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

Port of Weipa Long Term Seagrass Monitoring

September 2010

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Seagrass flowers observed throughout the large intertidal Enhalus acoroides meadow in May 2010.

EXECUTIVE SUMMARY

Seagrass habitats provide important ecological functions in the coastal zone including provision of primary productivity in the marine environment and nursery habitat for key fisheries species. The wide distribution on seagrasses in Queensland, and their capacity to show measurable responses to changes in water quality make them ideal candidates for monitoring the health of the marine environments. A network of long term seagrass monitoring sites has been established at various port locations throughout Queensland to assist Fisheries Queensland and port managers in planning and management to ensure port activities are having a minimal impact on the marine environment and fish habitats. The program is also used to help separate natural from anthropogenic change to seagrass meadows.

This report details the results of the September 2010 monitoring program in the Port of Weipa. Seagrasses in the Port of Weipa remained in a reasonable but vulnerable condition. Several meadows that had shown a long term declining trend since monitoring began in 2000 recorded a significant increase for the first time in 2010. The declines were likely associated with natural shifts in tidal exposure and changes in light and temperature associated with local climate conditions. The declines had been particularly concerning for *Enhalus acoroides* meadows, especially the large intertidal meadow opposite Lorim Point, where biomass reached a record low in 2008. In response to the declines, North Queensland Bulk Ports (NQBP) and Fisheries Queensland conducted an additional survey in both April 2009 and May 2010 to determine whether the large *Enhalus* meadow was in a healthier state outside of the regular survey period. The additional survey found that biomass was also significantly lower than found in past assessments at a similar time of year.

During the regular September 2010 monitoring survey, mean above-ground biomass in the large *Enhalus* meadow of most concern had increased significantly from the previous year and was significantly higher than the past five years of monitoring. The intertidal *Halodule uninervis* meadow on the Western bank of the Hey River had also re-established after disappearing in 2009. 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.

Seagrasses appear to have been resilient to the impacts associated with regular port maintenance dredging during the life of the current monitoring program. However, despite the positive signs of recovery for *Enhalus* meadows in the port, they are still in a potentially vulnerable state. An examination of light and temperature conditions at vulnerable seagrass meadows established in the port after the September 2010 survey will significantly enhance the ability of the monitoring program to pinpoint the causes of seagrass change. These data are currently being collected and results will be included the 2011 report.

INTRODUCTION

North Queensland Bulk Ports Corporation (NQBP) is the organisation responsible for managing and monitoring Weipa's port environment. 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, 2003, 2005). Seagrass habitats are valuable fisheries resources that show measurable responses to changes in water quality making seagrass meadows ideal candidates for monitoring the long term health of marine environments. The goals of the program are to minimise impacts of port activities and development on these habitats and to use seagrass condition to assess the overall health of Weipa's port environment.

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 was to focus monitoring effort on seagrass meadows located near the port and shipping infrastructure and activities (the Intensive Monitoring Area or IMA; Map 1). In August/September each year all seagrass meadows within the IMA are mapped. Within the IMA, five "core monitoring meadows" are assessed for biomass and species composition. These meadows represent the range of seagrass meadow communities identified in the region. At the time of the annual monitoring survey, an aerial reconnaissance of seagrasses in the greater port limits is conducted with re-mapping of the entire port limits occurring every three years (i.e. 2002, 2005 & 2008).

This report presents the results of the long term seagrass monitoring survey conducted in September 2010. The objectives of the 2010 long term seagrass monitoring of the Port of Weipa were to:

1. Map the distribution and abundance of the "core monitoring meadows";
2. Map the distribution and confirm species composition of seagrass meadows in 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.

Also presented are the results of an additional survey of the large intertidal *Enhalus* monitoring meadow (A2) opposite Lorim Point undertaken in May 2010 to assess the state of the meadow outside of regular monitoring.

Results of the seagrass monitoring surveys are used by NQBP to assess and demonstrate the health of the port's marine environment and to satisfy environmental monitoring requirements as part of the port's long term dredge management plan. The results are also used by agencies to assess the status and condition of seagrass resources in the region. The program also forms part of Fisheries Queensland's' network of long term monitoring sites for important fish habitats.

METHODS

Seagrass surveys within the Port of Weipa were conducted between the 4th and 6th of September 2010. Five core seagrass meadows were selected from the baseline surveys (Roelofs *et al.* 2001) for long term annual monitoring and have been surveyed since 2003. These meadows were representative of the range of seagrass meadow communities identified in the baseline survey, and were also located in areas likely to be vulnerable to impacts from port operations and developments. On the 1st May 2010 an additional assessment of the large intertidal *Enhalus* monitoring meadow (A2) opposite Lorim Point was also conducted to check for any seasonal recovery.

Two levels of sampling were used in the September 2010 survey:

1. Assess seagrass distribution, species composition and abundance in the five core monitoring meadows (A2, A3, A5, A6, and A7) (Map 1 & 2).
2. Map seagrass distribution and confirm species composition in other seagrass meadows within the IMA (Map 1).

Seagrass meadows were surveyed using a combination of helicopter aerial surveillance and boat-based camera surveys. At each survey site within the "core monitoring meadows', seagrass meadow characteristics, including seagrass species composition, above-ground biomass, percent algal cover, depth below mean sea level (MSL; for subtidal meadows), sediment type, time and position fixes (GPS; ±5m) were recorded. A complete outline of these methods can be found in Roelofs *et al.* 2001.

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

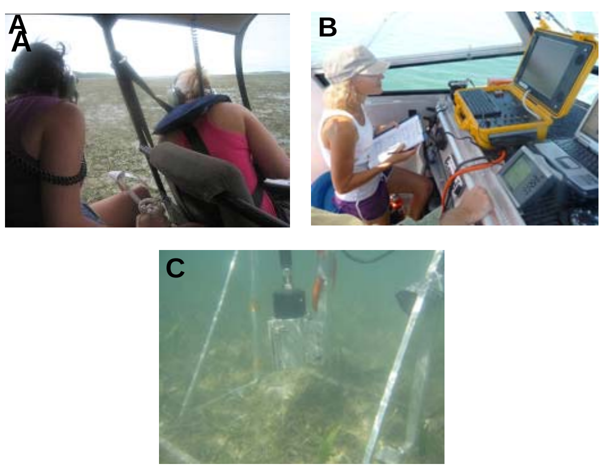


Plate 1. Seagrass methodology utilising (A) helicopter aerial surveillance and (B & C) boat based CCTV surveillance

The results of the baseline surveys (Roelofs *et al* 2003) suggested that meadows where *Enhalus acoroides* was present but not dominant, required a different approach compared to the analysis of biomass for meadows where *Enhalus acoroides* was dominant. 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* 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 these morphologically distinct species within the IMA.

Geographic Information System

Spatial data from the September 2010 survey were entered into the Port of Weipa Geographic Information System (GIS). Three seagrass GIS layers were created in ArcGIS®:

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

• **Seagrass meadow biomass and community types** – area data for seagrass meadows with summary information on meadow characteristics. Seagrass community types were determined according to species composition from nomenclature developed for seagrass meadows of Queensland (Table 1).

Table 1. Nomenclature for community types in the Port of Weipa 2010

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

• **Seagrass landscape category** – area data showing the seagrass landscape category (Figure 1) determined for each meadow.

Figure 1. Landscape categories used to describe seagrass cover within individual meadows.

<u>*Isolated seagrass patches*</u>
The majority of area within the meadows consisted of unvegetated sediment interspersed with isolated patches of seagrass

<u>*Aggregated seagrass patches*</u>
Meadows are comprised of numerous seagrass patches but still feature substantial gaps of unvegetated sediment within the meadow boundaries

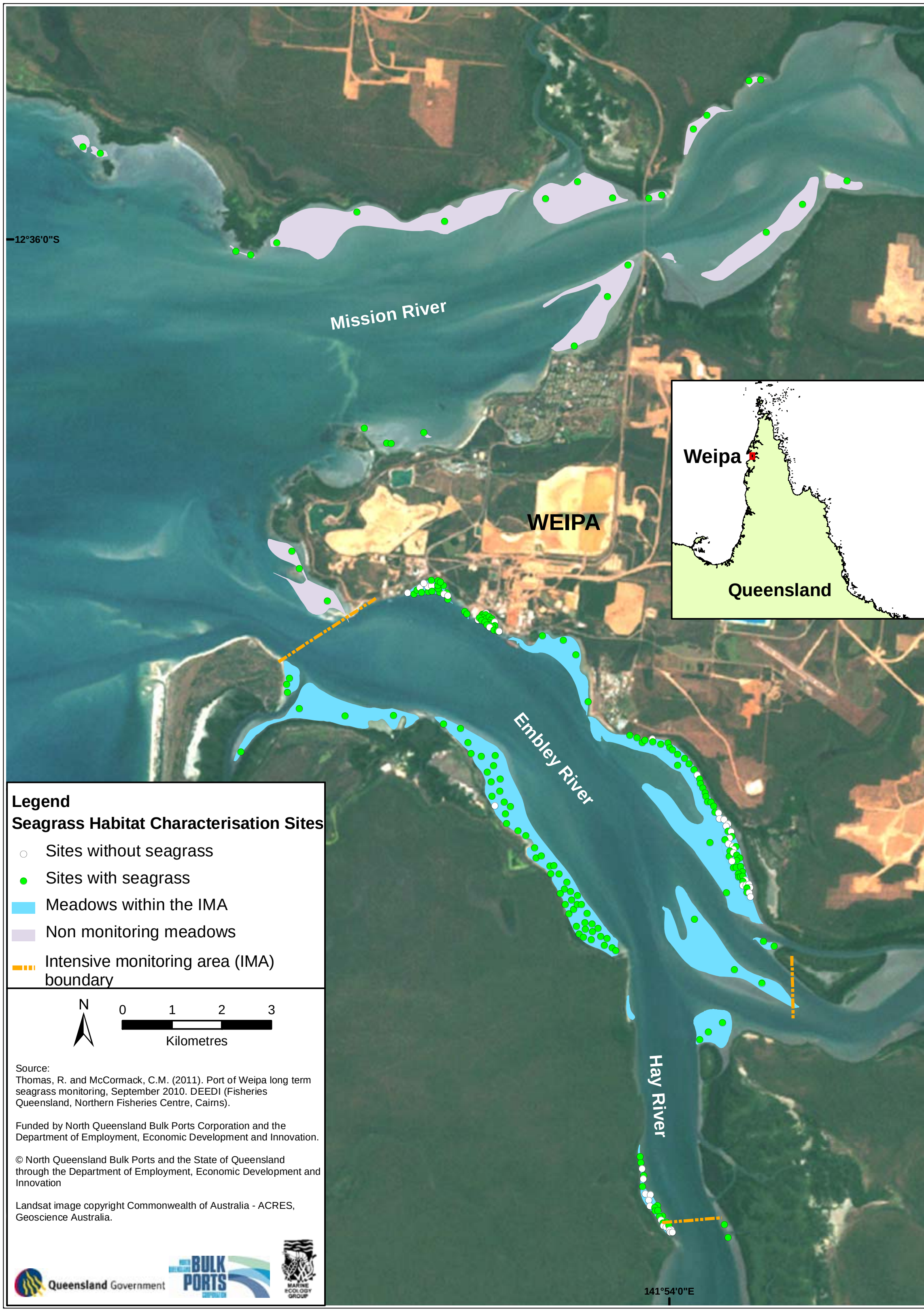
<u>*Continuous seagrass cover*</u>
The majority of area within the meadows comprised of continuous seagrass cover interspersed with a few gaps of unvegetated sediment.

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 5m for isolated intertidal seagrass meadows to 20m 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 the community-of-interest (i.e. 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 2. Mapping precision and methodology for seagrass meadows in the Port of Weipa 2010

Mapping precision	Mapping methodology
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.
20m	Meadow boundaries determined from a combination of 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.

Map 1. Location of habitat characterisation sites and seagrass meadows in the Port of Weipa, 2010



RESULTS

Seagrass species

Five seagrass species (from two families) were identified in the September 2010 monitoring survey (for a complete list of species present in the greater Weipa area see Roelofs *et al.* 2001):

Figure 2. Species of seagrass found in the Port of Weipa

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

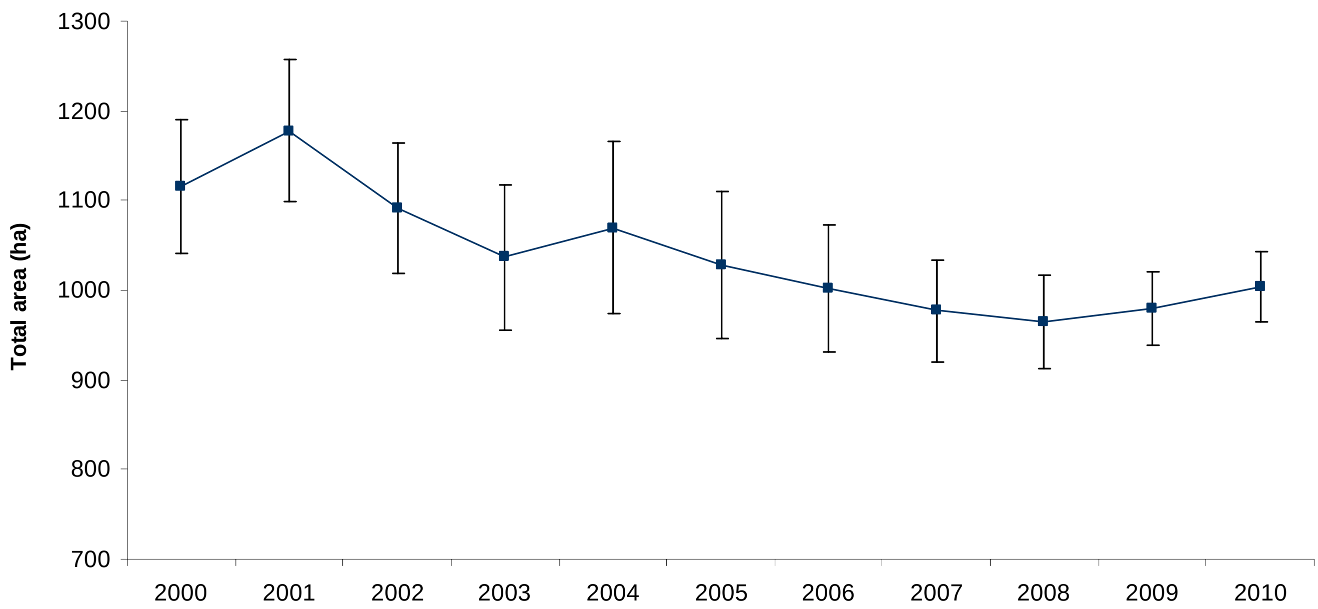
Intensive Monitoring Area

Thirteen seagrass meadows were mapped within the Intensive Monitoring Area (IMA) in September 2010 with a total combined area of 1003 ± 39 ha. This was slightly higher than the area mapped in the IMA in 2009 but remains below historical peak levels over the past ten years of monitoring (Figure 3). Individual meadow area ranged from 0.8 ha to 280 ha. The smallest meadows were located along the western bank of the Hey River and the largest meadows were found along the western bank of the Embley River (Map 2).

Ten of the thirteen monitoring meadows contained communities that were dominated by *Enhalus acoroides* (Map 2). Large *Enhalus* meadows were found on the intertidal banks and shallow subtidal areas of the Embley River and *Halodule uninervis* occurred in meadows in the Hey River and the southern section of the Embley River. A narrow *Halodule* meadow on the western bank of the Hey River had reappeared after disappearing in 2009, however some small *Halodule* meadows previously found in the southern section of the Embley River were not present (Map 3).

The condition known as burning – the browning and subsequent death of seagrass blades – was less prevalent throughout the study area than had been observed in 2009, indicating a lower level of exposure related stress to intertidal seagrasses leading up to the survey. Dugong feeding trails were evident in both the large A2 *Enhalus* meadow opposite Lorim Point and in the A4 meadow in the southern section of the Embley River as well as in the A5 *Halodule* meadow (south of Napranum) (Map 2).

Figure 3. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2010 (error bars = “R” reliability estimate)



Comparison of Core Monitoring Meadows

A total of 186 seagrass habitat characterisation sites were surveyed within the core monitoring meadows, 75% of which (140 sites) had seagrass present (Map 1). In 2010, biomass within the core monitoring meadows (A2, A3, A5, A6 & A7) remained below historical peak densities (2000 to present). Mean above-ground biomass ranged from 1.14 ± 0.5 g DW m^{-2} for the intertidal *Halodule* dominated A7 meadow to 15.36 ± 1.2 g DW m^{-2} for the intertidal *Enhalus* dominated A2 meadow (Table 3; Figure 4). This variability was dependent on the mix of species present. Total meadow area for all core monitoring meadows was 369 ± 15 ha in September 2010, which is the highest recorded value since 2005 (Table 4). The majority of this gain in area was due to the return of the *Halodule* monitoring meadow in the Hey River (A3) which had disappeared in 2009 (Table 4; Figure 4).

The most notable change over the past ten years of monitoring has been in the large intertidal *Enhalus* dominated meadow opposite the port facility at Lorim Point (A2; Map 2). While the total area of this meadow has remained relatively stable (Table 4; Map 3), mean above-ground biomass has trended downward since 2000, reaching its lowest recorded level in 2008 (Figure 4; Table 3). The meadow also become increasingly patchy over the same period and high seagrass biomass hotspots found in the north and south of the meadow decreased substantially from 2001 to 2008 (Map 4). For the past two years, an additional survey of the A2 meadow has been undertaken six months prior to annual sampling, in order to assess whether the meadow is in a healthier state outside of the regular annual monitoring event. The results of the April 2009 survey showed that seagrass biomass had increased from September 2008 but once again declined in September 2009 (Table 5; Map 5).

The May 2010 survey also showed that seagrass biomass had increased since the previous September but remained below historical levels for that time of year (Table 5; Map 5). *Enhalus* flowers were observed throughout the meadow for the first time since monitoring began in 2000, indicating sexual reproduction in the meadow. Subsequently, during the September 2010 survey, mean above-ground biomass in the A2 meadow was at its highest recorded level since 2002 (Figure 4; Table 3) and was significantly higher than the previous 5 years of monitoring (see Appendix). Seagrass biomass at the southern end of the meadow had increased from the very low levels observed in recent years and a biomass hotspot had reformed in the centre of the northern section of the meadow (Map 4). The A2 meadow has also shown a small shift in seagrass composition over the last three years with *Thalassia hemprichii* comprising a larger proportion of seagrass than previously recorded, as well as *Halodule uninervis* in 2010 (Figure 4).

The smaller *Enhalus* meadows near Lorim Point and Evans Landing (A6 & A7) have also displayed considerable declines over the course of the monitoring program. Average above-ground biomass in the mostly intertidal A6 meadow decreased from 2000 to its lowest recorded level in 2004 and has fluctuated since this time (Figure 4). The A6 meadow has shown a slight change in species composition with *Halophila ovalis* comprising a smaller proportion of seagrass than the previous year (Figure 4). Biomass in the mostly subtidal *Enhalus* A7 meadow fluctuated over the first five years of the monitoring program, trending downward to its lowest recorded level in 2005 (Figure 4). The area of the meadow decreased in 2008 but has subsequently returned to levels previously encountered over the majority of the monitoring program (Figure 4). The meadow had a slight change in species composition in 2010 with *Halodule uninervis* (narrow) and *Thalassis hemprichii* now comprising a small proportion of the seagrass (Figure 4).

Biomass in the intertidal *Halodule uninervis* dominated A3 and A5 meadows has shown high inter-annual variability over the course of the monitoring program with significant declines and increases in biomass over multiple years (Table 3; Figure 4; see Appendix). These changes are considered within the normal scope for this low biomass, patchy and naturally dynamic species. *Enhalus acoroides* is excluded from all biomass, area and species analyses in the A3 & A5 meadows in order to track the dynamics of the *Halodule* component. In 2009, the *Halodule* component of the A3 meadow had reduced to a single isolated patch of seagrass towards the southern end of the meadow (McKenna & Rasheed 2010). In 2010 however, both the mean biomass and the area of the A3 meadow increased significantly (Figure 4; Appendix). Biomass of the A5 meadow decreased significantly in 2010 but was within the range of mean biomass recorded over the previous 10 years of surveys (Figure 4). Both meadows had similar species compositions as observed over the previous few years of monitoring (Figure 4).

Table 3. Mean above-ground seagrass biomass and number of biomass sampling sites for each core monitoring meadow within the Port of Weipa. 2000 – 2010

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**
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 ± 1.2 (52)
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)	0.0012 ± 0 (31)	1.14 ± 0.5 (24)
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 ± 0.4 (61)
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 ± 1.1 (26)	6.22 ± 0.1.62 (31)	2.83 ± 0.55 (25)	1.47 ± 0.47 (29)	4.14 ± 1.0 (25)
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 ± 0.9 (21)

Table 4. Total meadow area for each core monitoring meadow within the Port of Weipa. 2000 – 2010

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**
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
A3 Intertidal *Halodule* dominated	30 ± 5	48 ± 5	34 ± 4	36 ± 4	41 ± 5	37 ± 5	31 ± 2	33 ± 2	32 ± 2	0.4 ± 0.1	22 ± 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
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
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
Total	**402 ± 37**	**417 ± 36**	**417 ± 31**	**399 ± 35**	**414 ± 36**	**398 ± 37**	**358 ± 23**	**368 ± 17**	**358 ± 23**	**345 ± 19**	**369 ±15**

Table 5. Mean above-ground seagrass biomass and number of biomass sampling sites for the A2 meadow within the Port of Weipa April and September 2000 – 2002 & 2010

Monitoring Meadow	Mean biomass ± SE (g DW m^{-2}) (No. of sites)									
	April 2000	**September 2000**	**April 2001**	**September 2001**	**April 2002**	**September 2002**	**April 2009**	**September 2009**	**April 2010**	**September 2010**
A2	71.15 ± 10.39 (29)	33.63 ± 5.82 (17)	45.39 ± 4.77 (49)	29.73 ± 2.88 (51)	34.61 ± 3.99 (52)	22.84 ± 2.99 (50)	10.8 ± 1.2 (62)	6.39 ± 0.77 (70)	16.01 ± 1.01 (61)	15.36 ± 1.2 (52)

Map 2. Meadow type and cover for seagrass meadows within the Intensive Monitoring Area 2010

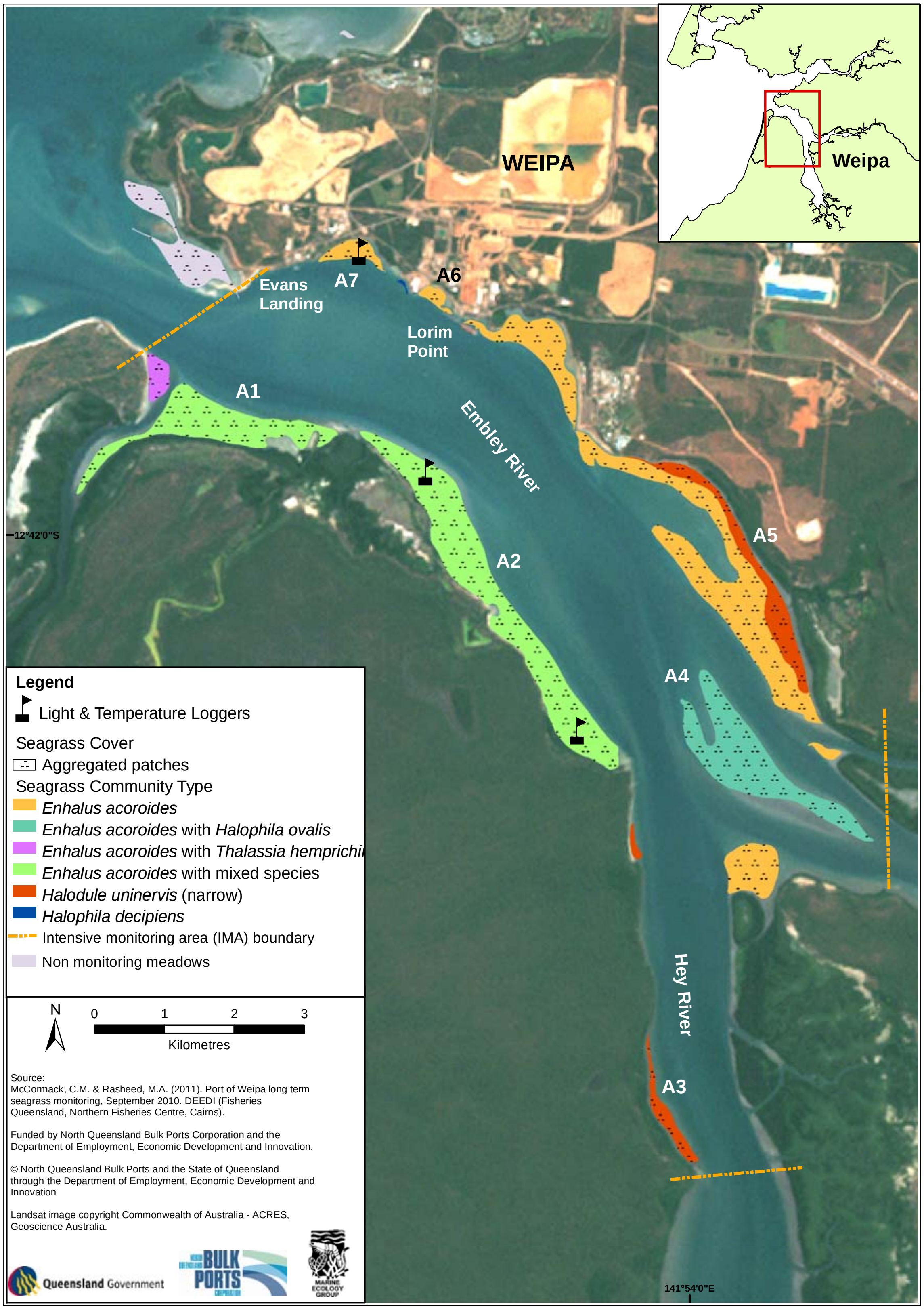
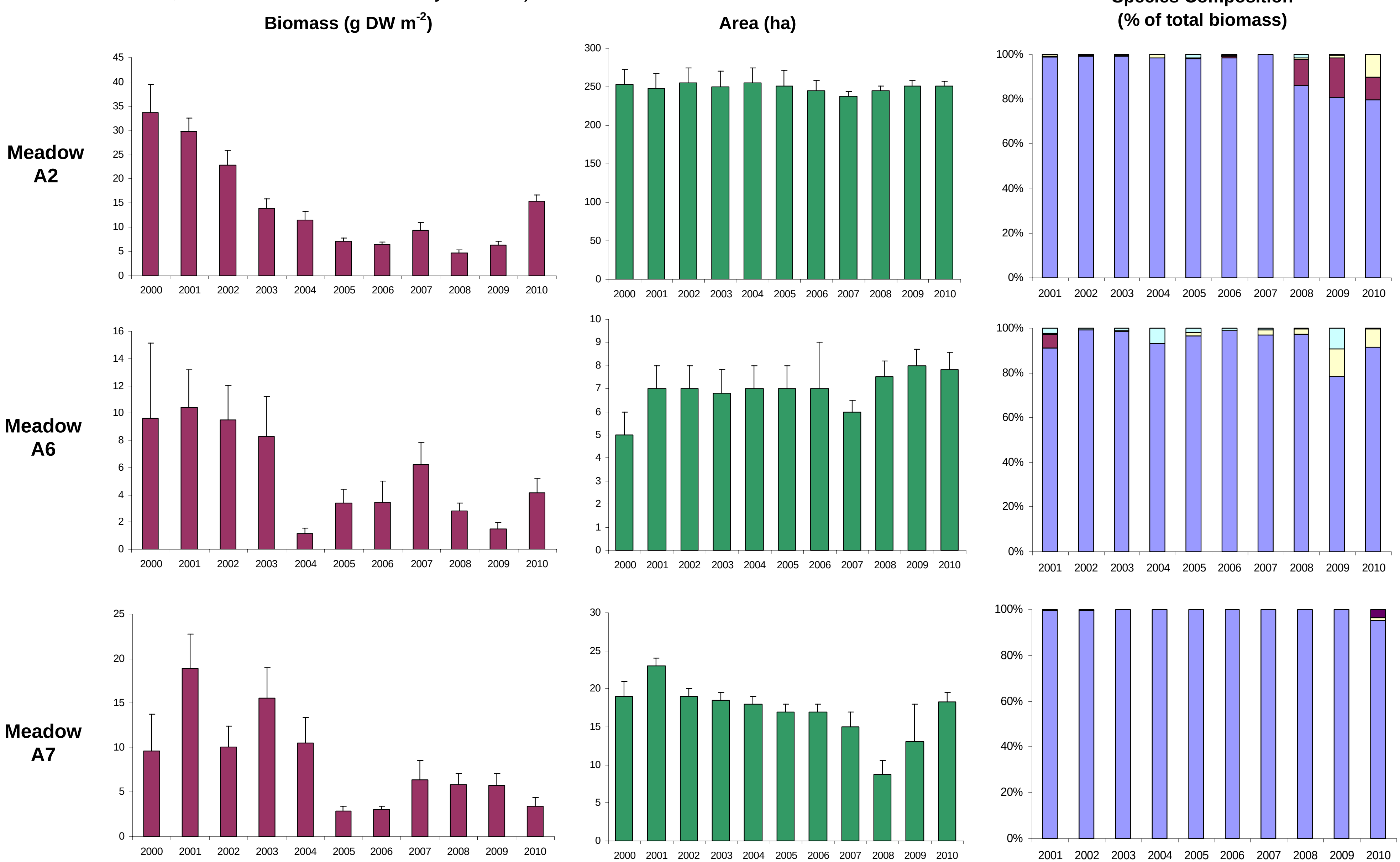
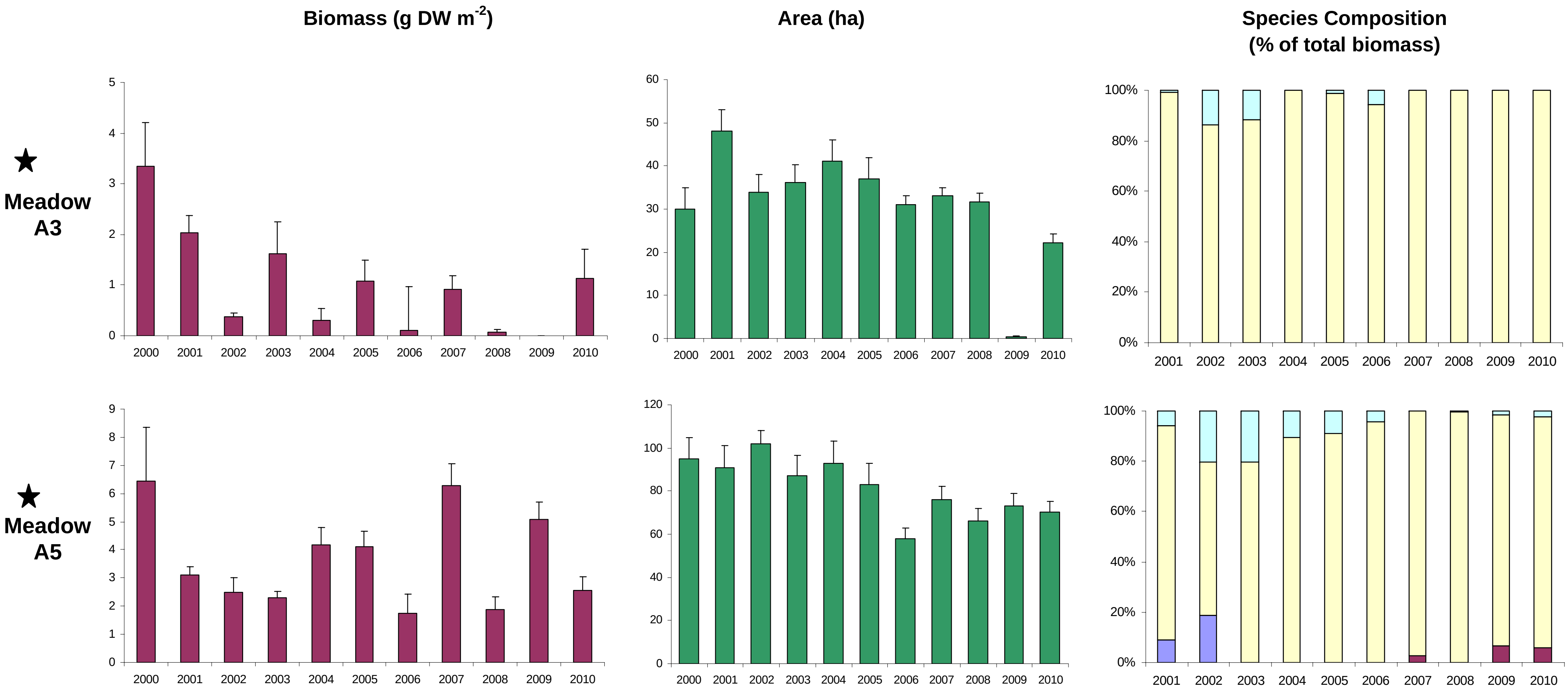
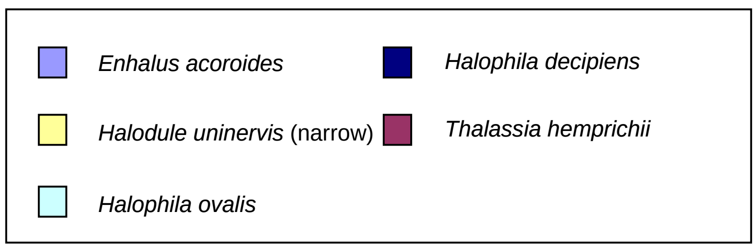


Figure 4. Changes in biomass area and species composition for the core monitoring meadows in Weipa from 2000 to 2010 (biomass error bars = SE; area error bars = “R” reliability estimate).

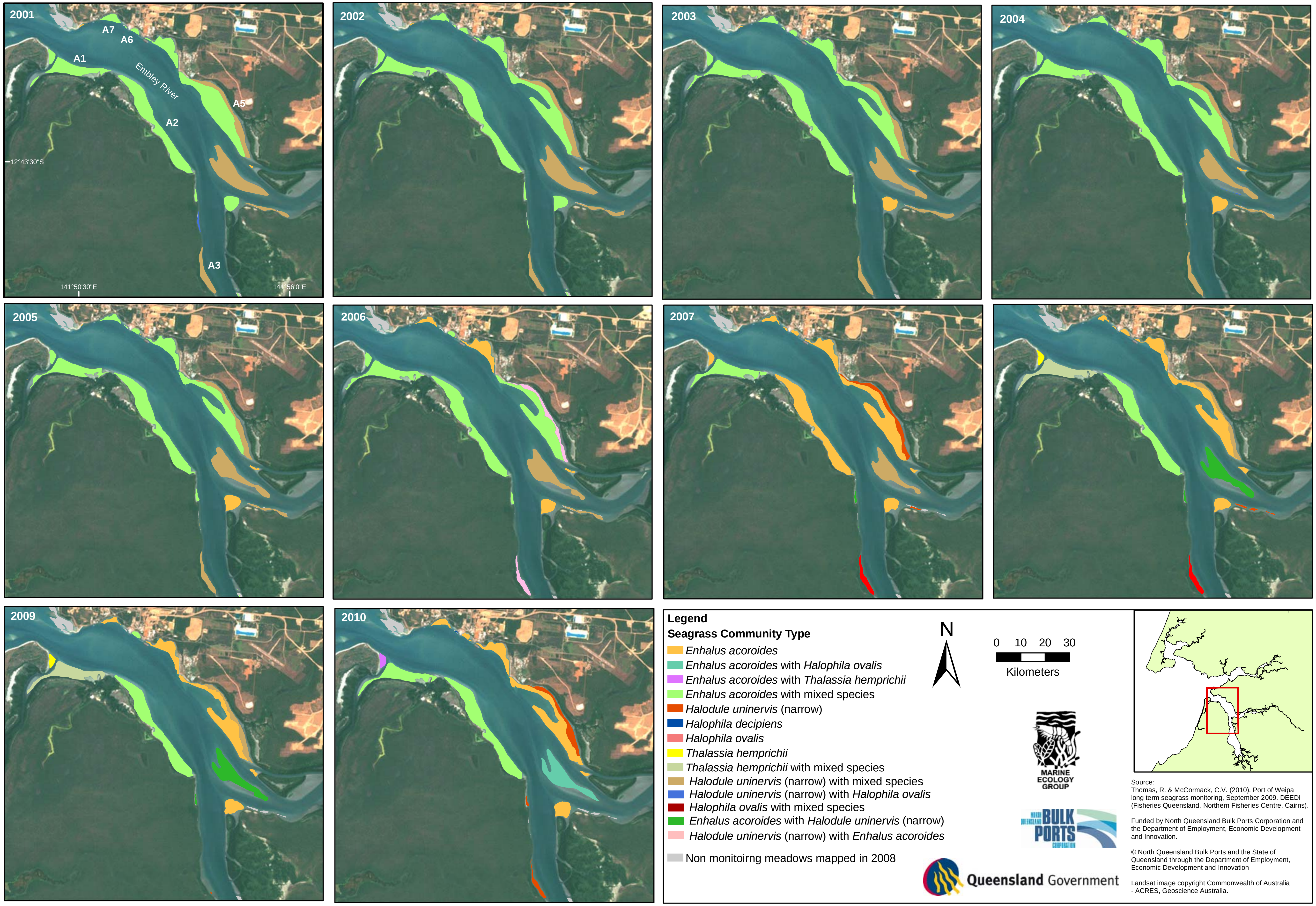




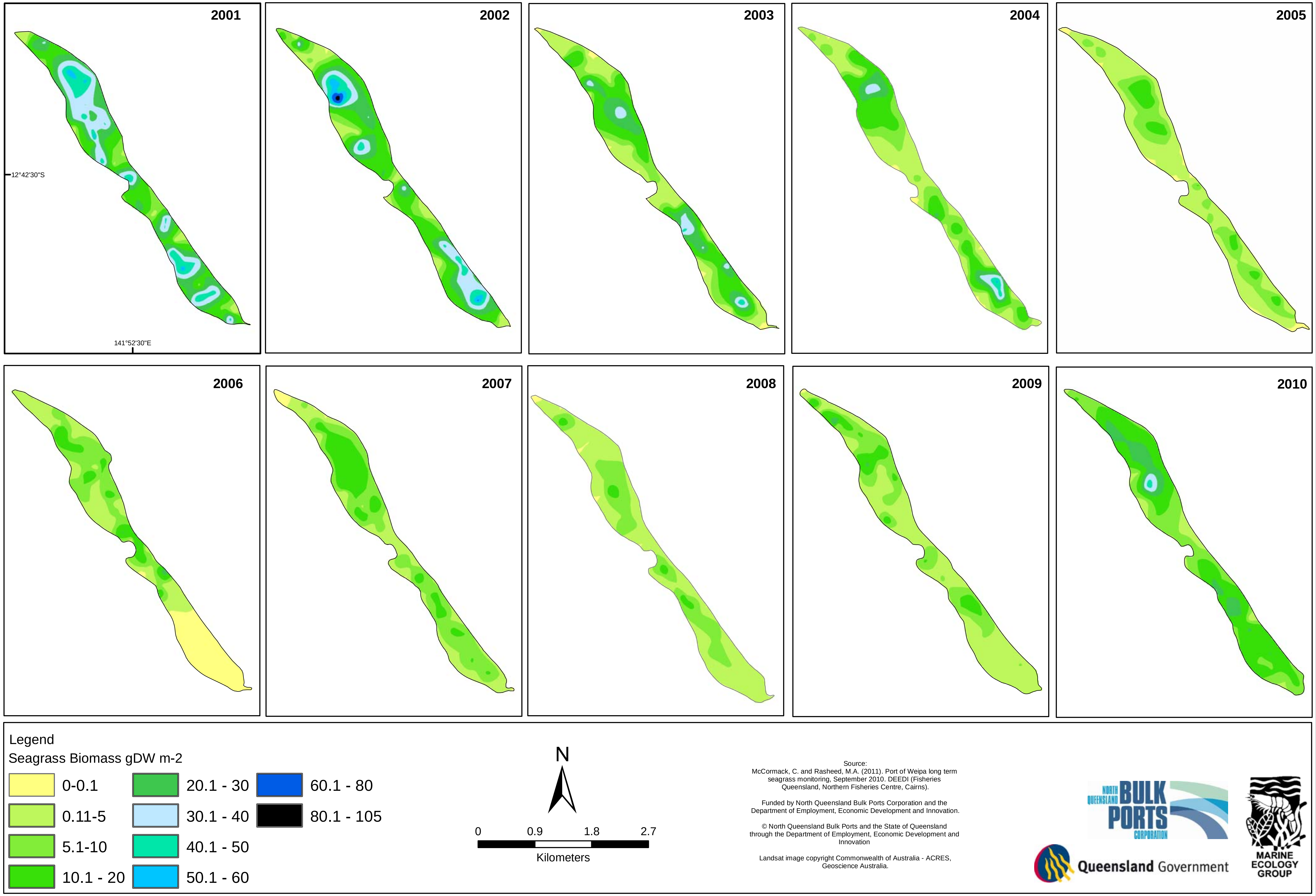


★ *Enhalus acoroides* excluded from biomass and species composition analysis

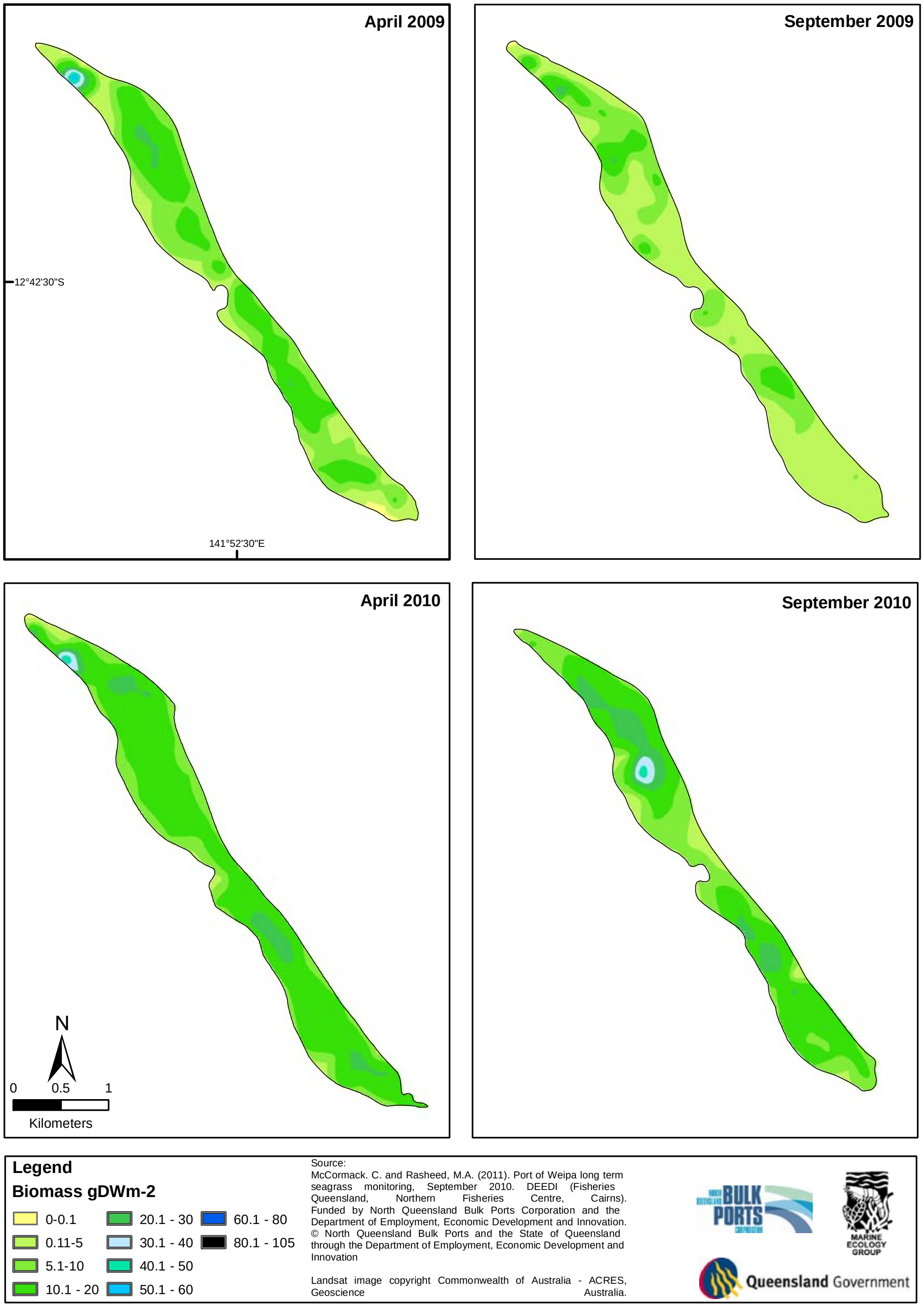
Map 3. Meadow type and distribution for the seagrass meadows within the IMA 2000 to 2009.



Map 4. Density of seagrass biomass in the A2 meadow from 2001 to 2010



Map 5. Density of seagrass biomass in the A2 meadow April 2009, September 2009, April 2010 & September 2010.



Weipa Climate and Seagrass Change

The total annual rainfall in Weipa in 2010 was slightly above the long-term average (since 1973; Figure 5) and higher than the total rainfall in 2009. This follows a large portion of the past decade with levels mostly below the long-term average. Both mean monthly solar radiation and average monthly mean maximum temperature have trended upward over the duration of the monitoring program with peaks between October and November most years (Figure 6; Figure 7). Annual daytime tidal exposure followed an increasing trend from 2000 to 2004 and has been decreasing for the past five years (Figure 8). In 2010, the number of daytime hours that seagrasses were exposed was at the lowest level recorded over the course of the monitoring program (Figure 8).

Using the methods described in Rasheed and Unsworth (2011), a partial least squares (PLS) regression analysis was undertaken to examine the effects of various climate factors (rainfall, solar radiation, temperature and daytime tidal exposure) on seagrass biomass over multiple timeframes prior to each years survey (e.g. 1, 2, 3, 6, 9 and 12 months). The results revealed that the variance in the biomass of the A2, A3 and A6 meadows is significantly correlated to tidal exposure for the prior month, and solar radiation for the prior twelve months leading up to the monitoring survey (Appendix; Rasheed *et al*, In Review).

In 2010, the total number of hours that intertidal seagrass meadows were exposed was considerably lower in August 2010 (Figure 9) than in August 2009 (60 hours and 101 hours respectively). This is likely to have contributed to the significant increase in biomass in both the A2 and A3 meadows. A decline in daytime exposure for intertidal meadows is likely to result in less desiccation and extreme temperature conditions at the seagrass blade surface which can lead to burning and thermal stress. Field observations indicated that burning was less prevalent than had been observed in 2009.

Figure 5. Total annual rainfall recorded at Weipa airport from 1973 to 2010 (Bureau of Meteorology, 2011)

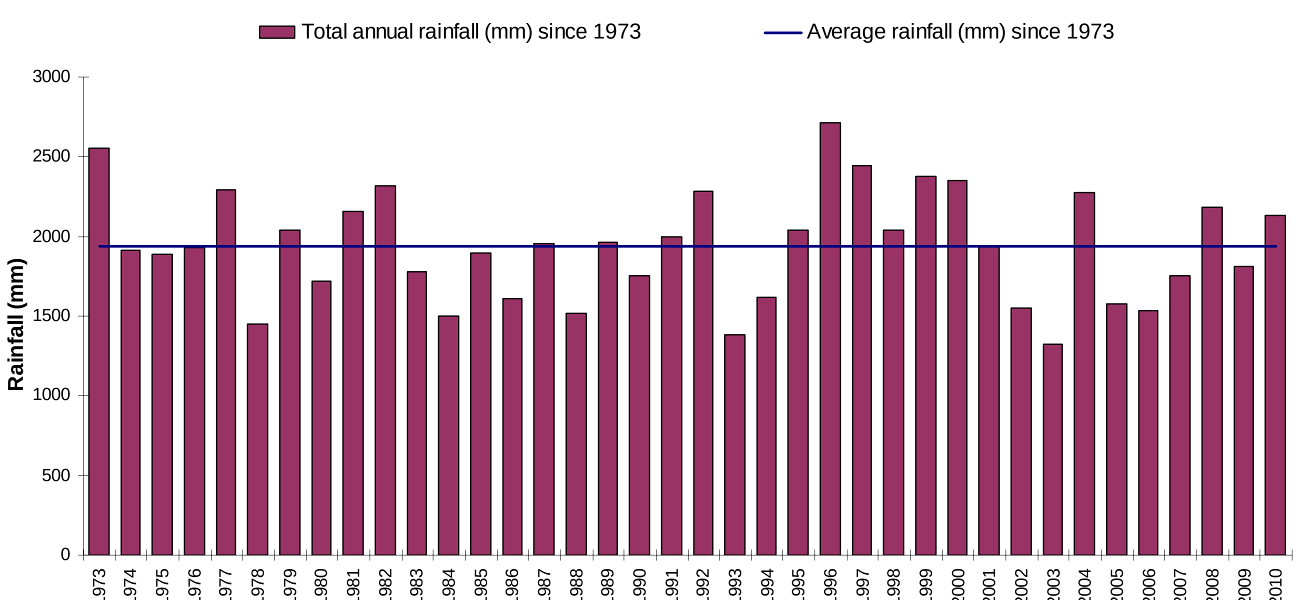


Figure 6. Mean monthly solar radiation recorded at Weipa airport from 2000 to 2010 (Bureau of Meteorology, 2011)

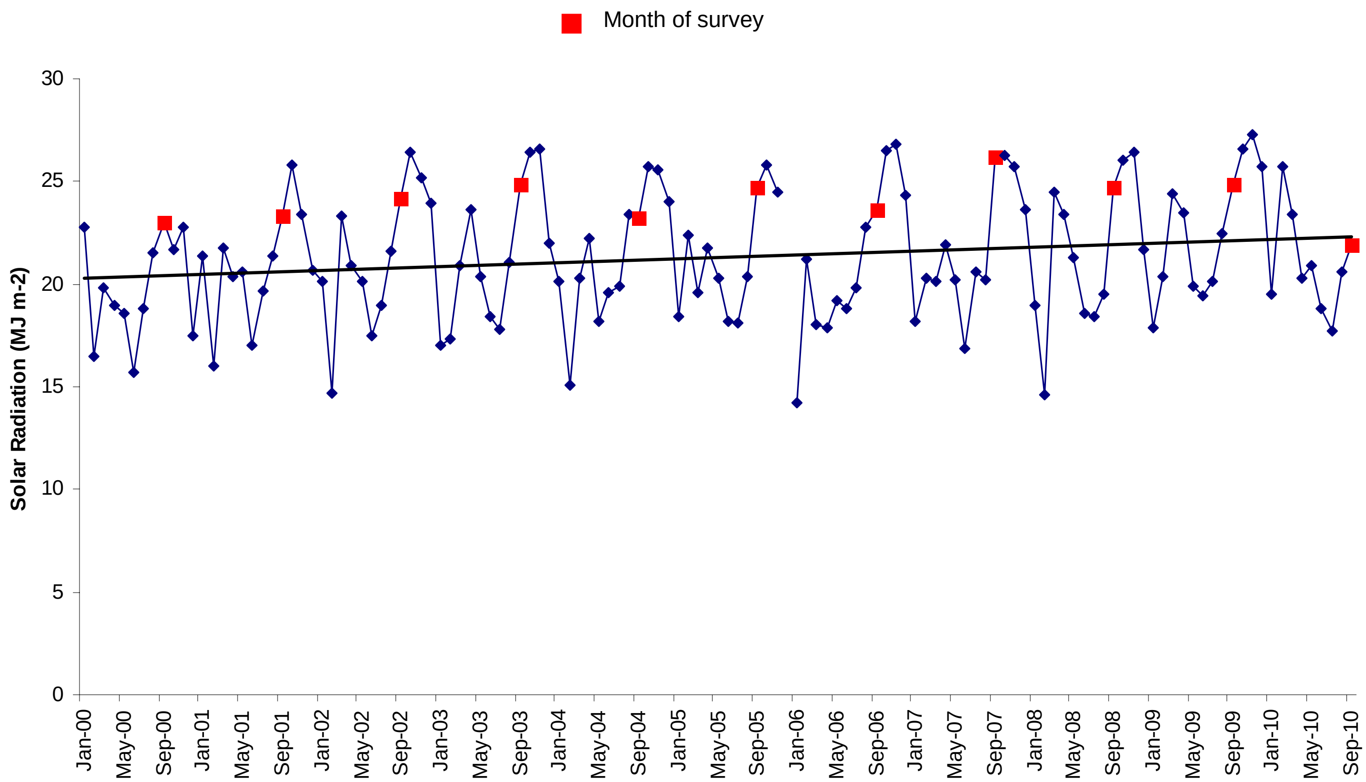
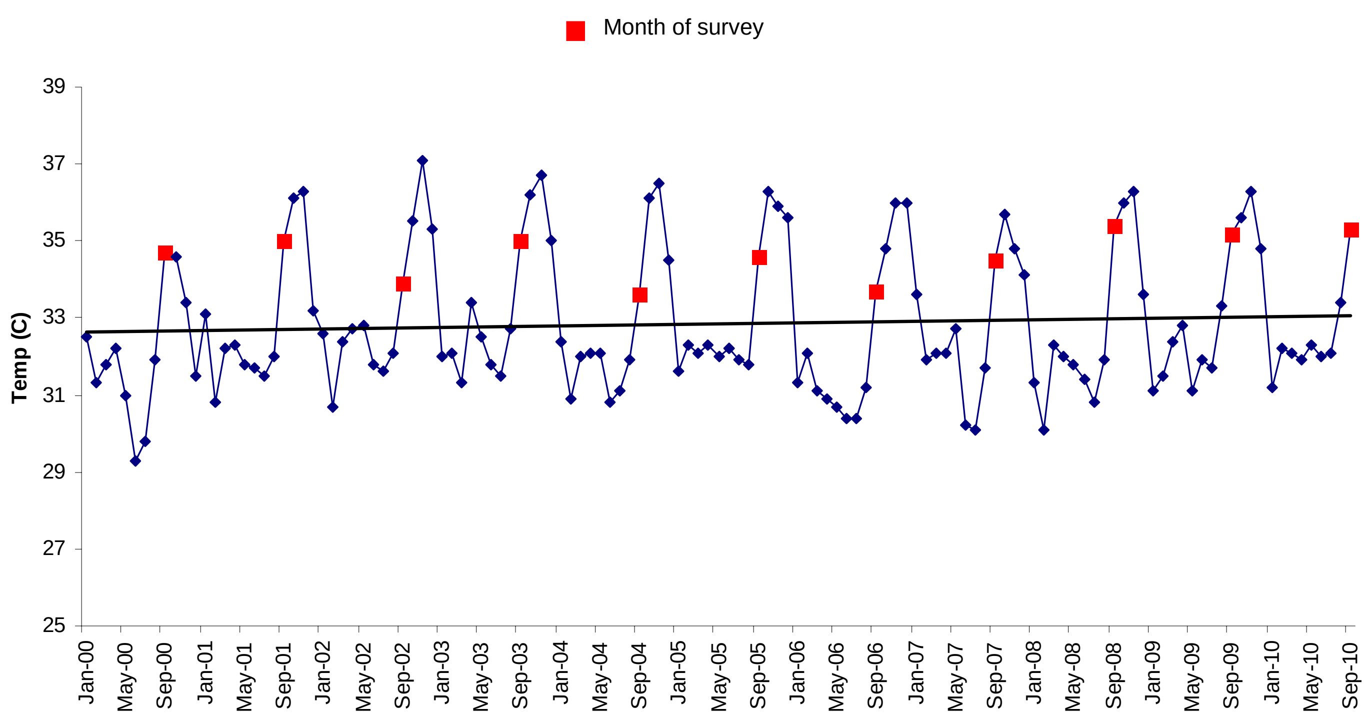
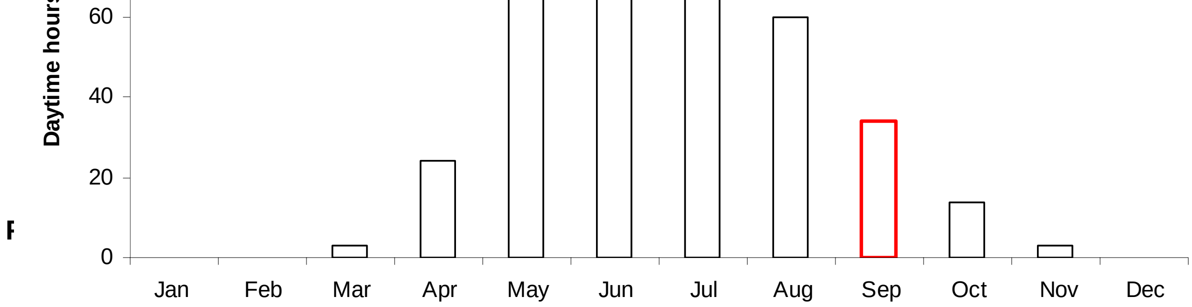


Figure 7. Average monthly maximum mean temperature recorded at Weipa airport from 2000 to 2010 (Bureau of Meteorology, 2011)





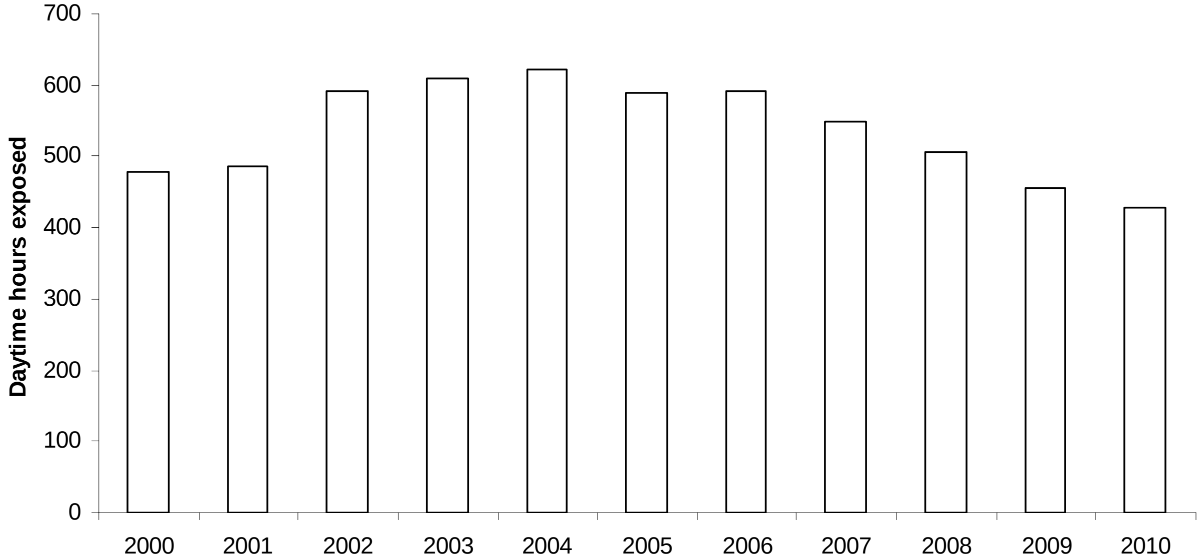
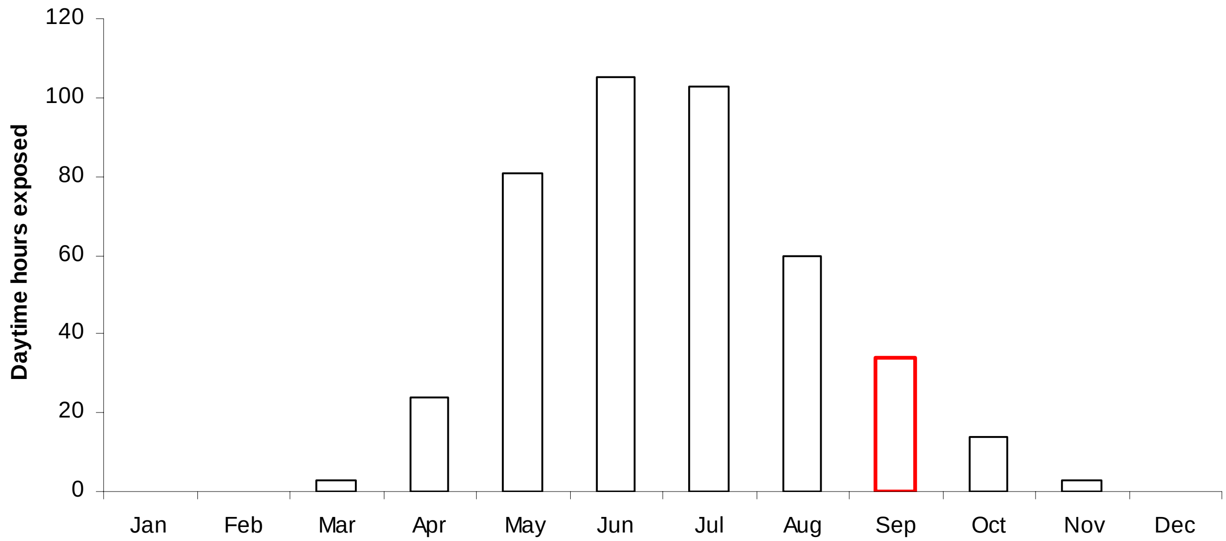


Figure 9. Total monthly hours intertidal seagrass meadows were exposed (<1m) in the Weipa region, 2010 (Maritime Safety Queensland, 2011)



DISCUSSION

Monitoring surveys in 2010 found that there had been substantial recovery of seagrasses that had been declining for several years. Despite this recovery in intertidal *Enhalus acoroides* seagrass meadows they remain in a vulnerable condition. Regional and local climate conditions such as low rainfall and a reduction in associated runoff, high air temperatures and greater exposure to more intense solar radiation are likely to have contributed to significant declines in seagrass biomass over the course of the monitoring program (McKenna and Rasheed 2010). In 2010, Weipa experienced higher than average rainfall and substantial decreases in daytime tidal exposure. These conditions were highly correlated with the observed seagrass change and may have facilitated increases in biomass for some meadows. However long term declining trends may have left meadows in a vulnerable condition with a reduced resilience and capacity to recover.

For some intertidal core monitoring meadows (A2, A3 and A6), daily tidal exposure in the month prior, and solar radiation in the twelve months prior to the September survey are significantly correlated with changes in biomass (Rasheed *et al*, In Review). The very low daytime tidal exposure in August 2010 was highly correlated with increases in biomass seen in the intertidal A2 and A3 meadows. Increased tidal exposure 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 (Rasheed and Unsworth 2011; Erftemeijer and Herman, 1994; Stapel, 1997; Bjork *et al*, 1999; Seddon *et al*., 2000; Kahn and Durako, 2009). These conditions can lead to declines in seagrass density and area and may contribute significantly to the changes observed for some intertidal seagrass meadows in Weipa.

Other meadows (A7 and A5) did not display the same correlation and changes are likely to be driven by a combination of a range of natural factors that affect seagrass growth. Being mostly subtidal, the A7 meadow is unlikely to be as affected by tidal exposure. Both the A3 and the A5 intertidal *Halodule* meadows have been highly patchy and variable throughout the monitoring program. While the A3 meadow showed signs of recovery in 2010, the A5 meadow declined significantly. Although these changes are within the range detected over the duration of the monitoring program, it should be noted that the make up of these naturally patchy meadows makes them highly susceptible to further natural or anthropogenic impacts. Further enhancements to the established seagrass program including an examination of light and temperature conditions at vulnerable seagrass meadows established after the September 2010 survey will significantly enhance the ability of the program to pinpoint the causes of seagrass declines. Fisheries Queensland and NQBP are currently collecting these data to incorporate into the monitoring program.

The increase in biomass and distribution seen in some meadows in Weipa in 2010 was consistent with changes in the Port of Karumba and in Torres Strait (McKenna and Rasheed 2011). In contrast, seagrasses on the east coast of Queensland have suffered major declines (Fisheries Queensland in preparation). The Torres Strait and the Gulf of Carpentaria has been less affected by La Nina events that were seen throughout the state in 2010. These conditions have likely contributed to major declines seen on the east coast through significant flooding and storm events.

Despite these signs of recovery, in 2010 seagrass densities for the core monitoring meadows remained below historical peaks. Long term declines may have left some meadows in a vulnerable condition to further natural and anthropogenic impacts with a reduced resilience and capacity to recover. The continuation of similar climate conditions as 2010 (increased rainfall, coupled with a continuing decrease in the amount of daytime exposure) may lead to continued recovery for seagrass meadows, however extra care should continue to be taken when conducting activities in the region that could further stress these meadows. While some environmental factors such as tidal exposure and solar radiation may be key variables driving seagrass change for meadows, there are a range of other natural and anthropogenic factors that cannot be ruled out as having an effect.

In summary results of the 2010 monitoring indicate that;

- Seagrass habitat in the Port of Weipa remains in a reasonable condition with the first signs of recovery for key seagrass meadows that have been declining for several years.
- The *Enhalus* meadow on the western bank of the Embley River had increased significantly but remains vulnerable to further impacts.
- The *Halodule* meadow on the eastern bank of the Hey River had returned but some smaller *Halodule* meadows remain absent from the Intensive Monitoring Area
- Multi-year tidal patterns and solar radiation may explain a significant component of the long term changes in biomass for some intertidal meadows however they not the only factors that could be contributing to changes in seagrass.
- Additional seagrass monitoring established after September 2010 and changes to dredge management measures will assist in protection of vulnerable seagrasses.

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APPENDIX

ANOVA Results

One Way Analysis of Variance on Ranks; Mean biomass for the five monitoring meadows from 2001-2010 (2000 not analysed due to small sample size). Years that share the same letter are not significantly different ($P<0.05$).

ANOVA

Meadow A2	DF	SS	MS	F	P
Between Years	9	30589.3	3398.81	23.13	**0.0000**
Within Years	517	75962.4	146.929		
Total	526	106552			
Meadow A3					
Between Years	8	98.04	12.26	3.78	**<0.05**
Within Years	239	774.48	3.24		
Total	247	872.52			
Meadow A5					
Between Years	9	1015.42	112.824	7.77	**0.0000**
Within Years	532	7729.25	14.5287		
Total	541	8744.67			
Meadow A6					
Between Years	9	2590.46	287.829	4.26	**0.0000**
Within Years	253	17009.1	67.5459		
Total	262	19679.6			
Meadow A7					
Between Years	9	7917.43	879.714	5.99	**<0.05**
Within Years	273	40112.9	146.934		
Total	282	48030.4			

Meadow A2	
Year	**Mean Biomass**
2001	29.73 a
2002	22.84 b
2003	13.91 cd
2004	11.47 cde
2005	7.04 ef
2006	6.43 f
2007	9.4 def
2008	4.66 f
2009	6.39 f
2010	15.362 c

Meadow A3	
Year	**Mean Biomass**
2001	2.04 a
2002	0.37 cd
2003	1.63 ab
2004	0.31 cd
2005	1.08 abc
2006	0.11 d
2007	0.92 bcd
2008	0.24 cd
2009	n/a
2010	1.14 abc

Meadow A5	
Year	**Mean Biomass**
2001	3.11 cd
2002	2.49 d
2003	2.29 d
2004	4.18 bc
2005	4.11 bc
2006	1.75 d
2007	6.27 a
2008	1.94 d
2009	5.09 b
2010	2.56 d

Meadow A6	
Year	**Mean Biomass**
2001	10.40 a
2002	9.49 a
2003	8.31 ab
2004	1.14 d
2005	3.37 cd
2006	3.44 bc
2007	6.22 abc
2008	2.83 cd
2009	1.47d
2010	4.14 bcd

Meadow A7	
Year	**Mean Biomass**
2001	18.89 a
2002	10.03 bcd
2003	15.57 ab
2004	10.56 bc
2005	2.84 e
2006	3.06 e
2007	6.41 cde
2008	5.85 cde
2009	5.75 cde
2010	3.46 de

PLS Regression Analysis

Partial least squares (PLS) regression analysis (final models following stepwise analysis) of annual mean seagrass biomass relative to available climate and environmental data at Wiepa, North Queensland, Australia (2000 to 2010). Table shows the overall 'global' ANOVA statistics for each of the regression models, the individual principal components and their cumulative R^2 values. Individual regression coefficients of the specific biomass predictors (environmental variables) are also shown.

Metric		PLS ANOVA			Model selection and validation				Predictors	
Meadow		P	F	DoF	Component	X Variance	R-Sq	R-Sq (pred)	Tidal Exp Previous Month	Solar Radiation Previous 12 Months
A2	ANOVA	0.005	13.71	1,10						
Biomass	PLS Model				1	0.55	0.60	0.20		
					2		0.60	0.19		
	Coefficients								-0.42 (exposed at 1.0m)	-0.61
A3	ANOVA	0.034	6.28	1,10						
Biomass	PLS Model				1	0.58	0.41	0		
					2		0.42	0		
	Coefficients								-0.36 (exposed at 0.8m)	-0.48
A6	ANOVA	0.002	14.05	1,10						
Biomass	PLS Model				1	0.55	0.76	0.58		
					2	1.0	0.78	0.61		
	Coefficients								-0.12 (exposed at 0.8m)	-0.85