DW $m^{-2}$ in 2011. Biomass in A5 in 2011 was similar to most other intermediate to high biomass years such as 2001 – 2005 and 2009. Biomass in A3 was characteristically low (0.84 ± 0.3 g DW $m^{-2}$) (Figure 3b). The patchiness of seagrass and large annual variation in biomass means that detecting changes in biomass statistically for this meadow is difficult.

The species composition of seagrass continued to shift in the A2 meadow with an increase in dominance of *Enhalus acoroides* from 80 to 90% between 2010 and 2011 at the expense of *Halodule uninervis* (narrow). The presence of *Halodule uninervis* decreased from 10% to less than 1% of biomass. *Thalassia hemprichii* continued to account for approximately 10% of the biomass in A2 (Figure 3a). Species composition also shifted in A6 with a decline in *Halodule uninervis* (narrow) from approximately 8% of biomass in 2010 to less than 1% in 2011, with a subsequent increase in *Enhalus acoroides* which accounted for 99.5% of biomass in A6 in 2011 (Figure 3a).

Species composition in A7 did not show the same patterns as A6, however, as *Enhalus acoroides* decreased from 95% to 82% of the meadow composition between 2010 and 2011. The remaining biomass in A7 was made up of 5% *Halophila ovalis*, which had been absent from A7 since 2005, and an increase in *Halophila decipiens* from 3 to 13% between 2010 and 2011 (Figure 3a). For the *Halodule uninervis* A3 and A5 meadows species composition in 2011 was similar to 2009 and 2010, with *Halodule uninervis* (narrow) accounting for 100% of the A3 meadow and 88% of the A5 meadow (*Enhalus acoroides* excluded) (Figure 3b).

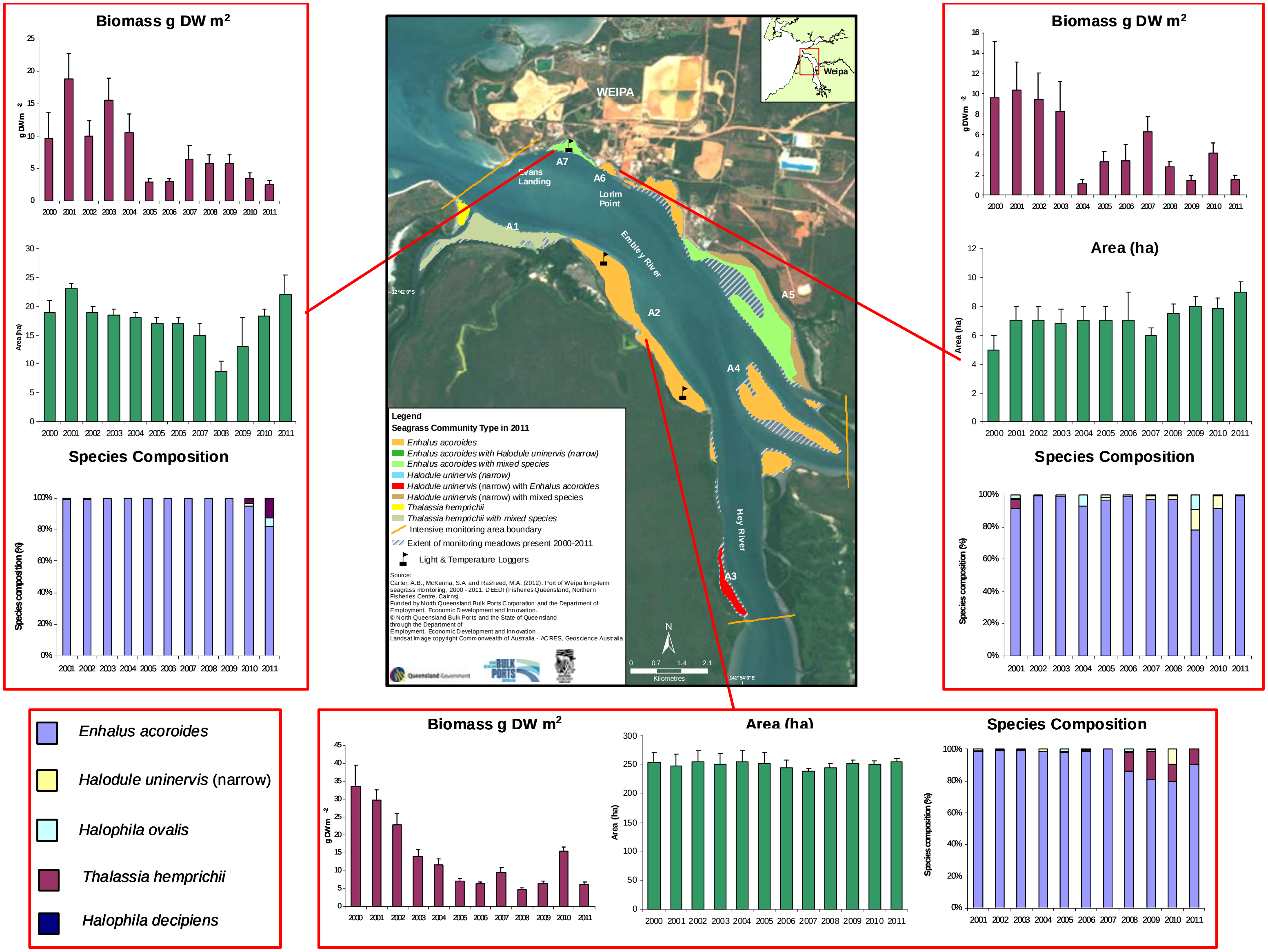
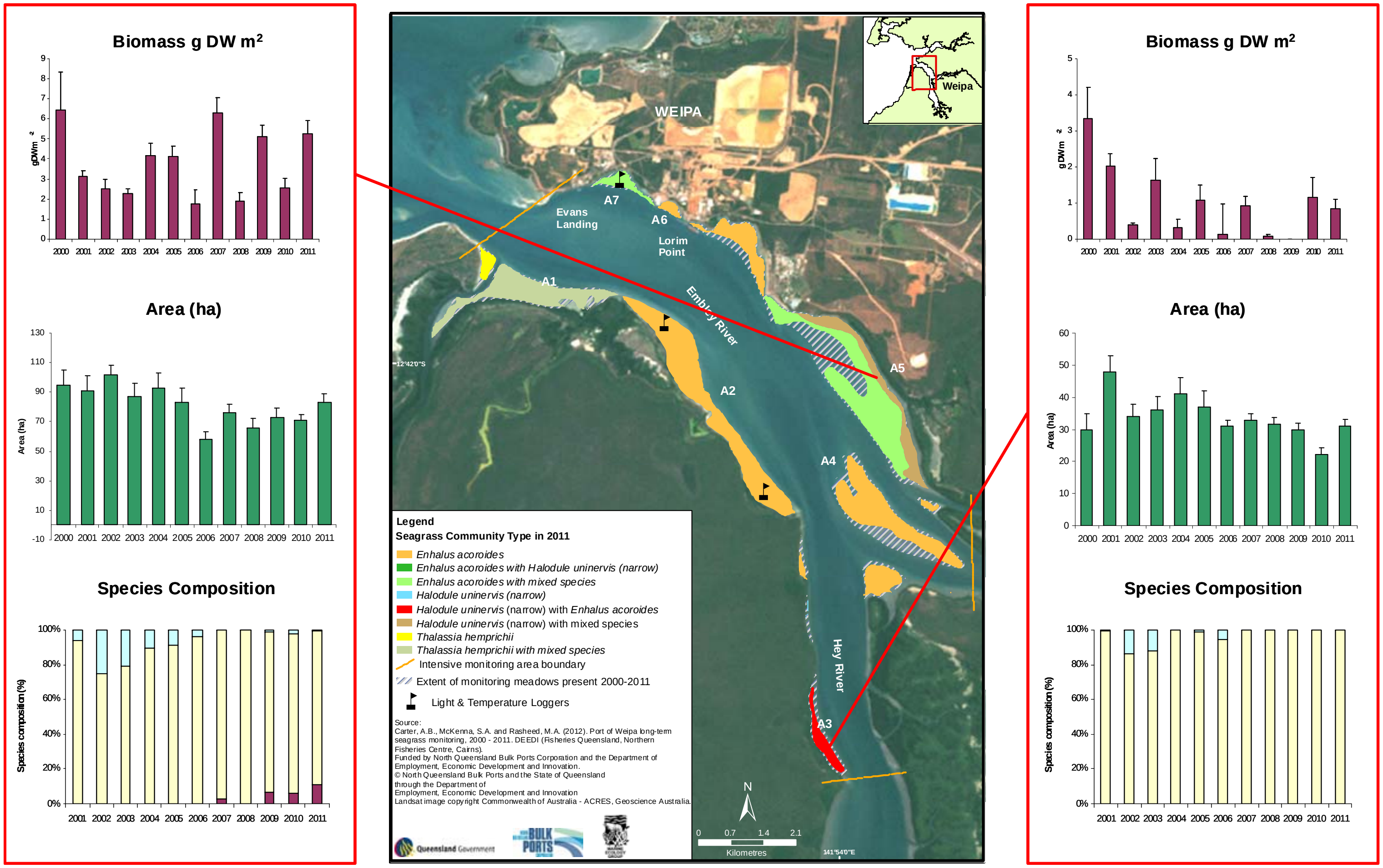
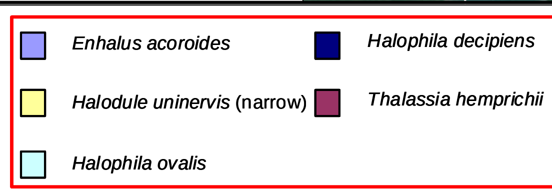



**Figure 3a.** Changes in biomass, area and species composition for the *Enhalus acoroides* dominated core monitoring meadows in Weipa from 2000 to 2011 (biomass error bars = SE; area error bars = "R" reliability estimate).

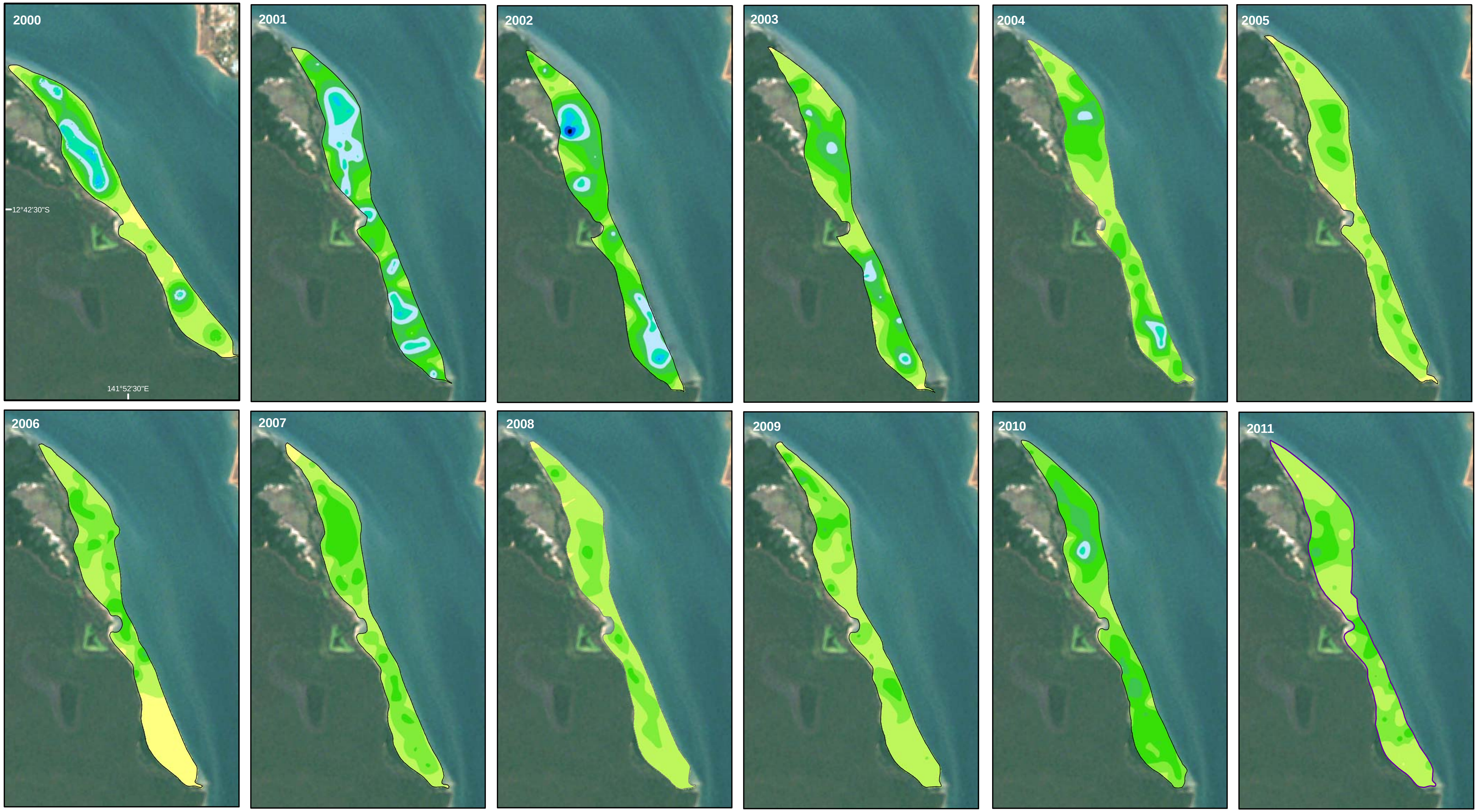



* *Enhalus acoroides* excluded from biomass and species composition analyses in the A3 & A5 meadows.

**Figure 3b.** Changes in biomass, area and species composition for the *Halodule uninervis* dominated core monitoring meadows in Weipa from 2000 to 2011 (biomass error bars = SE; area error bars = "R" reliability estimate).

**Map 3. Density of seagrass biomass in the A2 meadow, 2000 to 2011.**




**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

Kilometers

Source:
Carter, AB, McKenna, SA & Rasheed, MA 2012,
Port of Weipa long term seagrass monitoring, 2000 - 2011.
DEEDI (Fisheries Queensland, Northern Fisheries Centre, Cairns).

Funded by North Queensland Bulk Ports Corporation and the
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## Seagrass in the Broader Weipa Port Area

In 2011, 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 and 2008 (Figure 4, Maps 4 - 6). Total seagrass meadow area was at its highest level since 2001 with a meadow area of 3996 ± 231 ha, an increase of 21% since 2008 monitoring (Figure 4). Aggregated patches of seagrass continued to be the dominant landscape category and described 55% of meadows.

Hey River meadows were further reduced and fragmented since 2008's monitoring survey, although cover type and seagrass species had not changed. A continuous cover of *Halodule uninervis* (narrow) was present on the western bank and an *Enhalus acoroides* dominated meadow of isolated patches was present on the eastern bank of the Hey River (Map 4).

Seagrass community types in the Mission River remained a combination of isolated patches and aggregated patches of seagrass on the northern bank (Map 5). However, species composition changed from meadows dominated by *Enhalus acoroides* or *Halodule uninervis* in 2008 to meadows dominated by *Thalassia hemprichii*, or with equal components of *Thalassia hemprichii* or *Halophila ovalis* with *Enhalus acoroides* (Map 5). The largest meadows on the southern bank of Mission River remained dominated by isolated patches of *Enhalus acoroides*.

In Pine River Bay, the *Halodule uninervis* (narrow) meadows originally mapped in 2000 along the western banks appeared well established in 2011 and covered an area similar to that of the first baseline survey (Map 6). The second largest of these western meadows shifted from being a *Halodule uninervis* to a *Halophila ovalis* dominated meadow between 2008 and 2011. Species composition in the two large meadows at the mouth of Pine River Bay shifted from *Halodule uninervis* (narrow) and *Halophila ovalis* domination in 2008 to *Thalassia hemprichii* dominated meadows in 2011. As in 2008, *Syringodium isoetifolium* was absent from 2011 surveys at Pine River Bay.

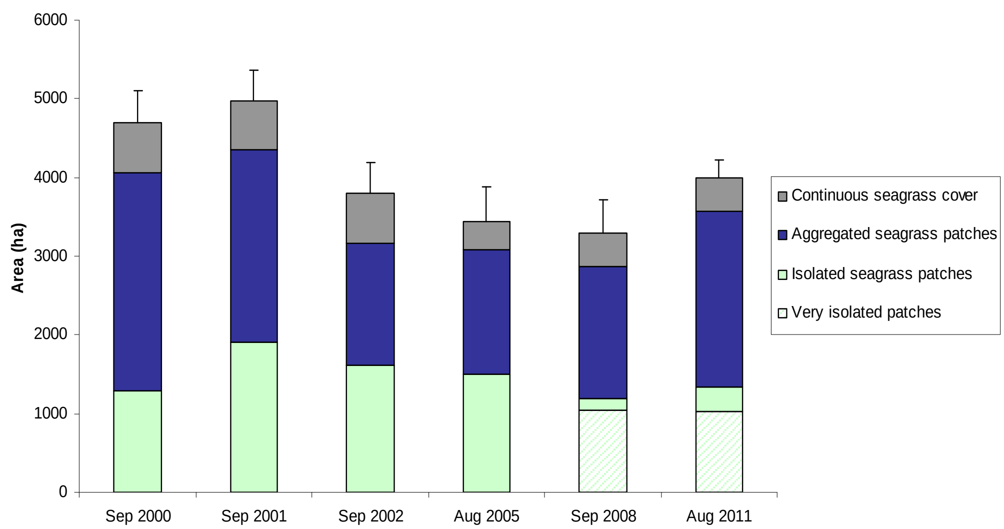
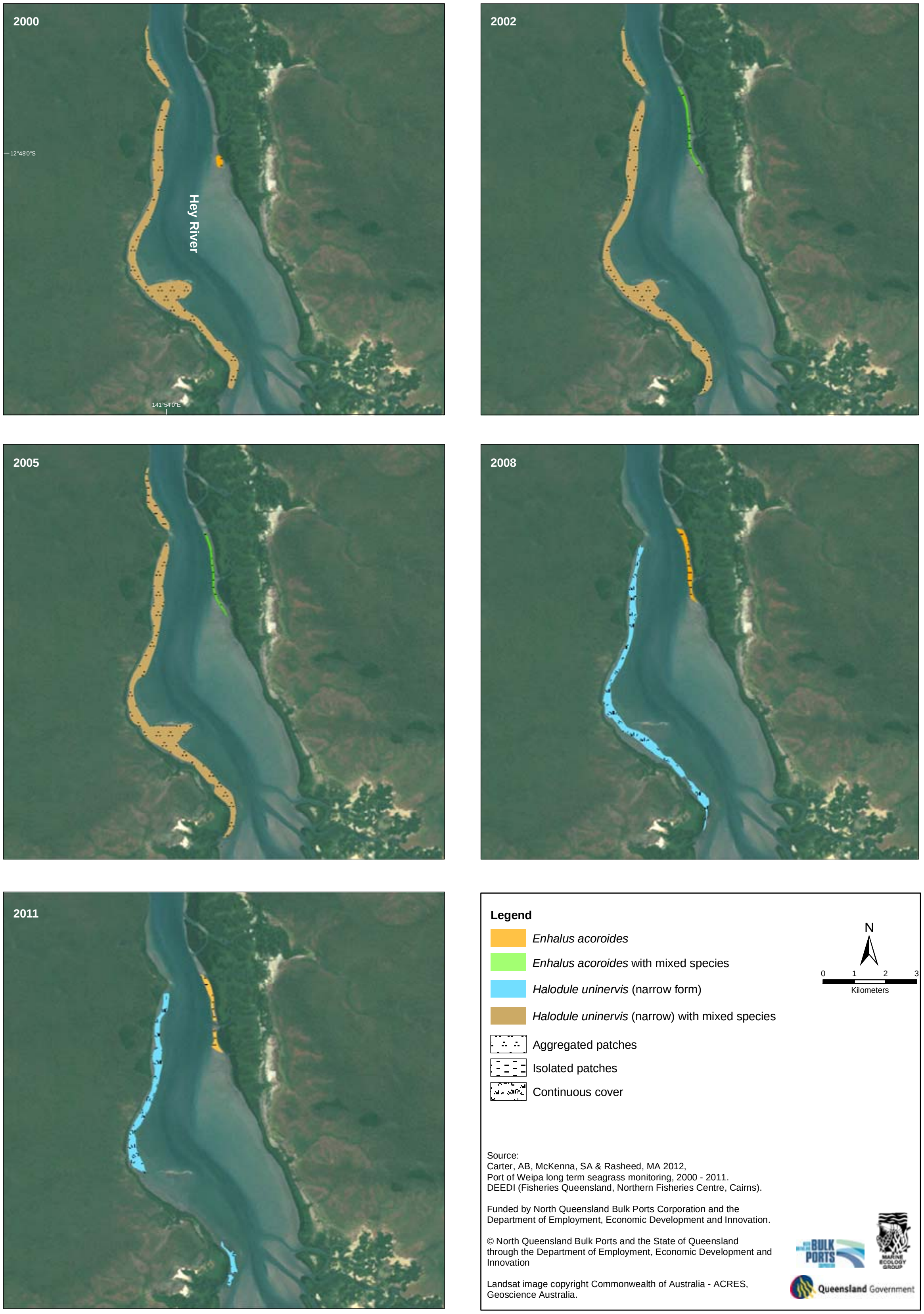
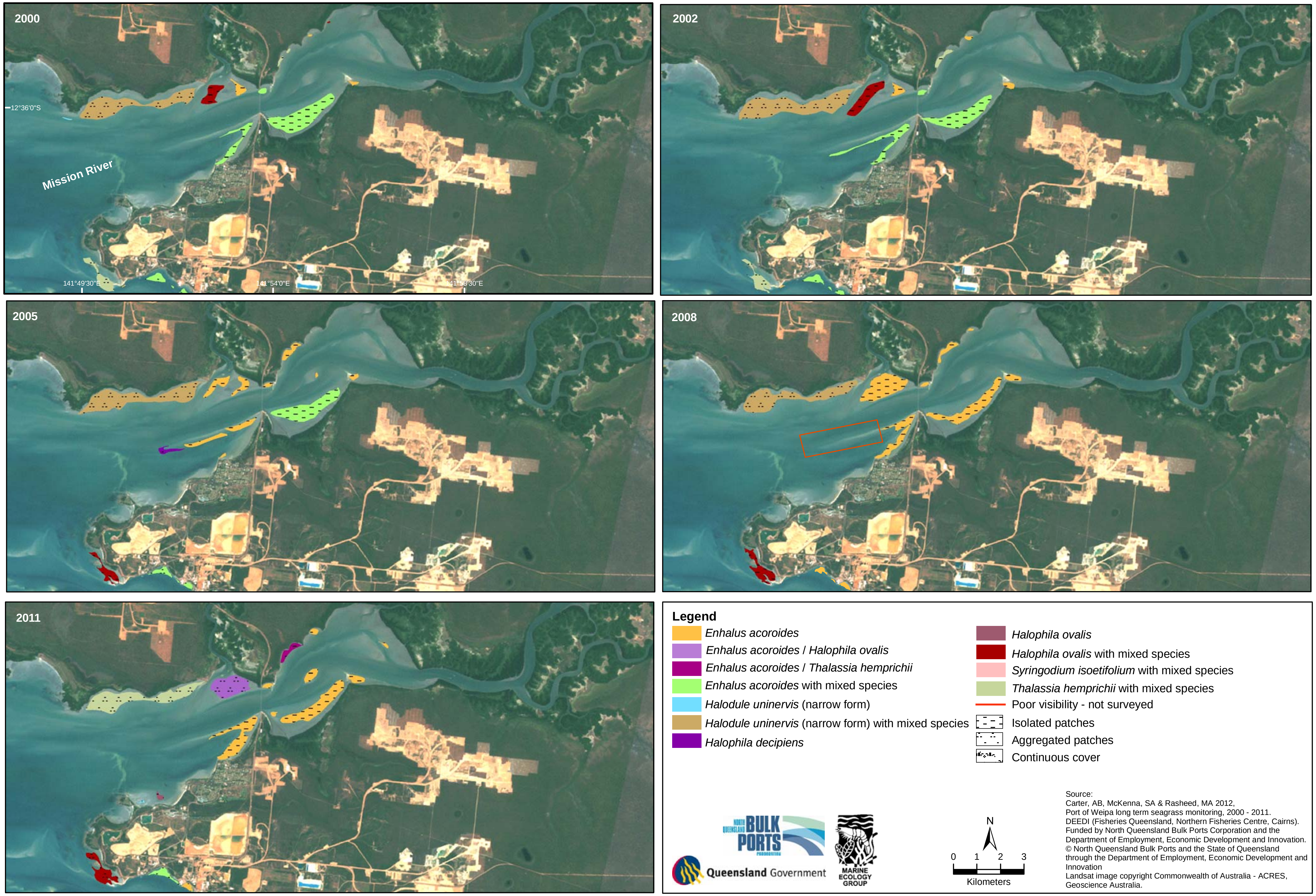



**Figure 4** Total seagrass area (hectares) area within the Weipa port limits, and the proportion of landscape cover from 2000 - 2002, 2005, 2008 and 2011. Error bars = "R" reliability estimate.

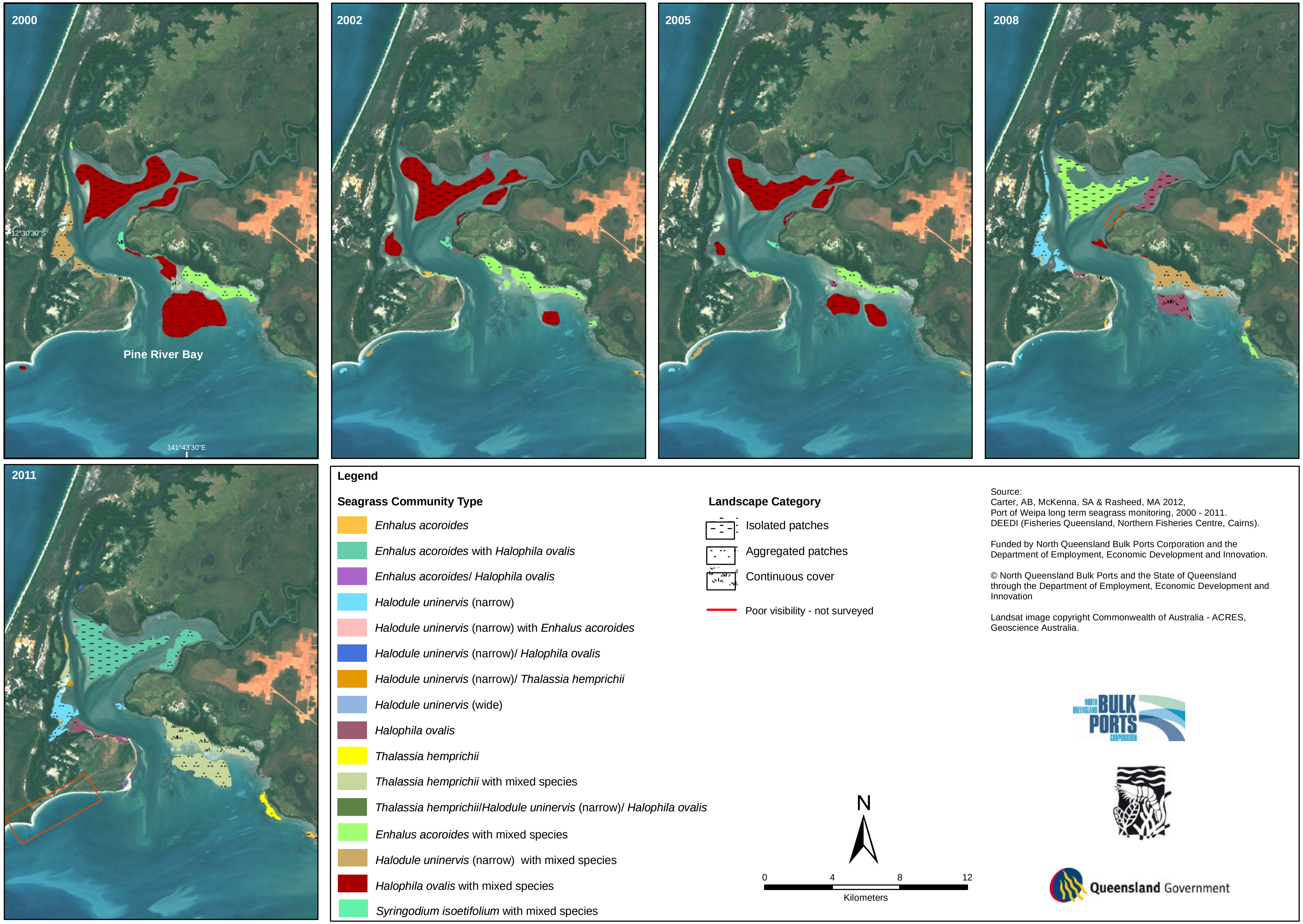
**Map 4. Community type for seagrass meadows in the Hey River, 2000 - 2011.**



**Map 5. Seagrass meadows in Mission River, 2000 to 2011.**



**Map 6. Seagrass meadows in Pine River Bay, 2000 to 2011.**



## Weipa Climate Data Analysis

### *Rainfall and Tidal Exposure*

Total annual rainfall in Weipa in the 12 months preceding the 2011 survey was 775.2 mm, above the long-term average and the highest total rainfall measured since 2000/2001 (Figure 5 inset). Rainfall was highly variable between days, but followed a general trend of summer peaks and winter lows (Figure 5). Total rainfall in January and April 2011 was particularly high with readings of 174 mm and 144 mm respectively (Figure 5).

Total amount of daytime hours that intertidal banks at Weipa were exposed has been below average for the last three years (Figure 6). Prior to 2008, exposure had been above average for seven years. The number of hours intertidal seagrass banks are exposed during the day is generally higher over the winter period and lower in summer (Figure 7). Exposure was below average every month in the 12 months preceding the 2011 survey (Figure 5). Exposure in the three months prior to each survey has been relatively low for the last three years, however, in 2011 exposure one month before the survey was the highest since 2006 with the meadows being exposed for 101 hours, compared to 49 hours in 2010 (Figure 8)

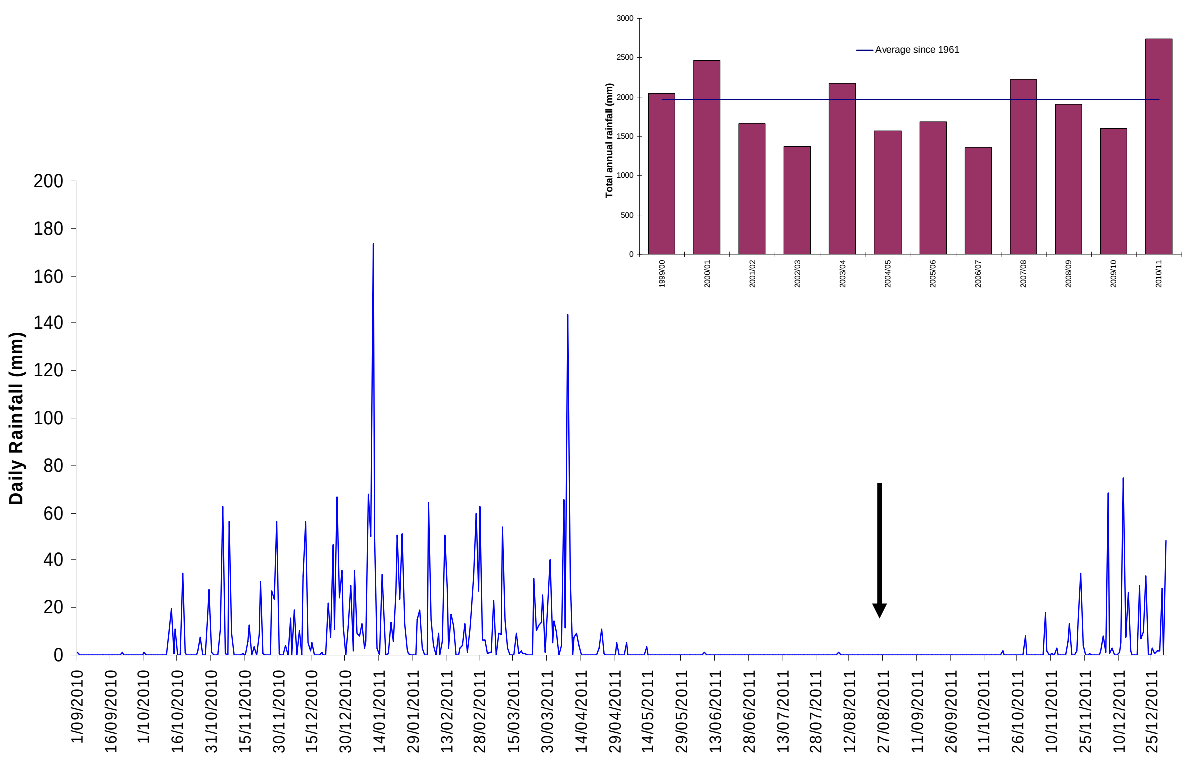



**Figure 5** Total daily rainfall (mm) from September 1 2010 – December 31 2011 and (Inset) total annual rainfall for the 12 months preceding each survey from 1999 – 2011 recorded at Weipa airport (Bureau of Meteorology, Station 027045) Black arrow indicates when survey was conducted.

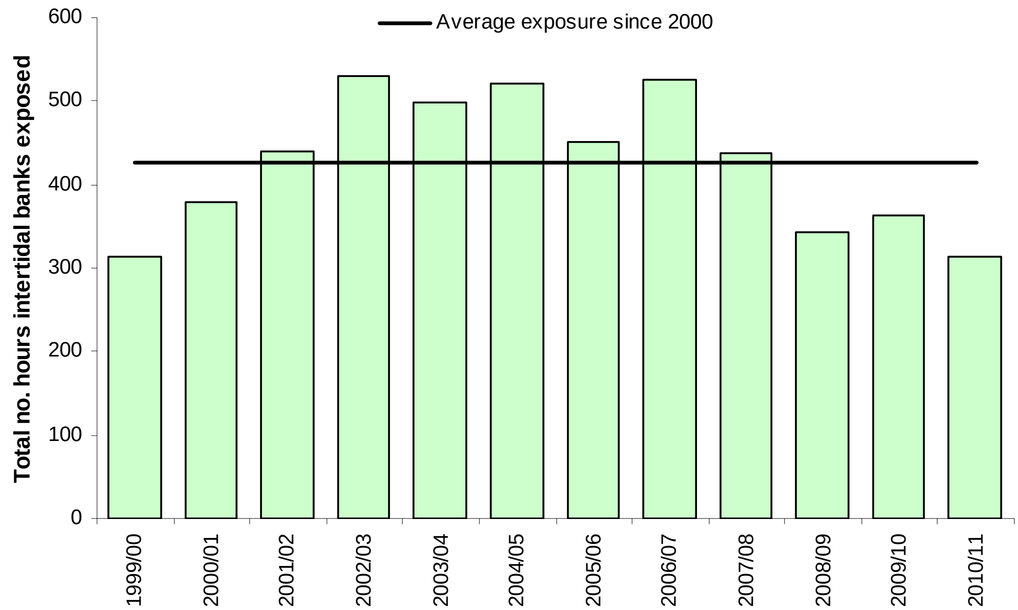



**Figure 6** Total number of daytime hours intertidal banks exposed (≤0.9m tidal height) in Weipa in the 12 months preceding each monitoring survey from 2000 - 2011 (Marine Safety Queensland, 2012).

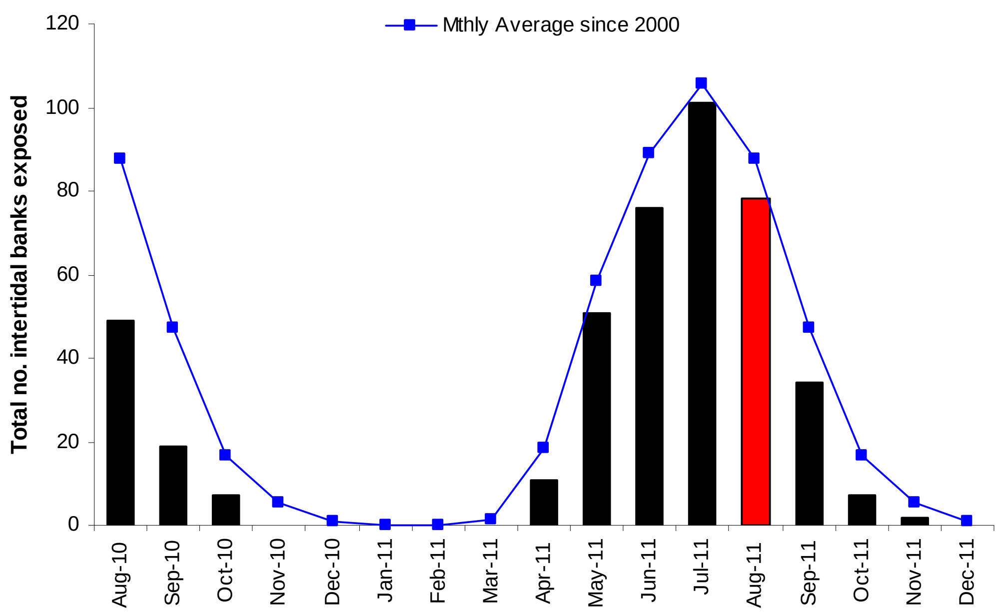



**Figure 7** Monthly total number of daytime hours intertidal banks exposed (≤0.9m tidal height) in Weipa in the 12 months preceding the 2011 monitoring survey (Marine Safety Queensland, 2012). Red bar indicates month when monitoring survey occurred.

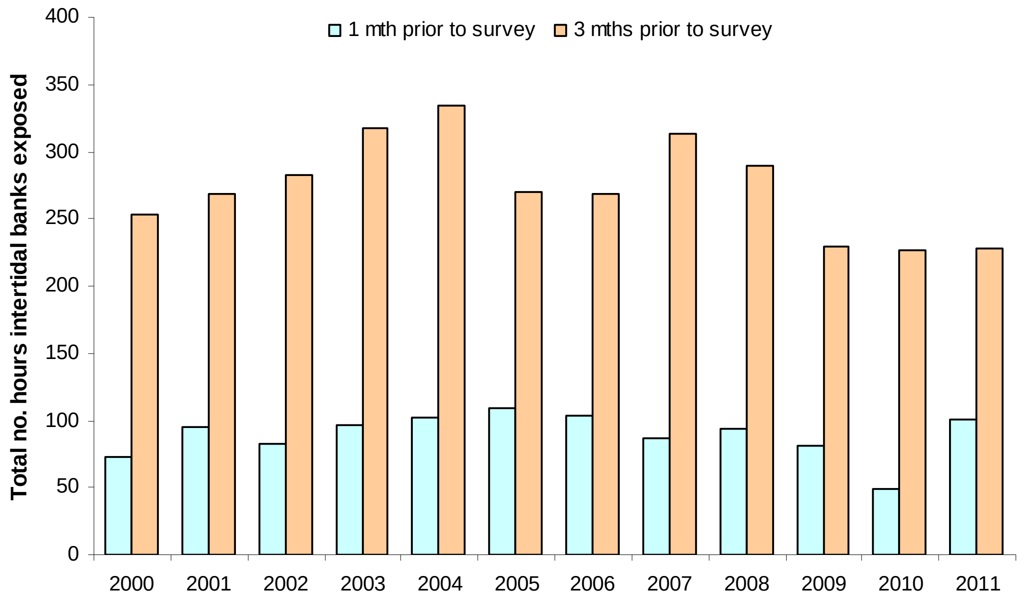



**Figure 8** Total number of daytime hours intertidal banks exposed (≤0.9m tidal height) in Weipa in the 1 and 3 months preceding each monitoring survey from 2000-2011 (Marine Safety Queensland, 2012).

***Light and Temperature***

Light (photosynthetically active radiation, PAR, mol $m^{-2}$ $day^{-1}$) and maximum daily water temperature (°C) data were collected from three sites in the port of Weipa from September 9 2010 to December 31 2011 (see Map 2 for location of loggers). This is the first time results from the PAR and temperature loggers have been presented for the port of Weipa, so the aim of this section in the report is to explain some of the general patterns and fluctuations recorded by the PAR and temperature loggers. Continued collection of light and temperature data will allow for future comparisons between months and years.

The data set over the 16 months loggers were deployed was incomplete (Figures 9a-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 or batteries expiring much earlier than expected. On one occasion, the PAR logger in the A6 meadow flooded and the data could not be retrieved. As more data is collected and the causes of malfunctions are rectified, a more complete data set will become available.

**Light**

The light data collected was generally indicative of the naturally turbid environment in which seagrasses persist in the port of Weipa. Total daily PAR in the intertidal A2 meadow was greater and more variable than in the subtidal A7 meadow. Mean daily PAR at the subtidal A7 site was 7.3 ± 0.3 mol $m^{-2}$ $day^{-1}$ compared with 12.9 ± 0.6 and 11.0 ± 0.5 mol $m^{-2}$ $day^{-1}$ in the intertidal sites at A2-2 (south) and A2-1 (north), respectively (Figure 9a-c). Total daily PAR ranged from less than 0.2 mol $m^{-2}$ $day^{-1}$ at all three sites, to a maximum daily PAR of 19.6 mol $m^{-2}$ $day^{-1}$ in the subtidal A7 meadow, and 32.2 and 40.7 mol $m^{-2}$ $day^{-1}$ at the intertidal sites A2-2 and A2-1, respectively (Figure 9a-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, although PAR decreased as rainfall increased between October and December 2011 in the A7 meadow (Figure 5, 9a). Total daily PAR did not appear to be influenced by total hours of tidal exposure as the maximum peaks in PAR recorded in September and October 2011 in the A2-1 site did not coincide with higher levels of exposure during those months (Figure 6, 9b). Tidal cycles, however, accounted for much of the variation in PAR. Total daily PAR at benthic sites was heavily influenced by the timing of the low tide. A low tide at 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 9d). 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.

**Temperature**

Maximum daily water temperature in the intertidal A2 meadow was higher and more variable than in the subtidal A7 meadow (Figure 9a-c). On average, maximum daily water temperature was higher in the intertidal A2 meadow sites (31.9 $\pm$ 0.2°C at A2-2; 31.6 $\pm$ 0.2°C at A2-1) compared with the subtidal A7 site (30.0 $\pm$ 0.1°C). Within meadow variation in water temperature is again likely due to slightly different hydrodynamic conditions and exposure periods between loggers in the A2 meadow. Higher mean temperature and temperature range in the southern A2-2 meadow was likely a product of this logger being deployed closer to the shoreline and possibly in shallower water than the northern A2-1 logger.

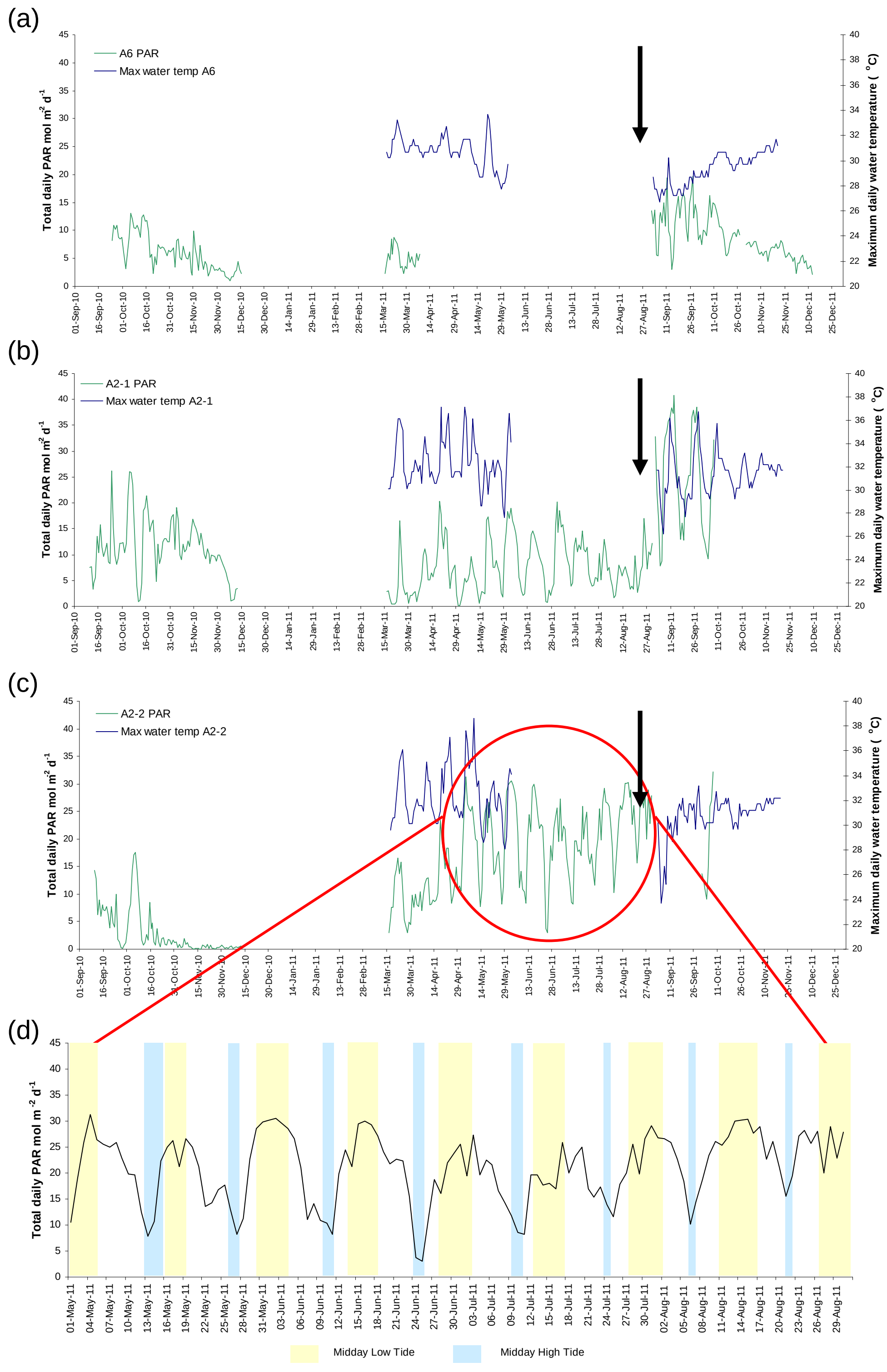



**Figure 9** Daily photosynthetically active radiation (PAR mol m$^{-2}$ day$^{-1}$) and maximum daily water temperature (°C) at Weipa, September 1 2010 – December 31 2011, at (a) subtidal meadow A6; (b) northern intertidal meadow A2-1; (c) southern intertidal meadow A2-2; with (d) detail of PAR data for southern A2, May 1 to Aug 30 2011. Black arrow indicates when seagrass monitoring survey was conducted

# DISCUSSION

Seagrasses in the Port of Weipa remained in a reasonable but vulnerable condition in 2011. Within the entire port limits total seagrass meadow area had increased 21% since the previous whole of port survey in 2008, and within the Intensive Monitoring Area (IMA) around the major port operations, modest increases in meadow area were recorded. However, seagrass biomass had generally declined within the majority of monitoring meadows within the IMA. Declines in seagrass biomass in Weipa in 2011 are likely due to regional and local climate conditions rather than anthropogenic or port related factors. 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). In 2011 tidal exposure was 101 hours in the month preceding the monitoring survey, double the number of hours meadows were exposed during the month prior to the 2010 survey. The very high daytime tidal exposure in July 2011 is likely to have facilitated significant decreases in biomass seen in the intertidal A2 and slight decreases in intertidal to subtidal meadows A3 and A6. These declines occur because tidal exposure coupled with high daytime temperature can lead to high levels of photosynthetic active radiation and ultra violet radiation as well as desiccation and temperature stress leading to physiological stress to the leaf structure and photosystems (Bjork et al., 1999; Kahn and Durako, 2009; Rasheed and Unsworth, 2011; Stapel, 1997). The increase in "burning" of seagrass leaves, reported at 11% of sites in Weipa in 2011, is further evidence Weipa's intertidal seagrasses experienced higher levels of exposure related stress in 2011 than in 2010.

In contrast with the general declines in meadow biomass, biomass increased significantly in the intertidal *Halodule* dominated meadow (A5) on the eastern bank of the Embley River. This occurred despite this intertidal meadow being subjected, like all of Weipa's intertidal meadows, to substantially increased tidal exposure in 2011. The reason for this apparent resilience to tidal exposure is most likely due to intertidal meadows made up of small-leaved species like *Halodule uninervis*, that lie flat on the surface when exposed, may be more protected from desiccation related stress than seagrasses with thick blades that do not lie flat on the substrate during periods of exposure, such as *Enhalus acoroides* (Unsworth et al., 2012). Meadow area increases were also most pronounced in the *Halodule* dominated A3 and A5 meadows. Biomass in meadow A3 remained low and similar to biomass recorded in 2010 of approximately 1g DW $m^{-2}$, which marked the re-emergence of this meadow following it's disappearance in 2009. Although biomass values for these *Halodule* meadows are within the range detected over the duration of the monitoring program, it should be noted that the natural patchiness of these meadows makes them highly susceptible to further natural or anthropogenic impacts.

The deployment of *in situ* light and temperature loggers from September 2010 will greatly enhance the existing monitoring program in the future. Preliminary data suggests PAR levels in Weipa showed the expected responses to tidal exposure, with average PAR levels and maximum peaks in PAR lowest in the subtidal A6 meadow, and lowest in the intertidal sites when high tides occurred around midday, indicating a high proportion of PAR is dispersed in the water column. Meadow A6 also experienced decreasing PAR as rainfall increased between October and December 2011. 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 requires a more complete data set that includes all loggers deployed over the summer wet season.

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 *Enhalus* dominated A2 meadow, which has experienced the most significant biomass declines, monitoring of within-meadow variation in water temperature and PAR using loggers in the north and south of the meadow may enhance the ability of the program to pinpoint the causes of seagrass declines and predict where biomass "hotspots" are likely to appear.

In 2011, seagrass meadow area increased while seagrass biomass for the core monitoring meadows remained below historical peaks. Long-term declines in seagrass biomass may have left some of Weipa's meadows in a vulnerable condition 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.

In summary results of the 2011 monitoring indicate that;

- Seagrass habitat in the Port of Weipa was in a reasonable but vulnerable condition
- Biomass in the *Enhalus* meadow (A2) on the western bank of the Embley River had decreased significantly and may be vulnerable to further impacts, and remains a concern for management.
- Multi-year tidal patterns and solar radiation may 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.

The deployment of PAR and temperature loggers at Weipa in 2010 has enhanced the monitoring program and will improve interpretations of meadow-scale change and enhance the ability of the program to pinpoint the causes of seagrass declines.

# APPENDIX

**Appendix 1.** (A) Results of one-way ANOVA comparing mean biomass between years (2001 – 2011) for the Weipa core monitoring meadows A2, A5, A6 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 |

| **Meadow A5** | | |
|---|---|---|
| **Year** | **Mean biomass (sqrt-transformed)** | |
| 2001 | 1.573 | c |
| 2002 | 1.293 | abc |
| 2003 | 1.367 | bc |
| 2004 | 1.609 | c |
| 2005 | 1.748 | cd |
| 2006 | 0.876 | a |
| 2007 | 2.126 | d |
| 2008 | 0.874 | a |
| 2009 | 1.609 | c |
| 2010 | 1.024 | ab |
| 2011 | 1.677 | c |

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

| **Meadow A6** | | |
|---|---|---|
| **Year** | **Mean biomass (sqrt-transformed)** | |
| 2001 | 2.249 | f |
| 2002 | 2.169 | ef |
| 2003 | 1.942 | cdef |
| 2004 | 0.632 | a |
| 2005 | 1.320 | abcd |
| 2006 | 1.234 | abc |
| 2007 | 2.059 | def |
| 2008 | 1.330 | abcde |
| 2009 | 0.778 | ab |
| 2010 | 1.493 | bcdef |
| 2011 | 0.809 | ab |

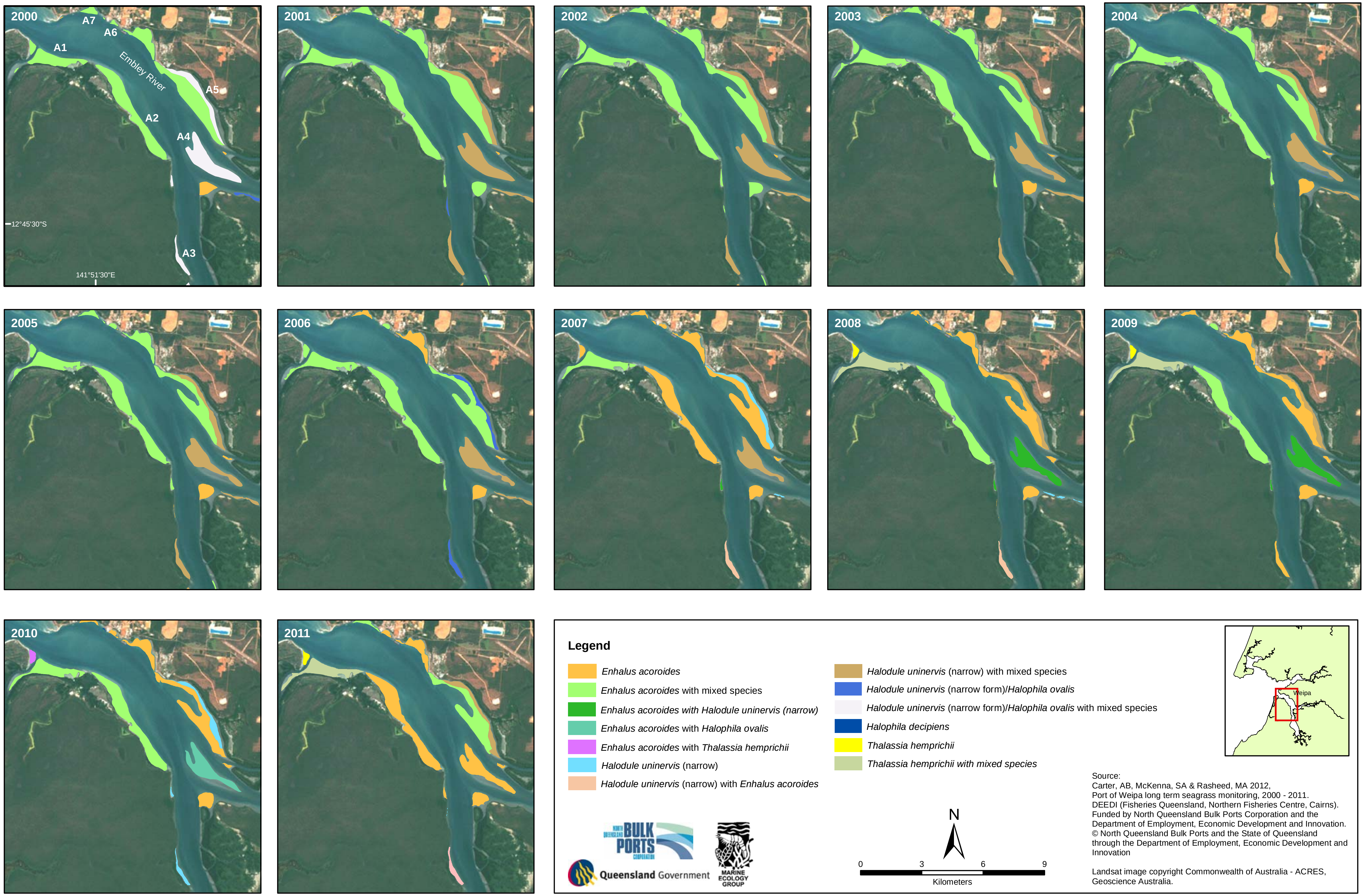
(B) Results of Kruskall-Wallace ANOVA in ranks with Dunn's post hoc comparison comparing median above-ground seagrass biomass in the core monitoring meadow A3 at Weipa. Cells marked with a "YES" indicates a significant difference in biomass of the meadow between comparison years and cells marked "NO"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

**Meadow A3**

| YEAR | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2000** | | | | | | | | | | | | |
| **2001** | NO | | | | | | | | | | | |
| **2002** | NO | NO | | | | | | | | | | |
| **2003** | NO | NO | NO | | | | | | | | | |
| **2004** | NO | YES | NO | NO | | | | | | | | |
| **2005** | NO | YES | NO | NO | NO | | | | | | | |
| **2006** | NO | YES | NO | NO | NO | NO | | | | | | |
| **2007** | NO | YES | NO | NO | NO | NO | NO | | | | | |
| **2008** | YES | YES | NO | NO | NO | NO | NO | NO | | | | |
| **2009** | YES | YES | NO | YES | NO | NO | NO | NO | NO | | | |
| **2010** | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | | |
| **2011** | NO | YES | 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 – 2011.

**Map 7. Meadow type and distribution for the seagrass meadows within the Intensive Monitoring Area, 2000 to 2011.**



**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 – 2011.

| 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** |
| **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) |
| **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) |
| **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) |
| **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) |
| **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) |

**Appendix 4.** Total meadow area for each core monitoring meadow within the Port of Weipa, 2000 – 2011.

| 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** |
| **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 |
| **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 |
| **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 |
| **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 |
| **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 |
| **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** |

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