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PORT OF ABBOT POINT LONG-TERM SEAGRASS MONITORING:

ANNUAL REPORT 2011 - 2012

McKenna SA & Rasheed MA

Report No. 13/02

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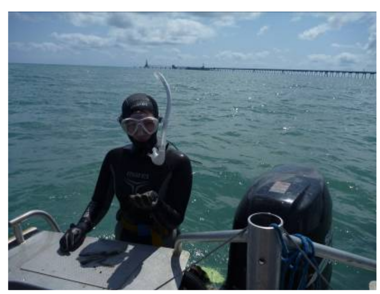

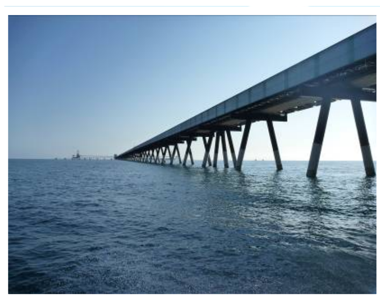

PORT OF ABBOT POINT LONG-TERM SEAGRASS MONITORING: ANNUAL REPORT 2011-2012

A Report for North Queensland Bulk Ports Corporation (NQBP)

Report No. 13/02

January 2013

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Errors:
In the 2011 Interim report (McKenna & Rasheed 2011) it was reported that the maximum distribution that coastal monitoring meadows have covered throughout the monitoring program was 270.13 ha (pg 14). This value was a typing error. The maximum distribution that coastal monitoring meadows have covered is 557.87 ha.

EXECUTIVE SUMMARY

This report summarises the results of the coastal and deep water seagrass monitoring program conducted between September 2011 and September 2012 at the Port of Abbot Point. The seagrass monitoring program at Abbot Point was developed in 2008 following two baseline assessments of the marine habitat within the port limits. Since 2008, seagrass at selected representative sites has been monitored quarterly.

Significant losses of density and distribution of seagrasses at Abbot Point were observed after the La Niña events of 2010/11 and severe Tropical Cyclone Yasi, the most likely factors that caused these losses. There is evidence of recovery of seagrass at some of the deep water monitoring sites, however, the coastal inshore meadows had not had any significant recovery by September 2012. Coastal habitats along the Queensland coast are regularly exposed to flooding & cyclones, but the scale and longevity of the 2010/11 La Niña events were unprecedented and may have left seagrasses at Abbot Point, particularly the inshore species, with substantially reduced resilience and capacity for recovery. Similar declines to coastal seagrass meadows have been recorded throughout the wet and dry tropics regions where seagrasses are monitored.

Seagrasses at Abbot Point have the potential to recover, however, this recovery is dependent upon the species present and the availability of seed reserves. *Halophila*, the dominant seagrass genera in the offshore meadows, has a high capacity for recovery through the use of seed reserves in the sediment. In contrast, the shallow near-shore species *Halodule uninervis* failed to recover quickly from experimental disturbance and relied on asexual propagation, making them more vulnerable to widespread loss. The same results have been reported for *Zostera capricorni*, another in-shore species at Abbot Point that has not recovered from natural events. Seed-bank assessments of *Halodule uninervis* and *Zostera capricorni* at Abbot Point indicate that the potential for these species to recover at Abbot Point may be restricted, as only a small bank of *Halodule uninervis* seeds and no *Zostera capricorni* seeds were found in the sediment at the monitoring meadows.

The declines in Abbot Point seagrasses over recent years mean that they likely have a reduced resilience to further impacts and stressors. The cumulative impacts of natural stressors combined with future developments associated with port expansions have the potential to impact seagrasses. Modeling indicates that turbidity associated with these planned developments is not likely to reach the coastal meadows that have been most effected, with any interactions occurring in the deeper offshore seagrasses closer to proposed expansions. Several initiatives have been included in the monitoring program to ensure relevant information is available to manage these seagrasses and ensure impacts from future port activity on seagrasses are minimised. These include an examination of the light requirements and capacity for recovery of the key offshore species so that appropriate management thresholds are developed to maintain the ability of seagrasses to grow and continue to recover.

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1 INTRODUCTION

North Queensland Bulk Ports Corporation (NQBP) is the organisation responsible for managing and monitoring Abbot Point's port environment. NQBP have recognised that seagrasses are an important and sensitive component of marine habitats within the port and are committed to monitoring and maintaining the health of these habitats.

Seagrass meadows are important ecosystem service providers to coastal environments. They provide functions such as coastal protection, nutrient cycling and particle trapping (Costanza et al. 1997; Hemminga and Duarte 2000). With globally developing carbon markets, the role that seagrasses play in sequestering carbon is also becoming more widely recognised (Kennedy and Björk 2009). Seagrasses also provide additional economic value in terms of nursery and feeding habitats for commercial and recreational fisheries species and are internationally important due to the food resources they provide for IUCN endangered and vulnerable species such as dugong and turtles (Unsworth and Cullen 2010; Hughes et al. 2009; Watson et al. 1993). Such species are also recognised in Australia under the *Environmental Protection and Biodiversity Conservation Act 1999*.

Seagrasses are highly sensitive to changes in their environment and show measurable responses to changes in water quality (Dennison et al. 1993), making them ideal sentinels of change in coastal systems. Results from long-term monitoring programs in other Queensland port locations have provided valuable information on the relationships between climatic changes, anthropogenic disturbance and seagrass abundance (Rasheed & Unsworth 2011; Chartrand et al. 2012; Unsworth et al. 2012). Documenting the large spatial extent of seagrass meadows in port areas by creating a 'baseline', and monitoring a sub-section of meadows over the long-term, has enabled port managers to make informed decisions regarding planning and development of port infrastructure that minimises the impact of port developments on fisheries and the marine environment.

In 2008, NQBP commissioned James Cook University's Marine Ecology Group (MEG) in the Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) (formally Fisheries Queensland) to develop and conduct a seagrass assessment and experimental program for the Port of Abbot Point. This program involved two baseline fine-scale surveys of the marine habitat within the port limits and manipulative experimental research of the seagrass at the port beginning in February 2008. The baseline surveys mapped more than 20,000 hectares of deep water and coastal seagrass communities within the port limits (McKenna et al. 2008).

The baseline assessments and experimental program at Abbot Point were then used to establish a longer term monitoring program to aid in the management of port development and dredge-related impacts, and to assess the long-term condition and trend of this fisheries habitat. Results from baseline surveys and consultation with port users culminated in the selection in nine areas for monitoring: five coastal meadows and four offshore meadows (Map 1). These monitoring areas represent the range of seagrass communities within the port and include meadows considered most likely to be impacted by port activity and development, as well as areas unlikely to be impacted by port development, to assist in separating out port related versus regional causes of seagrass change detected in the monitoring program (i.e. as a reference site). Quarterly monitoring of seagrass habitat within the port has continued since 2008.

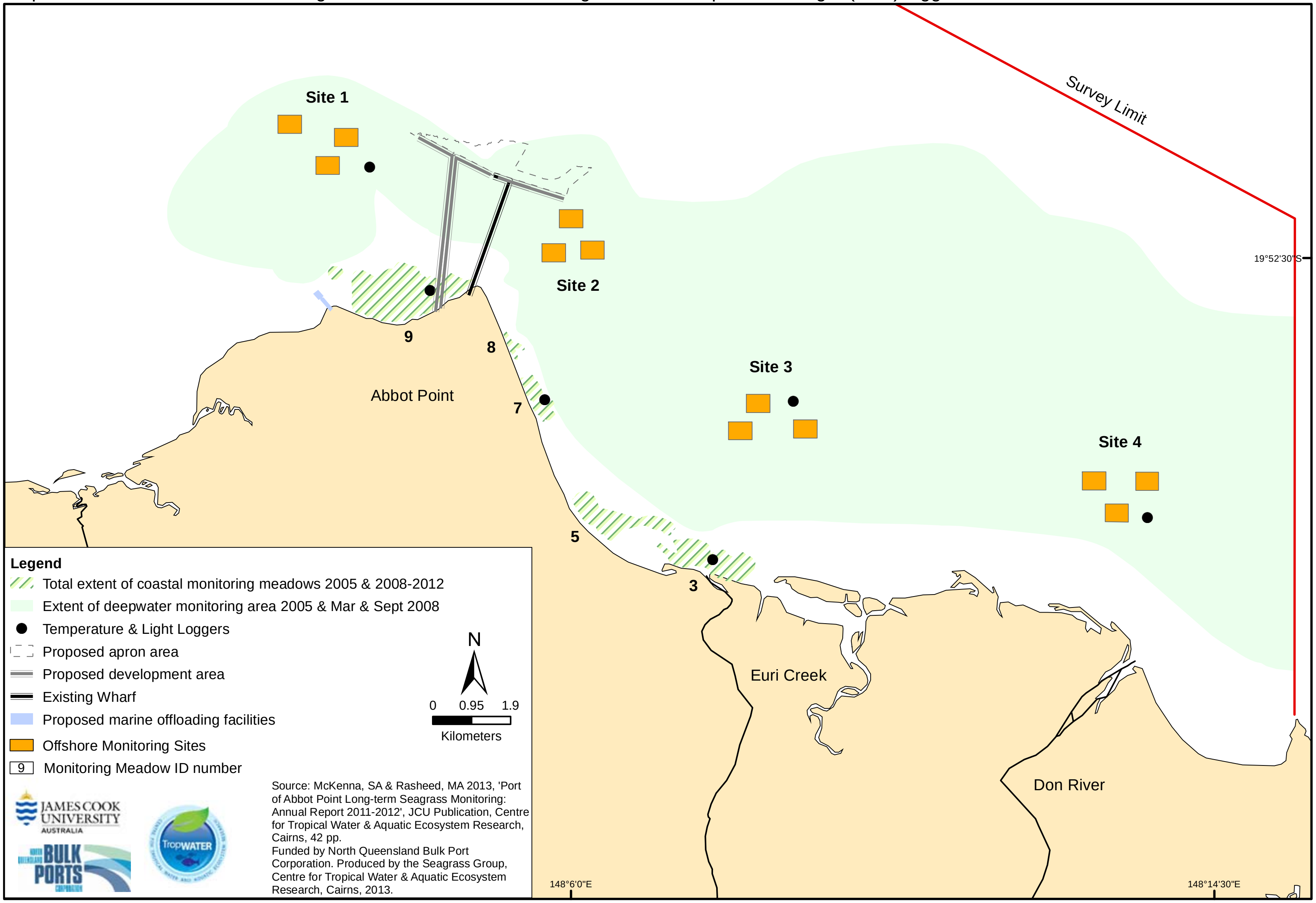
Understanding levels of background natural variability in seagrass meadows and the factors driving these changes is critical for separating the effects of any anthropogenic disturbance. Without detailed long-term datasets on the physicochemical conditions of seagrass meadows (i.e. canopy water temperature, turbidity, light and nutrient availability and sediment movements) the means to investigate changes is reliant upon relating potential surrogates such as broad-scale weather data (i.e. rainfall, river flow, solar radiation and air temperature) to seagrass habitat descriptors (e.g. meadow biomass and area). Whilst both approaches do not provide 'cause and effect', *in situ* environmental data enhances the capacity to interpret changes in seagrass dynamics. Since September 2011, light (photosynthetically active radiation, PAR) and temperature assessments have been conducted at Abbot Point and provide the first data to evaluate local seagrasses against local conditions. These assessments will help relate changes in the Abbot Point seagrass meadows to the major seasonal drivers of change and allow us to better distinguish anthropogenic versus natural impacts on the habitat. It is anticipated that the sites established in the monitoring program will also be used to assess any impacts during development and assess post-development recovery of seagrasses.

The objectives of the long-term seagrass monitoring program at Abbot Point are:

1. Compare results of baseline and seasonal monitoring events to assess any changes in seagrass distribution and abundance in relation to natural events or anthropogenic activities;
2. Relate changes measured in seagrass meadows to light and temperature data collected;
3. Discuss the implications of monitoring results for overall health of the Port of Abbot Point's marine environment and provide advice to relevant management agencies;

This report summarises the results of the coastal and deep water seagrass monitoring program conducted between September 2011 and September 2012, as well as light (PAR) and temperature measurements at the Port of Abbot Point. Quarterly monitoring results prior to September 2011 can be found in McKenna & Rasheed (2011).

Map 1. Location of coastal monitoring meadows, offshore monitoring sites and temperature & light (PAR) loggers



2 METHODOLOGY

2.1 Sampling Approach And Methodology

The long-term seagrass monitoring program at Abbot Point has two components, **(1)** quarterly assessments of established monitoring meadows, and **(2)** light and temperature assessments in the seagrass canopy.

2.1.1 Quarterly assessment of established monitoring meadows

From the results of the baseline surveys in 2008 (McKenna et al. 2008), five coastal meadows and four offshore areas were identified as suitable for long-term seagrass monitoring (Map 1). Monitoring meadows were representative of the range of seagrass communities identified in the baseline surveys and were also located in areas considered ideal sensitive receptor sites for assessing seagrass condition during and after port activity and development.

Seagrass monitoring has been conducted approximately quarterly (weather dependent) since May 2008, with the last monitoring survey conducted in September 2012. Quarterly assessments were established to determine within- and between-year variation in seagrass metrics prior to, during and after planned port development and capital dredging.

Methods for assessing the coastal seagrass monitoring meadows and offshore monitoring sites have followed those established for the Abbot Point program since 2008 (see McKenna et al. 2008, Unsworth et al. 2010 and McKenna & Rasheed 2011). The application of standardised methods at Abbot Point and throughout Queensland allows for direct comparison of local seagrass dynamics with the broader region. Free-diving and deep water sled tows using a CCTV camera system were used to survey coastal and offshore monitoring areas (see McKenna et al. 2008 for full description). At each survey site, seagrass habitat observations included seagrass species composition, above-ground biomass, per cent algal cover, depth below mean sea level (MSL), sediment type, time and position (GPS). The per cent cover of other major benthos at each site was also recorded. Above-ground seagrass biomass was estimated using a "visual estimates of biomass" technique (Kirkman 1978, Mellors 1991). This technique involves an observer ranking seagrass biomass within a randomly placed 0.25m^2 quadrat at each site. Ranks are made in reference to a series of quadrat photographs of similar seagrass habitats for which above-ground biomass has previously been measured. The relative proportion of the above-ground biomass (percentage) of each seagrass species within each survey quadrat was also recorded. Field biomass ranks were then converted into above-ground biomass estimates in grams dry weight per square metre (g DW m^2). At the completion of sampling, each observer ranked a series of calibration quadrats that represented the range of seagrass biomass in the survey. After ranking, seagrass in these quadrats was harvested and the actual biomass determined in the laboratory. A separate regression of ranks and biomass from these calibration quadrats was generated for each observer and applied to the field survey data to standardise the above-ground biomass estimates.

Sampling sites were assessed by deep water sled tows and free-divers to measure seagrass biomass and species composition to characterise the coastal habitat.

Habitat Mapping and Geographic Information System

All survey data was entered into a Geographic Information System (GIS) for presentation of seagrass species distribution and abundance. Satellite imagery of the Bowen/Abbot Point area with information recorded during the monitoring surveys was combined to assist with mapping seagrass meadows. Three seagrass GIS layers were created in ArcMap:

- ***Habitat characterisation sites*** – 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). Abundance categories (light, moderate, dense) were assigned to community types according to above-ground biomass of the dominant species (Table 2, 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 un-vegetated sediment interspersed with isolated patches of seagrass

Aggregated seagrass patches
Meadows are comprised of numerous seagrass patches but still feature substantial gaps of un-vegetated 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 un-vegetated sediment.

Table 2. Nomenclature for community types in the Port of Abbot Point 2008-2012

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 3. Density categories and mean above-ground biomass ranges for each species use in determining seagrass community density in the Port of Abbot Point 2008-2012

Density	Mean above ground biomass (g DW m^{-2})				
	H. uninervis (narrow)	*H. ovalis* *H. decipiens*	*H. uninervis* (wide) *C. serrulata/rotundata*	*H. spinulosa*	*Z. capricorni*
Light	< 1	< 1	< 5	< 15	< 20
Moderate	1 - 4	1 - 5	5 - 25	15 - 35	20 - 60
Dense	> 4	> 5	> 25	> 35	> 60

Each seagrass meadow was assigned a mapping precision estimate (±m) based on the mapping methodology utilised for that meadow (Table 4). Mapping precision estimates ranged from 10m for isolated seagrass meadows, to 500m for larger 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. Additional sources of mapping error associated with digitising aerial photographs onto base maps and with GPS fixes for survey sites were embedded within the meadow reliability estimates.

Table 4. Mapping precision and methodology for seagrass meadows in the Port Abbot Point 2008-2012

Mapping precision	Mapping methodology
10-20m	Subtidal meadow boundaries determined from diver surveys only; All meadows subtidal; Relatively high density of survey sites; Recent aerial photography aided in mapping.
30-60m	Subtidal meadow boundaries determined from diver surveys only; All meadows subtidal; Moderate density of survey sites; Recent aerial photography aided in mapping.
100-500m	Baseline meadows only; Larger subtidal meadows with boundaries determined from camera/grab surveys only; All meadows subtidal; Relatively low density of survey sites.

2.1.2 Light and temperature assessments

Light (photosynthetically active radiation, PAR) and water temperature conditions within the seagrass meadows were assessed at three coastal meadows and three offshore sites from September 2011 (Map 1). These environmental parameters were collected along with existing sources of daily weather data (rainfall, river flow, air temperature and solar radiation) publicly available from the Australian Bureau of Meteorology (www.bom.gov.au) and the Department of Environment and Heritage Protection (www.ehp.qld.gov.au).

PAR and temperature within the seagrass canopy were recorded every 15 minutes. Loggers were exchanged and downloaded approximately every 90 days. The Odyssey PAR loggers logged a cumulative reading at 15 minute intervals, which was calibrated and summed to gain total average PAR per day (mol

m^{-2} day^{-1}) 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 were exposed to air was also made. Air exposure times were 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 those exposure times divided by 1.3 as outlined in Collier et al. (2009). PAR data were converted to total daily irradiance.

PAR & temperature loggers deployed at Abbot Point

2.1.3 Statistical analysis

Seagrass above-ground biomass was compared between sampling periods using one-way analysis of variance (ANOVA) with Tukey's post hoc comparison. Prior to statistical testing, residuals were examined and biomass data was log(x+1) transformed to improve the assumptions of ANOVA. A one-way ANOVA was deemed appropriate for offshore monitoring meadows 2-4; however, for all coastal meadows and offshore meadow 1, transforming the data did not improve normality and homogeneity. A Kruskal-Wallis one-way ANOVA on ranks with Dunn's post-hoc comparison for unequal sample sizes was therefore conducted on these meadows. In some instances (coastal meadows 3, 5 & 7), the Kruskal-Wallis test detected a statistically significant difference between sampling periods yet the Dunn's test was unable to identify where these differences were. For these sites it was decided that a one-way ANOVA would be used to determine which sampling periods were most likely to be different from each other, noting that for these sites, the assumptions of ANOVA were not met. Sampling events at any monitoring site that had a sample size of <3, or where no seagrass was found, were not included in any of the statistical analyses. Detailed results of statistical analyses are in Appendix A.1. Statistical analysis was conducted using Genstat 14.0 and SigmaPlot 11.0.

3 RESULTS

3.1 Quarterly Assessments Of Established Monitoring Meadows

3.1.1 Seagrass species, distribution, abundance and changes

Seven seagrass species have been identified within the Abbot Point region between February/March 2008 and September 2012.

Family HYDROCHARITACEAE Jussieu:
Halophila decipiens Ostenfeld
Halophila ovalis (R. Br.) Hook. F.
Halophila spinulosa (R.Br.) Aschers. In Neumayer

Family CYMODOCEACEAE Taylor:
Halodule uninervis (wide and narrow leaf morphology) (Forsk.) Aschers. in Boissier
Cymodocea serrulata (R.Br.) Aschers and Magnus
Cymodocea rotundata Ehrenb. et Hempr. ex Aschers

Family ZOSTERACEAE Drummortier:
Zostera capricorni Aschers.

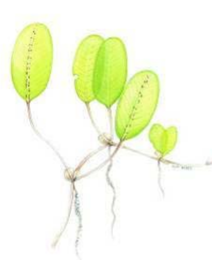
Cymodocea serrulata

Cymodocea rotundata

Halodule uninervis (wide and narrow leaf morphology)

Zostera capricorni

Halophila spinulosa



Halophila ovalis

Halophila decipiens

Prior to the La Niña-related events of 2010/11 and severe Tropical Cyclone (TC) Yasi in February 2011, there was a broad seasonal pattern at Abbot Point for seagrass biomass and distribution to be at a minimum at the end of the wet season and a maximum in late spring/early summer; a trend consistent with observations of seagrasses throughout Queensland (Figures 1 & 2; Appendices A.1–A.3). Following the summer of 2010/11, significant losses in density and distribution of seagrasses at both coastal and offshore monitoring sites were observed. There is evidence of seagrass recovery at some of the deep water monitoring sites (Figure 2); however the coastal inshore meadows have not undergone any significant recovery (Figure 1; Appendices A.1-A.3).

Coastal Monitoring Meadows

During the monitoring program Abbot Point coastal monitoring meadows at their maximum extent covered an area of 557.87 ha (Map 1). However these meadows have been highly variable in distribution and biomass between monitoring events. Meadows often disappeared at the end of the wet season and typically re-established in the spring (Figure 1; Appendix A.2). Coastal meadows in the Abbot Point area generally consisted of isolated to aggregated patches of seagrass dominated by *Halodule uninervis*, although Meadow 3 west of Euri Creek was dominated by *Zostera capricorni* (Figure 1). Seagrass above-ground biomass when present in the coastal monitoring meadows has ranged from 0.03 g DW m^2 to 8.91 g DW m^2, while the area of individual meadows when present have ranged from 1.4 ha to 127.54 ha (Figure 1; Appendix A.2).

In March 2011, following the 2010/2011 floods and TC Yasi, four of the five coastal monitoring meadows were absent and these meadows have not recovered since. Meadow 7 dominated by *Halodule uninervis* was the only meadow to persist after the floods, however by September 2012, no seagrass was recorded in any of the five coastal monitoring meadows (Figure 1; Appendices A.2 & A.3). Seed-bank assessments conducted in Meadow 3; traditionally dominated by *Zostera capricorni*, during 2012 found no *Zostera capricorni* seeds, parts of seeds or pericarps (outer casing of seed) in any sediment cores, indicating the *Zostera* seed-bank in Meadow 3 is either very poor or non-existent.

Offshore Monitoring Sites

Seagrass biomass in offshore monitoring sites was highly variable between surveys, with seagrass at some of the sites being absent for periods of time, and all meadows undergoing major declines in biomass after the 2010/2011 floods and TC Yasi (Figure 2, Appendices A.2 & A.3). Since March 2011, biomass has been slowly increasing in three of the four offshore monitoring sites (Sites 2-4), a positive sign of recovery and resilience to disturbance. For example, biomass in Site 2 adjacent to the Abbot Point jetty, increased from 0.20 ± 0.08g DW m^2 in March 2011 to 0.59 ± 0.16g DW m^2 in September 2012 (Figure 2; Appendix A.2). Seagrass at Site 1 to the west of the port facilities and ship loaders remained absent from March 2011 (post floods and cyclone). This was the only offshore site dominated by *Halodule uninervis* (Figure 2a), the same species that dominated coastal meadows. This species has struggled to recover in the Abbot Point area since the 2010/11 floods.

Changes in species composition since the 2010/2011 floods and TC Yasi has been varied in offshore sites. At Site 1 there was a sudden shift from what was traditionally a *Halodule uninervis* dominated site, to 100% cover by *Halophila spinulosa* in March 2011, the first survey after the floods (Figure 2a). Seagrass at Site 2 remained dominated by *Halophila spinulosa* immediately following the floods (March 2011). However, by May 2011 species composition had completely shifted to another pioneering species *Halophila decipiens* (Figure 2a). Since May 2011 the proportion of biomass made up by *Halophila decipiens* has gradually decreased with *Halophila spinulosa* becoming the dominant species again in 2012. The increased dominance of *Halophila spinulosa* over the last three surveys is also reflected in the increased biomass at Site 2, as *Halophila spinulosa* is a heavier species than *Halophila decipiens*. Species composition in offshore monitoring Sites 3-4 has remained relatively consistent throughout the monitoring program, with *Halophila spinulosa* generally the dominant species (Figure 2b). Interestingly, *Cymodocea serrulata* reappeared in September 2012 at Site 3 (1% of species composition). This is the first time this species has been found in any of the offshore monitoring areas since March 2011, and the first time this species has been present at Site 3 since August 2009. As a higher light requiring species this may be an indication of a general improvement in the light environment in deeper areas of Abbot Point.

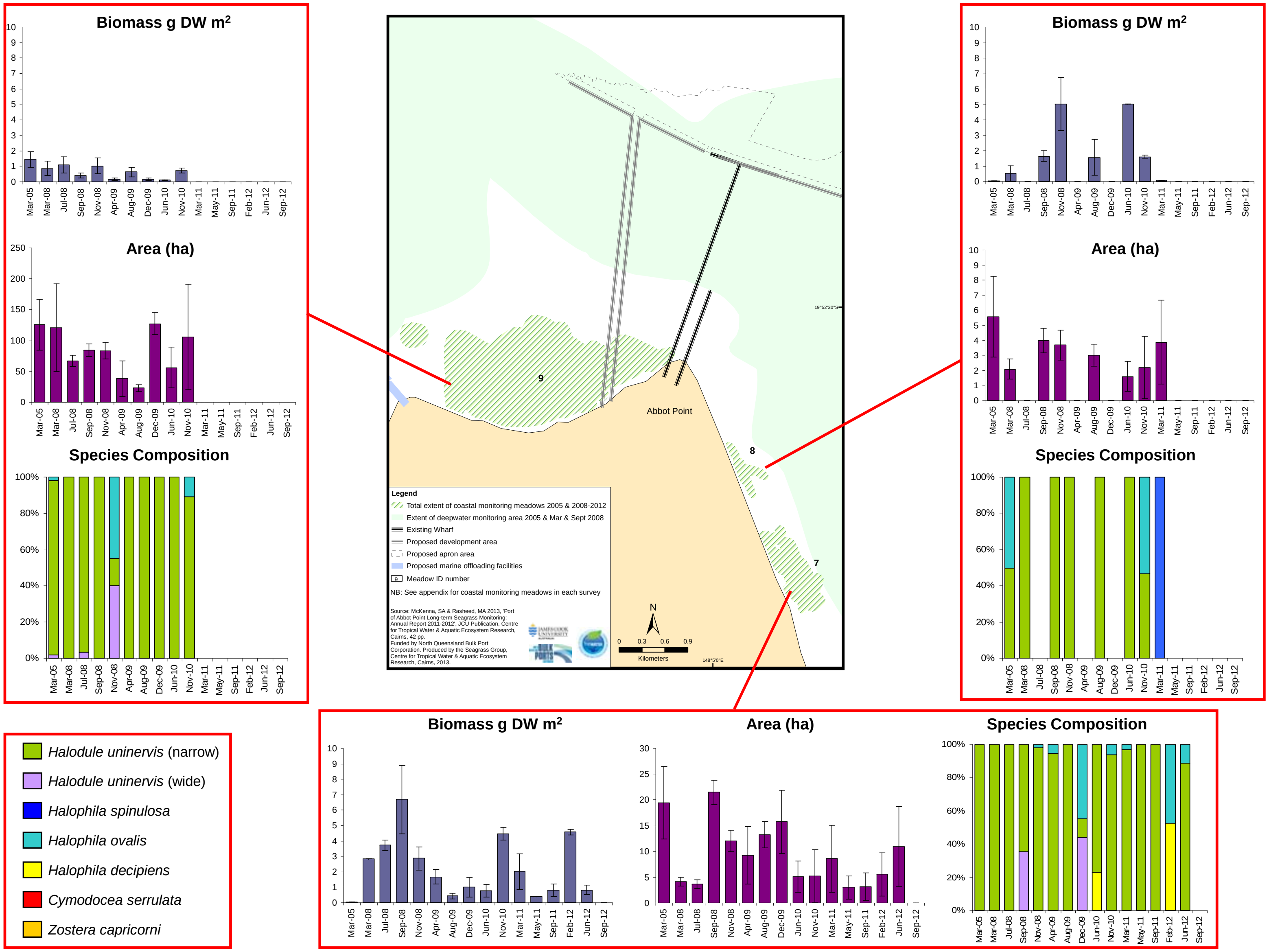


Figure 1a. Meadow biomass, area and species composition for coastal monitoring Meadows 7, 8 and 9, March 2005 - September 2011.

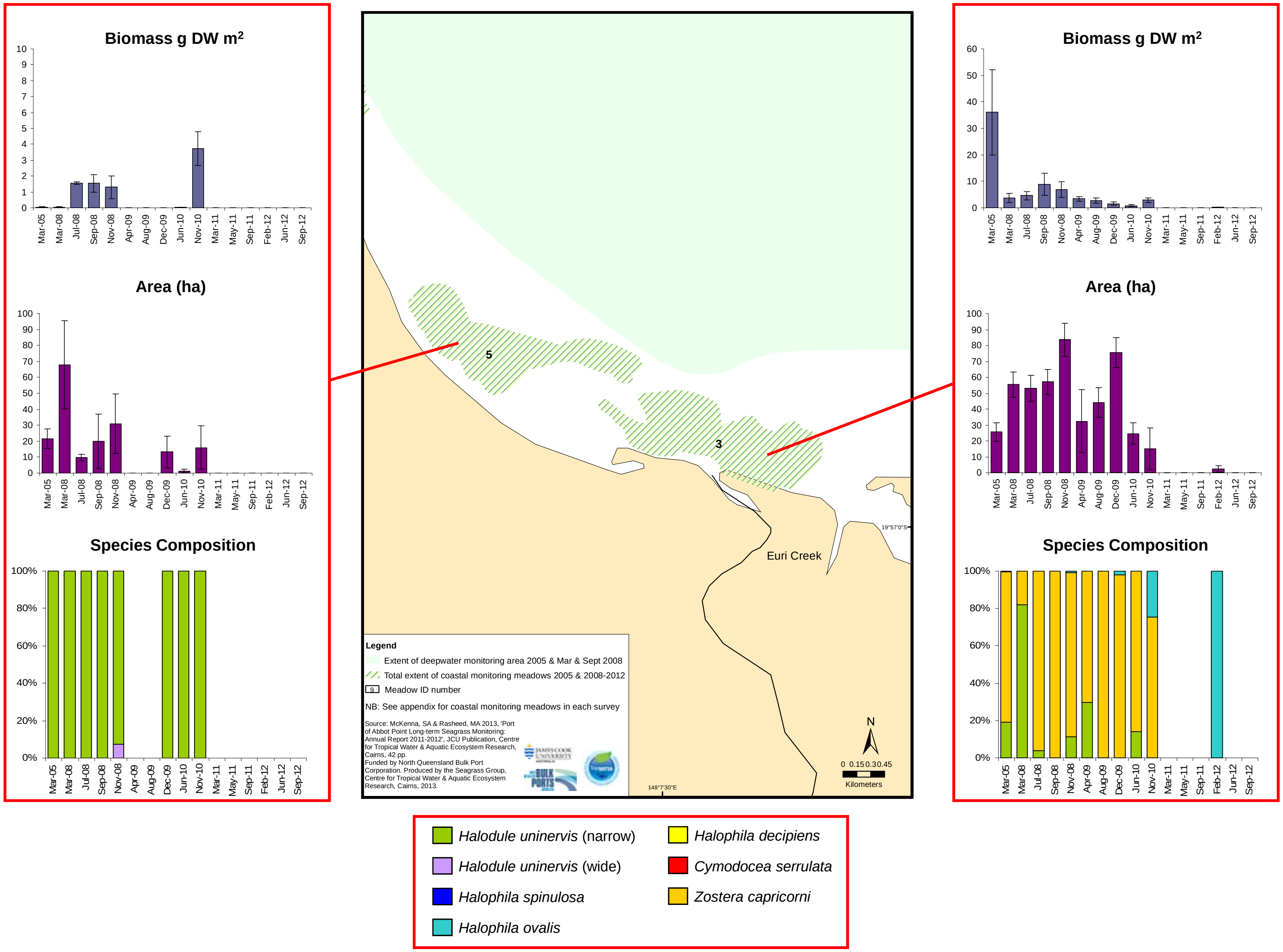


Figure 1b. Meadow biomass, area and species composition for coastal monitoring Meadows 3 and 5, March 2005 - September 2011.

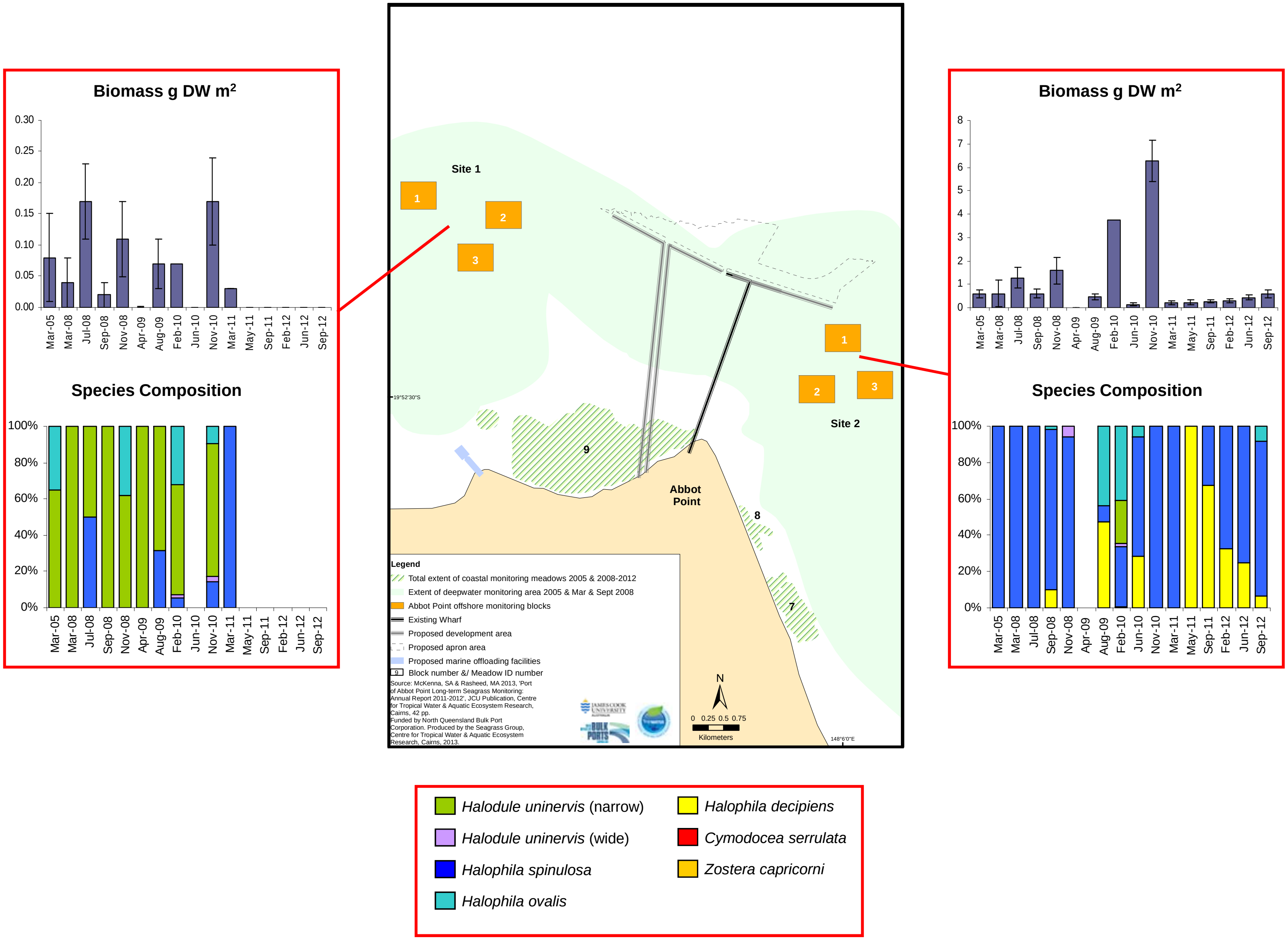


Figure 2a. Meadow biomass and species composition of seagrass in offshore monitoring Sites 1 and 2, March 2005 - September 2011.

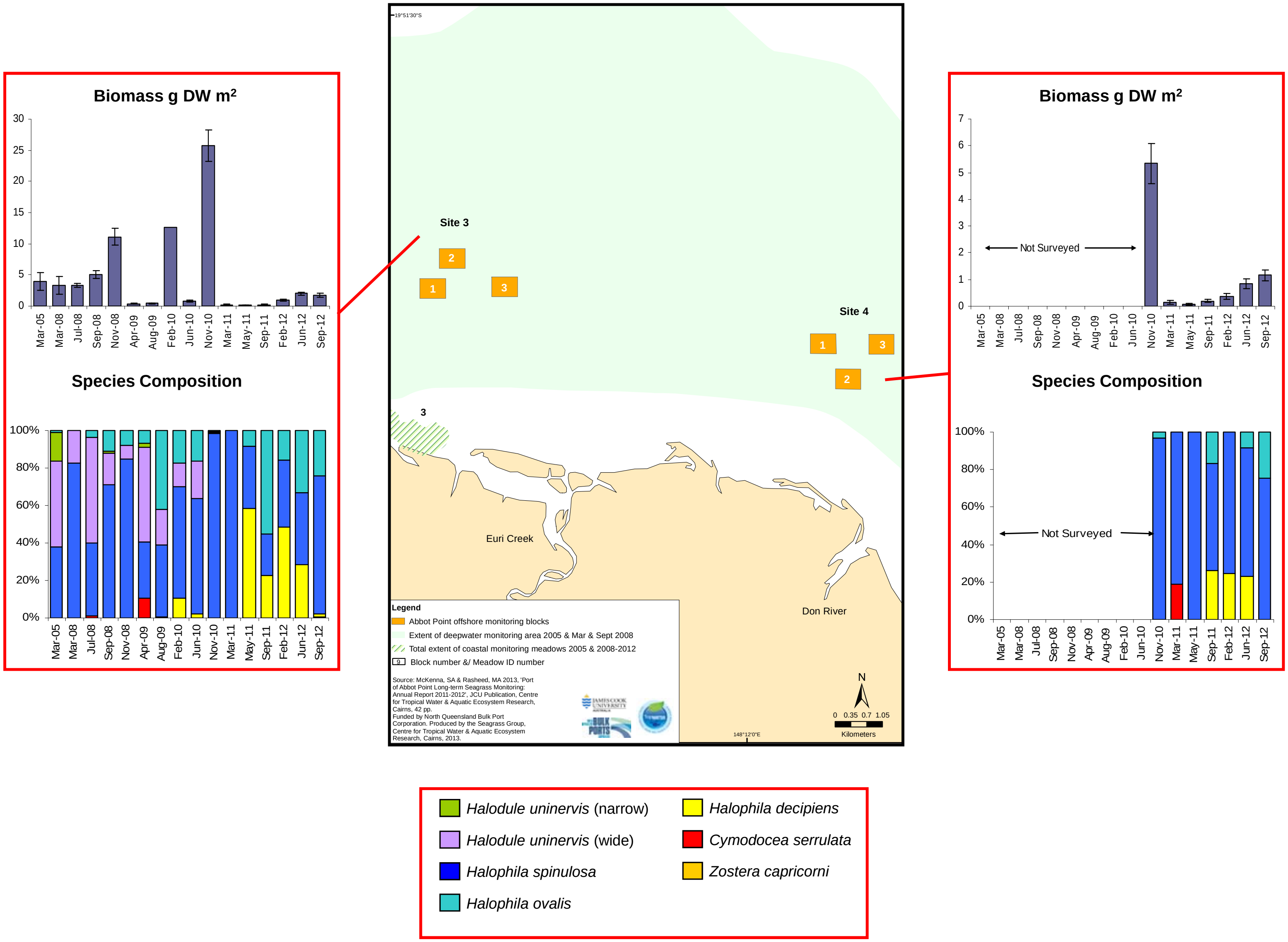


Figure 2b. Meadow biomass and species composition of seagrass in offshore monitoring Sites 3 and 4, March 2005 - September 2011.

3.2 Light (PAR) And Temperature Assessments

The amount of light that reached seagrasses varied between sites and over time. Total daily PAR levels at the seagrass sites ranged from 0 to 34 mol m^{-2} d^{-1} in coastal meadows and 0 to 12 mol m^{-2} d^{-1} in deeper offshore monitoring sites (Figure 3). Changes in PAR were strongly linked to weather and tidal patterns. PAR was generally greater in the dry season and lower in the wet season. During periods of heavy rainfall, PAR decreased at all locations. This reduction was likely due to a combination of a high cloud cover and turbidity from above average river and creek flows (Figure 3). For example, PAR levels were much reduced across all sites during the March-May 2012 period following above average rainfall and river flow in March 2012 (Figures 3-5). There was approximately 426ml of rainfall in Bowen in March 2012, nearly four times the monthly average (117ml) for this time of year (Figure 4). There was also variability in PAR within and between each of the coastal monitoring sites most likely due to influences from tidal regimes (Figure 3b). At the coastal sites, benthic PAR was highest for the shallowest site (Meadow 3) which was at least 1.5 metres shallower than the other coastal monitoring sites (Figure 3b).

Water temperature within the seagrass canopy at all monitoring sites slowly declined from February and reached a minimum in August, in line with the transition from the hot wet season to cooler dry season months (Figure 3). The maximum instantaneous water temperature recorded at the seabed at any of the sites was 33.7°C in August 2012 at coastal Meadow 3 (Euri Creek) (Figure 3b). This corresponded with a spike in PAR and a midday low tide of 0.54m (Figure 3b). Meadow 3 is the shallowest of all monitoring areas and during low tide the shallow water over the meadow can become super-heated. Maximum daily water temperature at the seabed in the deepest offshore monitoring site (Site 4; 11m below mean sea level) was 30.6°C. Generally water temperatures at deeper sites were similar to the coastal sites except that they didn't have the extreme peaks during low tides (Figure 3). Maximum daily water temperatures in the coastal meadows ranged between 29.7 – 33.7°C and 19.7 – 31.1°C for the deeper monitoring sites (Figure 3b).

Some initial equipment reliability issues resulted in missing light data for the first 12 months of the program (see Figure 3). Subsequent improvements to the design of equipment and establishing some logger redundancy should minimise future data losses.

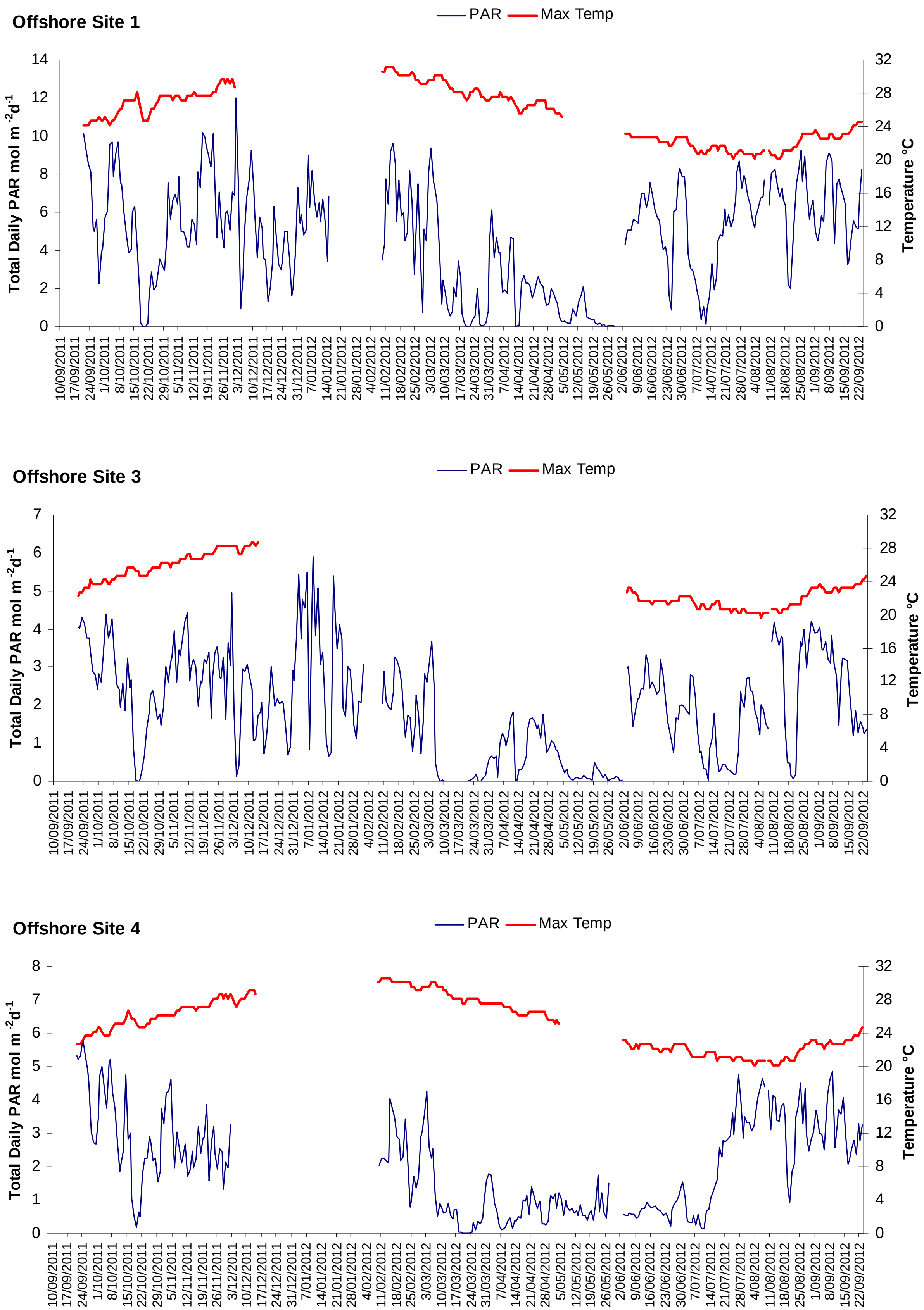


Figure 3a. Benthic total daily PAR (mol m^{-1} day^{-1}) and maximum daily water temperature (°C) recorded by *in situ* PAR and temperature loggers in the seagrass canopy of offshore monitoring sites at Abbot Point, September 2011-September 2012.

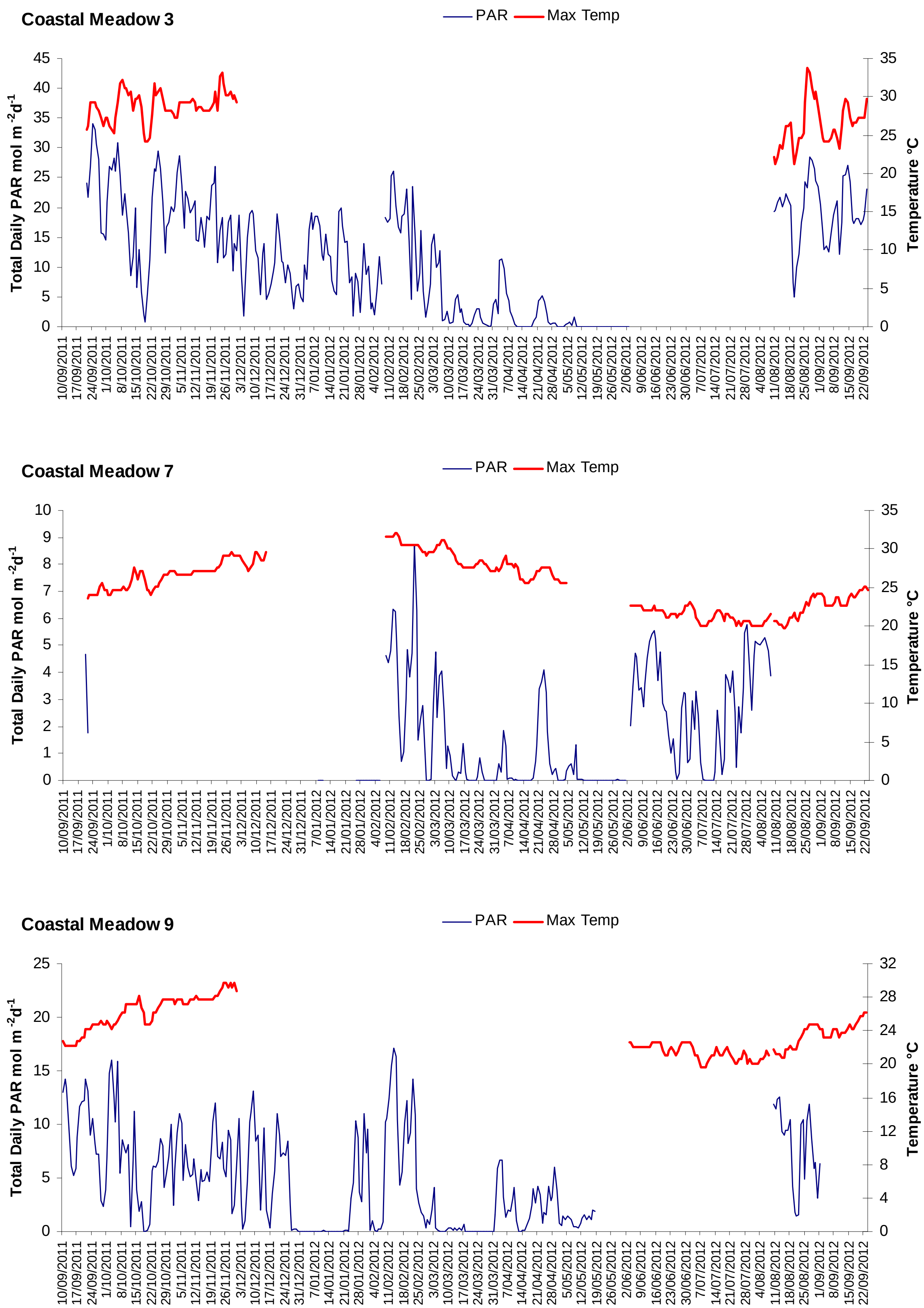


Figure 3b. Benthic total daily PAR (mol m^{-1}day^{-1}) and maximum daily water temperature (°C) recorded by *in situ* PAR and temperature loggers in the seagrass canopy of coastal inshore monitoring sites at Abbot Point, September 2011-September 2012.

3.3 General Abbot Point Climate Patterns During Monitoring

There have been numerous significant weather events that have directly affected the Bowen/Abbot Point area since the monitoring program began in February 2008. Several monsoonal troughs and cyclones have resulted in major rainfall leading to flooding, tidal surges, and high wind gusts. Of note was the development of the significant 2010 La Niña system which ran from July 2010 to June 2011 (Bureau of Meteorology 2012).

Rainfall

The La Niña system in 2010/11 was one of the strongest on record and contributed to the extremely high and prolonged rainfall experienced in Queensland from November 2010 to March 2011 (Figure 4). Since April 2011, rainfall in the Bowen area has generally remained below average, with the exception of March 2012 when rainfall was nearly four times the monthly average (Figure 4). Rainfall in July 2012 was also above the long-term average. Total annual rainfall in Bowen in the 12 months preceding the September 2012 survey was 1036.6mm, 150mm above the long-term average (Figure 4 inset).

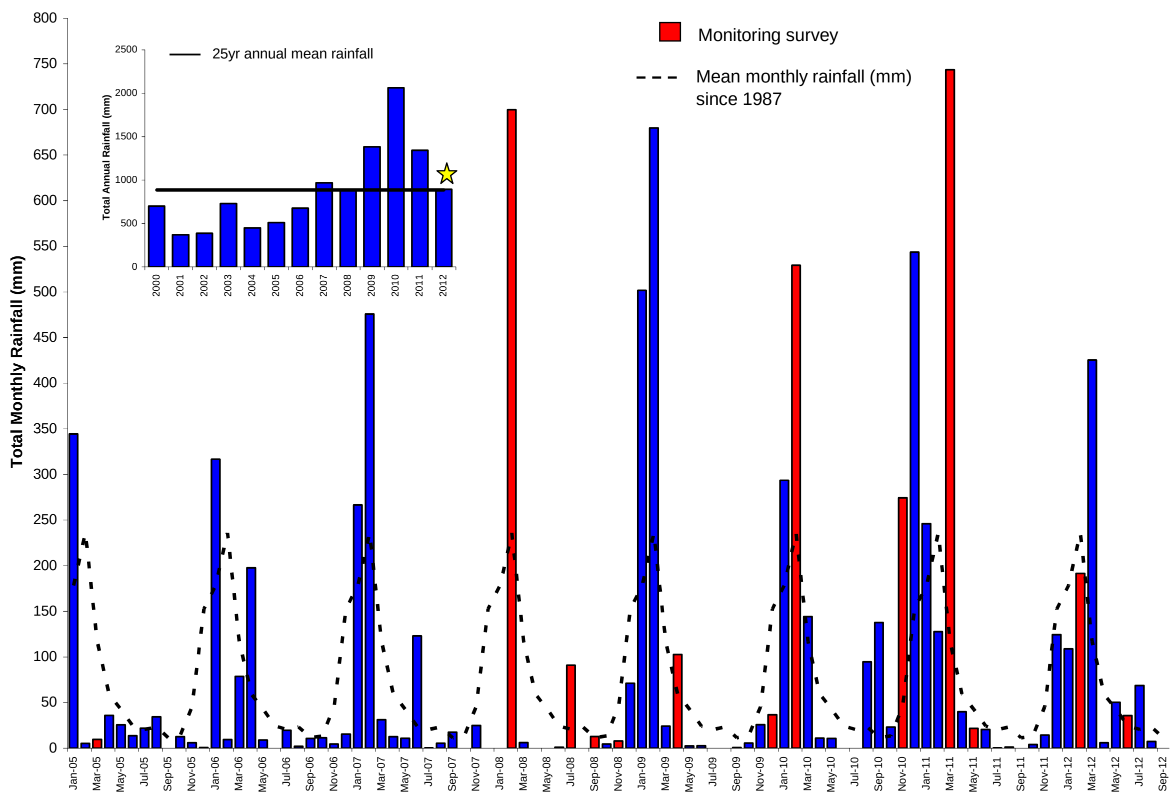


Figure 4. Total monthly rainfall (mm) from January 2005 to September 2012 and (inset) total annual rainfall from 2000 to 2012 for the Bowen area. NB ☆ : Annual value for 2012 is for January to October 2012 only. Rainfall data courtesy of Bureau of Meteorology, available at www.bom.gov.au (Station #33257).

River Flow (Don River)

The major rainfall that occurred in summer 2010/11 coincided with high flows within the Don Basin, the catchment area for Abbot Point. Don River flows exceeded monthly averages from November 2010 through to June 2011, with 2011 having the highest total annual river flow since 1991 (Figure 5). River flow remained above the long-term average until November 2011 (Figure 5). Between December 2011 and April 2012, river flow was well below the long-term monthly average but by March 2012 river flow peaked to nearly five times the long-term monthly river flow average. This coincided with above average rainfall for the same period. River flow since March 2012 returned to average values.

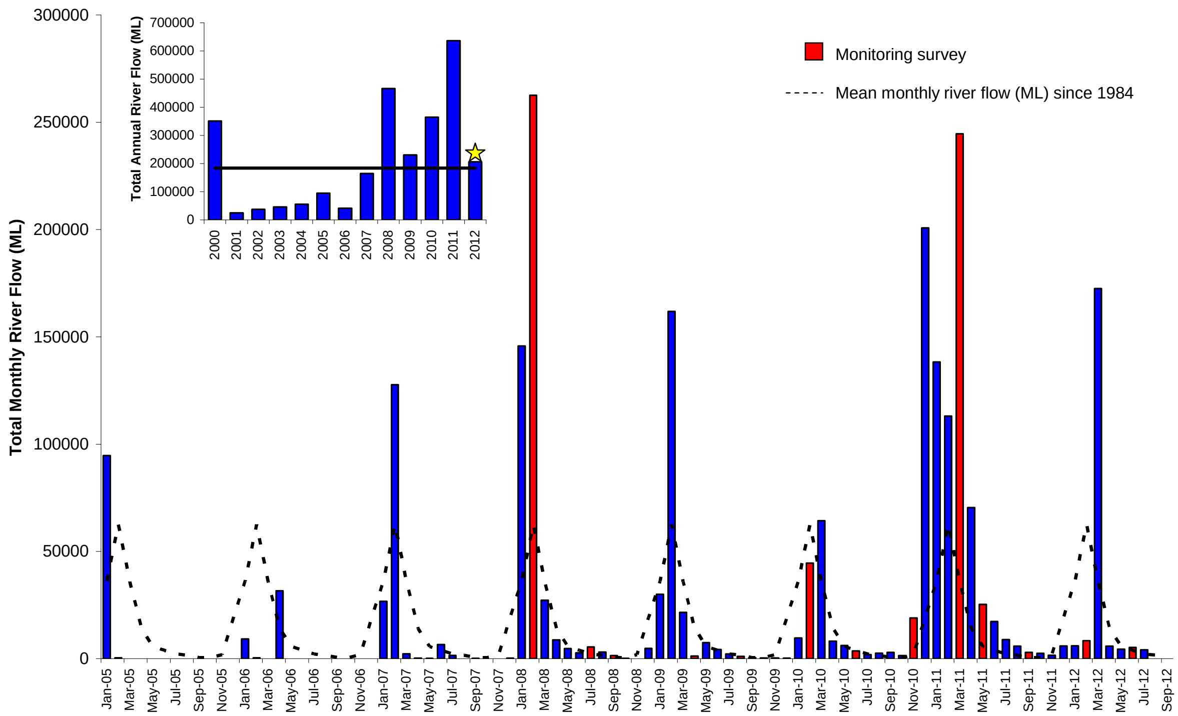


Figure 5. Total monthly river flow from January 2005 to June 2012 and (inset) total annual river flow from 2000 to 2012 for the Don River. **NB** ☆ : Annual value for 2012 is January to July 2012 only. River flow data courtesy of Department of Environment and Heritage Protection, available at www.ehp.qld.gov.au (Station #121003A).

Air Temperature

Air temperature in the Bowen area generally remained below the long-term mean monthly maximum between November 2010 and October 2011 (Figure 6). Between November 2011 and September 2012, air temperature remained at or below the long-term average for all months except February 2012, where the mean monthly temperature was slightly higher than the monthly average (Figure 6).

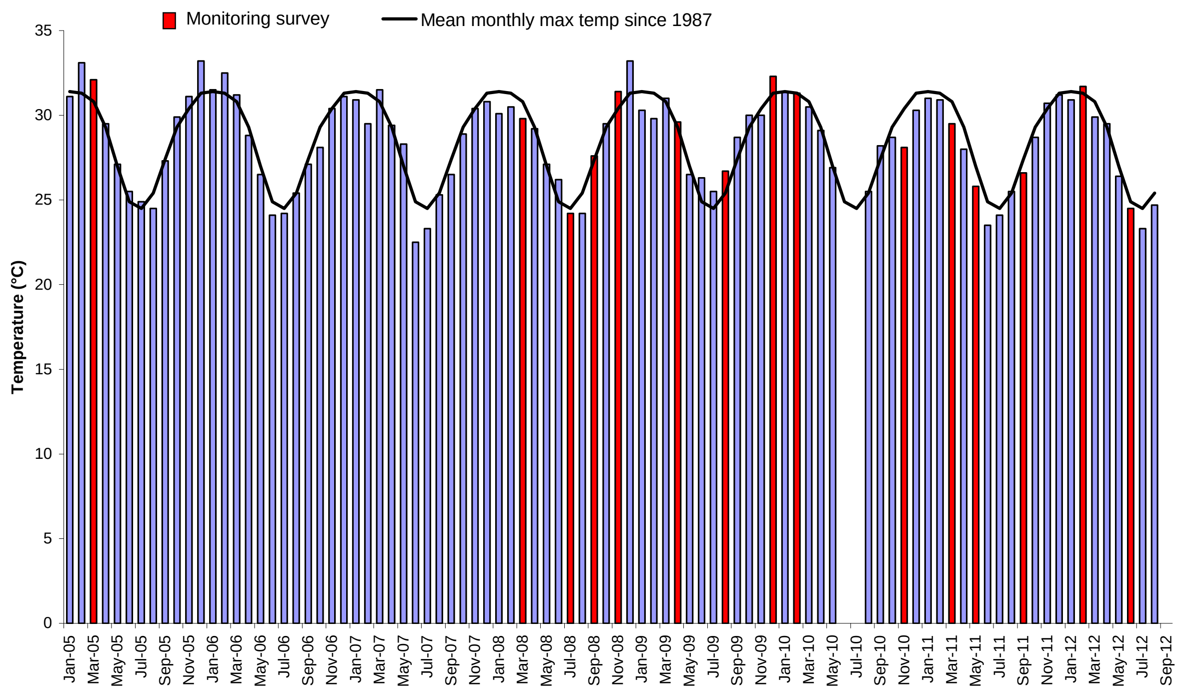


Figure 6. Mean monthly maximum air temperature between January 2005 and August 2012 for the Bowen area. Air temperature data courtesy of Bureau of Meteorology, available at www.bom.gov.au (Station #33257).

Daily Global Solar Exposure

Daily global solar exposure at Bowen ranged from 11.9 to 29.6 MJ m^{-2}, with the two highest values (29.6 MJ m^{-2}) recorded in November 2011 and November 2006 (Figure 7). Daily global solar exposure is a measure of the total amount of solar energy falling on a horizontal surface in one day. The values were usually highest in clear sun conditions during the spring/summer prior to the wet season beginning and lowest during winter (Figure 7).

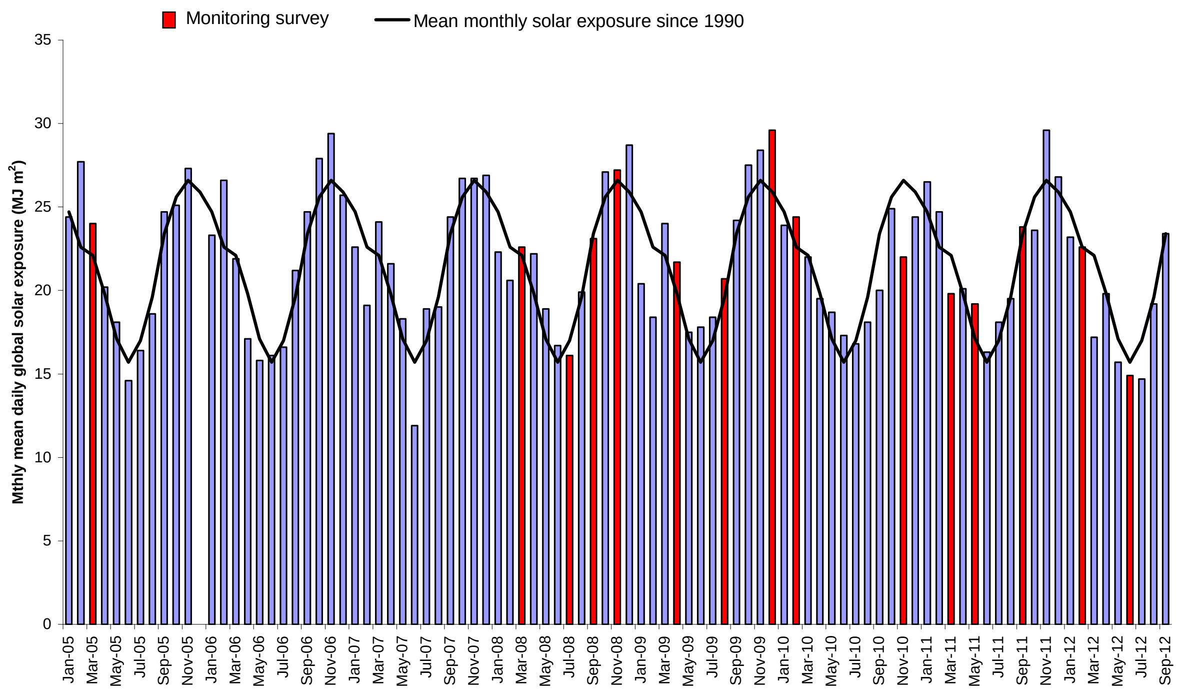


Figure 7. Mean monthly daily global solar exposure (MJ m^{-2}) between January 2005 and September 2012 for the Bowen area. Global solar exposure data courtesy of Bureau of Meteorology, available at www.bom.gov.au (Station #33257).

4 DISCUSSION

Significant losses of seagrass density and distribution at Abbot Point were observed after the 2010/11 La Niña events and Tropical Cyclone Yasi. Since that time recovery of seagrass has occurred at some of the deep water monitoring sites however, the coastal inshore meadows have not had any significant recovery. These results indicate that coastal seagrasses in particular are likely to have a low resilience to further impacts It has been estimated that across Queensland, approximately 98% of intertidal seagrass area in the regions directly affected by the path of TC Yasi (Lucinda to Innisfail) was lost as a consequence of destructive winds, and only a few isolated shoots remained in many coastal and reef habitats (McKenzie et al. 2012). The cumulative impacts of multiple above average wet seasons may have potentially reduced the resilience and capacity for recovery of Abbot Point coastal seagrasses and made seagrasses more susceptible to wet season conditions compared to previous years.

Although coastal habitats along the Queensland coast are regularly exposed to flooding and cyclones, the scale and longevity of the 2010/11 La Niña events were unprecedented. Storms and cyclones have the potential to negatively impact seagrass either physically (burial, scouring, direct removal of plants and seed-banks) (Preen et al. 1995; Bach et al. 1998; Campbell & McKenzie 2004) or physiologically (light limitation, excess nutrients and changes in salinity) (Björk et al. 1999; Ralph et al. 2007; Chartrand et al. 2012). The quality and quantity of light is a critical determinant of seagrass growth and abundance (Ralph et al. 2007) and low light levels associated with coastal rainfall and river plumes are thought to be the primary factor limiting the growth of many coastal seagrasses (Waycott et al. 2005). Studies of seagrasses in tropical regions have indicated that genera such as *Zostera* and *Halodule* have significantly greater light requirements (Grice et al 1996; Bach et al. 1998; Longstaff & Dennison 1999; Longstaff 2003; Collier et al. 2009) than other genera such as *Halophila* species (Udy & Levy 2002; Fourqurean et al. 2003; Freeman et al. 2008). At Abbot Point it has been the higher light requiring species; *Zostera capricorni* and *Halodule uninervis* that have been most affected with many inshore areas and one offshore area previously dominated by these species being lost.

Recent studies in Gladstone have indicated that *Zostera capricorni* requires 6 mol m^{-2} d^{-1} of light during the 'growing' season (Jul – Jan for Gladstone seagrasses) sustained over a minimum period of two weeks to effectively grow (Chartrand et al. 2012). Similarly, Collier et al. (2012) reported that losses of more than 50% of *Halodule uninervis* meadows at Magnetic Island occurred when average PAR fell below 5.2 mol m^{-2} d^{-1}, and suggested that the loss in seagrass observed was as a result of low light. As low light conditions are prolonged, growth rates slow and plants drop leaves and shoots, thus reducing their abundance (Ralph et al. 2007; Collier et al. 2012). At Abbot Point, monthly mean light levels at the two inshore *Halodule uninervis* dominated sites where PAR was recorded ranged between 0.31 - 6.6 mol m^{-2} d^{-1} in the wet season and between 2.1 – 9.11 mol m^{-2} d^{-1} in the dry season. PAR levels were below 5.2 mol m^{-2} d^{-1} for up to 30 days in both the wet and dry seasons. This may potentially mean that *Halodule uninervis* at Abbot Point was already living close to their minimum light requirements prior to impacts caused by the 2010/11 floods and TC Yasi and were less likely to be able to deal with further light reductions associated with the storm effects.

During the last seagrass growing season (July to January), light levels at the Abbot Point *Zostera capricorni* meadow (meadow 3) were likely to be above the minimum requirement for seagrass growth based on research for the same species in Gladstone (Chartrand et al. 2012). Mean daily PAR for this period at Abbot Point was 16.13 mol m^{-2} d^{-1} and light did not fall below Chartrand et al's (2012) 6 mol m^{-2} d^{-1} requirement for longer than 4 days. The fact that *Zostera* was unable to recover during this period is probably due to the lack of available propagules (seeds or remaining adult plants). This meadow was completely lost after the 2010/2011 floods and cyclones, and recent examinations found that there was no seagrass seed bank for this meadow. The nearest population of *Zostera capricorni* from which recruitment could occur is in Upstart Bay to the North which would make re-establishment difficult.

The large deeper offshore seagrass meadows in Abbot Point have had a much more successful recovery than the coastal meadows. These meadows are dominated by *Halophila* species which initially underwent significant declines in biomass post flooding and TC Yasi, but unlike the coastal meadows, have shown recovery. This loss and recovery is typical for *Halophila* species which are well adapted to low light conditions (Udy & Levy 2002; Fourqurean et al. 2003) but are quick to decline when stressed by adverse conditions (Longstaff & Dennison 1999). The life history strategy of *Halophila* species means they are well adapted for recovery once conditions become favourable again, as they are fast growing and rapid colonisers (Hammerstrom et al. 2006; Unsworth et al. 2010), producing large numbers of long lived seeds (McMillan 1991, Hammerstrom & Kenworthy 2003, Hammerstrom et al. 2006). These seeds can lie dormant in a sediment “seed bank” for at least two years and it is likely the recovery of these meadows at Abbot Point resulted from such seed banks.

There is little information available on the light requirements for *Halophila* species in subtidal meadows, although it is clear these species have a lower light requirement than the larger growing species such as *Zostera* and *Halodule* that dominate the shallower “higher light” areas of Abbot Point. Estimates of light availability in *Halophila spinulosa* meadows in Moreton Bay indicate that the species can survive at light intensities of less than six per cent surface irradiance (Udy and Levy 2002). In Abbot Point monthly mean light levels in the offshore sites dominated by *Halophila* species ranged between 0.55 – 3.3 mol m^{-2} d^{-1} in the wet season and 0.28 – 4.5 mol m^{-2} d^{-1} in the dry season. These lower light levels in deeper water areas are well below the requirements for *Zostera* and *Halodule* which explain the dominance of lower light requiring *Halophila* species at these sites.

Lack of recovery for the coastal seagrass meadows may be a result of a limited availability of seeds. As previously discussed, the light environment post floods should have been sufficient to support seagrass recovery. Substantial seed-banks have been documented elsewhere in Queensland for *Halodule* (Townsville 7,000/m^2; McKenzie et al. 2010) and *Zostera* (Gladstone 700-900/m^2; McCormack et al. 2012). Although this is not a uniform phenomenon, with many other meadows and locations appearing to have limited or no seed-banks present, such as *Halodule* meadows in Gladstone (McCormack 2012) and mixed species seagrass meadows offshore from Cairns (Rasheed 2004). The assessments of seed banks at Abbot Point over a 13 month period found only very low densities of seeds for *Halodule uninervis* (maximum of 1.33 seeds m^2) and no *Zostera capricorni* seeds in the Euri Creek meadow in a survey conducted in June 2012. To date, no seed bank assessments for the offshore *Halophila* meadows have been undertaken.

Data from the Reef Rescue Marine Monitoring Program has found that the number of seeds and reproductive effort of *Halodule uninervis* and *Zostera capricorni* at Townsville monitoring sites has been steadily declining in recent years (McKenzie et al. 2012). Flooding and cyclones may result in seed-banks being removed or buried by deposited sediments (e.g. Preen et al. 1995; Campbell & McKenzie 2004) which may also have occurred at Abbot Point following the cyclone.

Seagrasses can recover from loss by two main mechanisms: vegetative growth (asexual reproduction) and recruitment from propagules (seeds/sexual reproduction). Recovery by sexual reproduction is particularly important when there is complete loss of plants, as may have been the case for *Zostera capricorni* and *Halodule uninervis* at Abbot Point. It has been established that coastal meadows dominated by *Halodule uninervis* at Abbot Point are likely to have a strong reliance on asexual reproduction for recovery from losses (Unsworth et al. 2010). The same results were found for *Halodule uninervis* in the Torres Strait (Taylor et al. 2012) and for *Zostera capricorni* in Cairns (Rasheed 2004). Long-term recovery in the absence of rhizome or asexual propagules (seagrass fragments) would therefore be dependent on the supply of seeds. Recolonisation by drifting vegetative fragments can possibly occur, but this may be only a very low frequency event (Rasheed 2004). In contrast, the deep water *Halophila* meadows at Abbot Point recovered quickly from experimental disturbance (3 months) through a combination of sexual and asexual reproduction, indicating a greater capacity for meadow recovery from larger scale disturbances (Unsworth et al. 2010) The recent post flood results in the monitoring program support this.

The likely high reliance of *Halodule uninervis* and *Zostera capricorni* on asexual reproduction for recovery combined with the lack of seed-banks/reserves of these species at Abbot Point has important implications for recovery potential and suggests that re-establishing these meadows may be a slow process.

Implications for Port Management

The declines in Abbot Point seagrasses over recent years mean they are likely have a reduced resilience to further impacts and stressors. Results of the latest surveys indicate that the inshore coastal seagrass meadows have yet to show any recovery. In contrast, the offshore *Halophila* meadows have shown some good initial recovery during 2012 but had yet to reach pre-cyclone levels. Future port activities and development should consider the current state of seagrass resilience as part of ongoing management strategies.

Seagrass distribution, density, composition and health are strongly influenced by a range of environmental conditions, and disturbance related events that lead to an imbalance in their environmental requirements (Collier & Waycott 2009). Although port activities during the life of the monitoring program (since 2008) are unlikely to have had substantial long-term impacts on seagrasses in the area, the scale and duration of planned developments for the port that include capital dredging programs have a greater potential to impact seagrasses especially combined with the generally reduced state of resilience for most meadows.

In response to this, several initiatives have been included in the Abbot Point seagrass monitoring program to ensure relevant information is available to manage seagrasses and ensure impacts from future port activity on seagrasses are minimised. These include an examination of the light requirements and capacity for recovery of the key species so that appropriate management thresholds are developed to maintain the ability of seagrasses to grow and continue to recover. The available information indicates that it would be critical to manage the local water quality (particularly light availability) at Abbot Point in a way that ensures the long-term viability of remaining adult populations of coastal seagrass, particularly *Halodule uninervis* and *Zostera capricorni*, as no or very minimal seed-banks are present for these species at Abbot Point. Hydrodynamic modelling for planned capital dredging at Abbot Point, indicates that dredge related turbid plumes are not expected to reach the coastal meadows that have been most effected by recent climate impacts (CDM Smith 2013) but instead will be more localised over deeper offshore seagrasses that have shown some recovery.

The current monitoring program at Abbot Point provides a sound basis for developing effective light management triggers for both the offshore and coastal seagrass meadows that are appropriate to the ecological requirements of local seagrass species. There is data on the light requirements of *Halodule uninervis* (Collier et al. 2012) and *Zostera capricorni* (Chartrand et al. 2012) at other ports in Queensland however, light requirements of species may be regionally variable and these light requirement values may not apply specifically to Abbot Point seagrasses. Light data currently being collected at Abbot Point combined with regular assessments of seagrass change provide a good framework to develop a light requirements management approach, although some additional *in situ* or laboratory based experimental research may also be needed and could be added to the program if required.

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A APPENDICES

A.1 Statistical Analysis

Table 1. Results of Kruskal-Wallis One-way ANOVA of Ranks showing the sample size (N = sampling events), H statistic, degrees of freedom (df) and significance (P) of the difference among mean above-ground biomass versus time (sampling events) at coastal monitoring Meadow 9 and offshore site 1.

Location	N	H	df	P
Coastal Meadow 9	10	21.75	9	<0.05
Offshore Site 1	4	5.42	3	>0.05

Results of a Dunn's pairwise multiple comparison showing whether the difference between time (sampling events) was significant (YES) or not significant (NO) at P <0.05 at Coastal Meadow 9.

Sampling Time	Mar-05	Mar-08	Jul-08	Sep-08	Nov-08	Apr/May 09	Aug-09	Dec-09	Jun-10	Nov-10
Mar-05										
Mar-08	NO									
Jul-08	NO	NO								
Sep-08	NO	NO	NO							
Nov-08	NO	NO	NO	NO						
Apr/May 09	NO	NO	NO	NO	NO					
Aug-09	NO	NO	NO	NO	NO	NO				
Dec-09	NO	NO	NO	NO	NO	NO	NO			
Jun-10	NO	NO	NO	NO	NO	NO	NO	NO		
Nov-10	NO	NO	NO	NO	NO	NO	NO	YES	NO	

NB – no seagrass was present at Meadow 9 for sampling times in Mar 11, May 11, Sep 11, Feb 12, Jun 12, Sep 12 so these months did not get tested.

Table 2. Results of one-way ANOVA tests for mean above-ground biomass versus time (sampling events) for coastal monitoring meadows 3, 5 & 7.

NB – these monitoring meadows failed both the normality test and equal variance test. A Kruskal-Wallis one-way ANOVA of variance on ranks was then used. When doing a Kruskal-Wallis one-way ANOVA, a statistically significant difference was detected however pairwise multiple comparison tests failed to detect what sampling events were significantly different. Because of this an ANOVA was used and pairwise comparison done on the ANOVA.

Coastal Meadow 3

Source of variation	d.f.	s.s.	m.s.	f.	p.
Between Groups	9	6742.26	749.14	6.92	<0.001
Residual	116	12556.11	108.24		
Total	125	19298.37			

Results of a pairwise multiple comparison showing whether the difference between time (sampling events) was significant (YES) or not significant (NO) at P <0.05 at Coastal Meadow 3.

Sampling Time	Mar-05	Mar-08	Jul-08	Sep-08	Nov-08	Apr/May 09	Aug-09	Dec-09	Jun-10	Nov-10
Mar-05										
Mar-08	YES									
Jul-08	YES	NO								
Sep-08	YES	NO	NO							
Nov-08	YES	NO	NO	NO						
Apr/May 09	YES	NO	NO	NO	NO					
Aug-09	YES	NO	NO	NO	NO	NO				
Dec-09	YES	NO	NO	NO	NO	NO	NO			
Jun-10	YES	NO	NO	NO	NO	NO	NO	NO		
Nov-10	YES	NO	NO	NO	NO	NO	NO	NO	NO	

Coastal Meadow 5

Source of variation	d.f.	s.s.	m.s.	f.	p.
Between Groups	5	16.51	3.30	3.55	<0.05
Residual	27	25.08	0.93		
Total	32	41.59			

NB - Significant difference detected however pairwise comparisons could not detect where the differences were.

Coastal Meadow 7

Source of variation	d.f.	s.s.	m.s.	f.	p.
Between Groups	9	333.82	37.09	3.20	<0.05
Residual	69	800.51	11.60		
Total	78	1134.32			

Results of a pairwise multiple comparison showing whether the difference between time (sampling events) was significant (YES) or not significant (NO) at P <0.05 at Coastal Meadow 7.

Sampling Time	Jul-08	Sep-08	Nov-08	Apr/May 09	Aug-09	Dec-09	Jun-10	Nov-10	Mar-11	Jun-12
Jul-08										
Sep-08	NO									
Nov-08	NO	NO								
Apr/May 09	NO	NO	NO							
Aug-09	NO	YES	NO	NO						
Dec-09	NO	YES	NO	NO	NO					
Jun-10	NO	YES	NO	NO	NO	NO				
Nov-10	NO	NO	NO	NO	NO	NO	NO			
Mar-11	NO	NO	NO	NO	NO	NO	NO	NO		
Jun-12	NO	NO	NO	NO	NO	NO	NO	NO	NO	

Table 3. Results of t test showing the significance (P) for difference in seagrass mean biomass between November 2008 and March 2011 for coastal monitoring Meadow 8.

Coastal Meadow 8

Sampling Event	T	N (small)	N (big)	Man U statistic	P
Nov 08 vs Mar 11	18	3	4	0.0	>0.05

Sampling Event	N	Median	25%	75%	P
Nov 2008	3	6.65	1.57	6.82	>0.05
March 2011	4	0.07	0.07	0.07	

Table 4. Results of one-way ANOVA tests for mean above-ground biomass versus time (sampling event) for offshore monitoring sites 2 – 4 at Abbot Point.

Offshore site 2

Source of variation	d.f.	s.s.	m.s.	v.r.	p.
Year	14	16.4763	1.1769	4.83	<0.001
Residual	118	28.7430	0.2436		
Total	132	45.2193			

Results of Least Significant Difference (LSD) pairwise comparisons of mean above-ground biomass versus time (sampling event) for Offshore Site 2. Means that share a common letter for each sampling event are not significantly different.

Sampling Period	Mean Biomass
April 2009	0.0000 a
June 2010	0.1114 a
March 2011	0.1703 a
May 2011	0.1940 a
Sept 2011	0.2273 a
Feb 2012	0.2575 a
March 2005	0.2608 a
March 2008	0.2941 a
Aug 2009	0.3184 a
June 2012	0.3365 a
July 2008	0.3994 a
Sept 2008	0.4126 a
Sept 2012	0.4269 a
Nov 2008	0.5737 a
Nov 2010	1.5797 b

Offshore site 3

Source of variation	d.f.	s.s.	m.s.	v.r.	p.
Year	14	80.0174	5.7155	12.55	<0.001
Residual	120	54.6683	0.4556		
Total	134	134.6857			

Results of Least Significant Difference (LSD) pairwise comparisons of mean above-ground biomass versus time (sampling event) for Offshore Site 3. Means that share a common letter for each sampling event are not significantly different.

Sampling period	Mean Biomass
May 2011	0.0882 a
Sept 2011	0.1495 a
March 2011	0.1703 a
April 2009	0.2835 a
Aug 2009	0.3332 ab
June 2010	0.5248 ab
Feb 2012	0.6182 abc
Sept 2012	0.8885 abcd
March 2005	0.9120 abcd
March 2008	0.9333 abcd
June 2012	0.9852 abcd
July 2008	1.3978 bcd
Sept 2008	1.6592 cd
Nov 2008	1.8944 d
Nov 2010	2.9977 e

Offshore site 4

Source of variation	d.f.	s.s.	m.s.	v.r.	p.
Year	6	16.2130	2.7022	13.34	<0.001
Residual	56	11.3446	0.2026		
Total	62	27.5576			

Results of Least Significant Difference (LSD) pairwise comparisons of mean above-ground biomass versus time (sampling event) for Offshore Site 4. Means that share a common letter for each sampling event are not significantly different.

Sampling Period	Mean Biomass
May 2011	0.0588 a
March 2011	0.1147 a
Sept 2011	0.1498 a
Feb 2012	0.2539 a
June 2012	0.4667 a
Sept 2012	0.6154 a
Nov 2010	1.6258 b

A.2 Abundance And Distribution Comparisons 2005 - 2012

A. Mean above-ground biomass (g DW m^{-2}) of coastal monitoring meadows within the Port of Abbot Point, March 2005, February 2008 – September 2012.

Mean Biomass ± SE (g DW m^{-2}) (no. sites present in meadow)					
Meadow #	**3**	**5**	**7**	**8**	**9**
Mar 05	0.09 ± 0.03 (6)	0.03 ± 0 (1)	0.06 ± 0 (1)	0.03 ± 0 (1)	1.63 ± 0.54 (16)
Mar 08	3.71 ± 1.72 (8)	0.05 ± 0.02 (9)	2.84 ± 0 (1)	0.52 ± 0.52 (2)	0.86 ± 0.47 (17)
Jul 08	4.55 ± 1.68 (15)	1.57 ± 0.08 (3)	3.72 ± 0.33 (4)	NP	1.10 ± 0.53 (12)
Sep 08	8.91 ± 4.17 (11)	1.54 ± 0.57 (6)	6.7 ± 2.21 (12)	1.65 ± 0.33 (2)	0.40 ± 0.15 (17)
Nov 08	6.98 ± 2.95 (14)	1.34 ± 0.71 (6)	2.87 ± 0.74 (9)	5.01 ± 1.72 (3)	1.02 ± 0.51 (20)
Apr 09	3.34 ± 0.95 (9)	NP	1.68 ± 0.46 (8)	NP	0.17 ± 0.08 (10)
Aug 09	2.76 ± 0.99 (14)	NP	0.43 ± 0.18 (7)	1.57 ± 1.18 (2)	0.63 ± 0.30 (23)
Dec 09	1.59 ± 0.55 (31)	0.005 ± 0.003 (5)	1.0 ± 0.62 (13)	NP	0.15 ± 0.08 (15)
Jun 10	0.84 ± 0.4 (13)	0.06 ± 0 (1)	0.76 ± 0.4 (4)	5.04 ± 0 (1)	0.11 ± 0.02 (6)
Nov 10	2.92 ± 0.86 (5)	3.74 ± 1.06 (3)	4.46 ± 0.41 (3)	1.61 ± 0 (2)	0.73 ± 0.16 (12)
Mar 11	NP	NP	2.03 ± 1.16 (5)	0.07 ± 0 (4)	NP
May 11	NP	NP	0.40 ± 0 (1)	NP	NP
Sept 11	NP	NP	0.69 ± 0.4 (3)	NP	NP
Feb 12	0.23 ± 0 (1)	NP	4.58 ± 0.19 (3)	NP	NP
Jun 12	NP	NP	0.82 ± 0.31 (5)	NP	NP
Sep 12	NP	NP	NP	NP	NP

NP – No seagrass present in meadow

B. Area (ha) of coastal monitoring meadows within the Port of Abbot Point, March 2005, February 2008 – September 2012.

Area ± R (ha)						
Meadow #	**3**	**5**	**7**	**8**	**9**	**TOTAL meadow area**
Mar 05	25.6 ± 6	21.5 ± 6.1	19.5 ± 7.1	5.6 ± 2.7	125.8 ± 41	**198 ± 62.9**
Mar 08	55.5 ± 8	67.9 ± 27.6	4.2 ± 0.9	2.1 ± 0.7	120.8 ± 71.4	**250.5 ± 108.6**
Jul 08	53.1 ± 8.3	9.7 ± 1.9	3.6 ± 0.9	NP	67.0 ± 9	**133.4 ± 20.1**
Sep 08	56.95 ± 8.06	19.83 ± 17.1	21.47 ± 2.38	4 ± 0.81	83.96 ± 10.26	**186.21 ± 38.61**
Nov 08	83.6 ± 10.5	30.9 ± 18.6	12 ± 2.1	3.7 ± 1	83.1 ± 13.1	**213.3 ± 45.3**
Apr 09	32.4 ± 19.9	NP	9.2 ± 5.6	NP	38.20 ± 28.7	**79.8 ± 54.2**
Aug 09	44.2 ± 9.3	NP	13.2 ± 2.6	3 ± 0.7	22.9 ± 5.1	**83.3 ± 17.7**
Dec 09	75.4 ± 9.3	13.3 ± 10.1	15.7 ± 6.2	NP	127.5 ± 17.8	**231.9 ± 43.4**
Jun 10	24.6 ± 6.8	1.4 ± 1	5.1 ± 3	1.6 ± 1	56.3 ± 33.3	**89 ± 45.1**
Nov 10	15.04 ± 13.2	16.04 ± 13.67	5.25 ± 5.09	2.18 ± 2.07	105.38 ± 85.44	**143.89 ± 119.47**
Mar 11	NP	NP	8.58 ± 6.46	3.88 ± 2.78	NP	**12.46 ± 9.24**
May 11	NP	NP	3.01 ± 2.23	NP	NP	**3.01 ± 2.23**
Sep 11	NP	NP	3.12 ± 2.66	NP	NP	**3.12 ± 2.66**
Feb 12	2.48 ± 2.05	NP	5.55 ± 4.16	NP	NP	**8.03 ± 6.21**
Jun 12	NP	NP	10.97 ± 7.79	NP	NP	**10.97 ± 7.79**
Sep 12	NP	NP	NP	NP	NP	NP

NP – No seagrass present in meadow

C. Mean above-ground biomass (g DW m-2) of offshore monitoring sites in the Port of Abbot Point, March 2005, February 2008 – September 2012.

Sampling Date	**Mean Biomass ± SE (g DW m^{-2})** (dominating seagrass species)			
	Site 1	**Site 2**	**Site 3**	**Site 4**
Mar 05*	0.08 ± 0.07 (*Halodule uninervis* (thin))	0.59 ± 0.15 (*Halophila spinulosa*)	3.98 ± 1.43 (*Halophila spinulosa/Halodule uninervis* (wide))	Site not established
Feb/Mar 08*	0.04 ± 0.04 (*Halodule uninervis* (thin))	0.60 ± 0.57 (*Halophila spinulosa*)	3.28 ± 1.38 (*Halophila spinulosa*)	Site not established
Jul 08	0.17 ± 0.06 (*Halodule uninervis* (thin) & *Halophila spinulosa*)	1.27 ± 0.44 (*Halophila spinulosa*)	3.31 ± 0.38 (*Halodule uninervis* (wide))	Site not established
Sept 08	0.02 ± 0.02 (*Halodule uninervis* (thin))	0.61 ± 0.17 (*Halophila spinulosa*)	5.10 ± 0.65 (*Halophila spinulosa*)	Site not established
Nov 08	0.11 ± 0.06 (*Halodule uninervis* (thin) & *Halophila ovalis*)	1.58 ± 0.55 (*Halophila spinulosa*)	11.07 ± 1.33 (*Halophila spinulosa*)	Site not established
Apr/May 09	0.0006 ± 0.0006 (*Halodule uninervis* (thin))	NP	0.34 ± 0.06 (*Halodule uninervis* (wide))	Site not established
Aug 09	0.07 ± 0.04 (*Halodule uninervis* (thin) & *Halophila ovalis*)	0.46 ± 0.11 (*Halophila spinulosa*)	0.45 ± 0.09 (*Halophila spinulosa*)	Site not established
Feb 10**	0.07 ± (*Halodule uninervis* (thin) & *Halophila ovalis*)	3.75 ± (*Halophila ovalis/Halophila spinulosa*)	12.69 ± (*Halophila spinulosa/Halophila ovalis*)	Site not established
June 10	NP	0.14 ± 0.05 (*Halophila spinulosa*)	0.77 ± 0.12 (*Halophila spinulosa*)	Site not established
Nov 10	0.17 ± 0.07 (*Halodule uninervis* (narrow))	6.26 ± 0.89 (*Halophila spinulosa*)	25.76 ± 2.52 (*Halophila spinulosa*)	5.34 ± 0.76 (*Halophila spinulosa*)
Mar 11	0.03 ± 0 (*Halophila spinulosa*)	0.20 ± 0.08 (*Halophila spinulosa*)	0.20 ± 0.08 (*Halophila spinulosa*)	0.14 ± 0.06 (*Halophila spinulosa & Cymodocea serrulata*)
May 11	NP	0.23 ± 0.09 (*Halophila decipiens*)	0.20 ± 0.08 (*Halophila decipiens*)	0.07 ± 0.05 (*Halophila spinulosa*)
Sep 11	NP	0.26 ± 0.07 (*Halophila decipiens/Halophila spinulosa*)	0.18 ± 0.06 (*Halophila ovalis*)	0.19 ± 0.06 (*Halophila spinulosa*)
Feb 12	NP	0.31 ± 0.09 (*Halophila spinulosa /Halophila decipiens*)	0.97 ± 0.17 (*Halophila decipiens /Halophila spinulosa*)	0.37 ± 0.10 (*Halophila spinulosa /Halophila decipiens*)
Jun 12	NP	0.44 ± 0.09 (*Halophila spinulosa /Halophila decipiens*)	1.97 ± 0.24 (*Halophila spinulosa Halophila ovalis/Halophila decipiens*)	0.83 ± 0.18 (*Halophila spinulosa /Halophila ovalis*)
Sep 12	NP	0.59 ±0.16 (*Halophila spinulosa*)	1.76 ± 0.26 (*Halophila spinulosa Halophila ovalis*)	1.16 ± 0.21 (*Halophila spinulosa Halophila ovalis*)

* - Mar 05 & Feb/Mar 08 surveys were Baseline surveys so the location of Monitoring Blocks were not established thus Biomass is derived from transects in the baseline survey that were located closest to monitoring blocks that were established in July 2008.

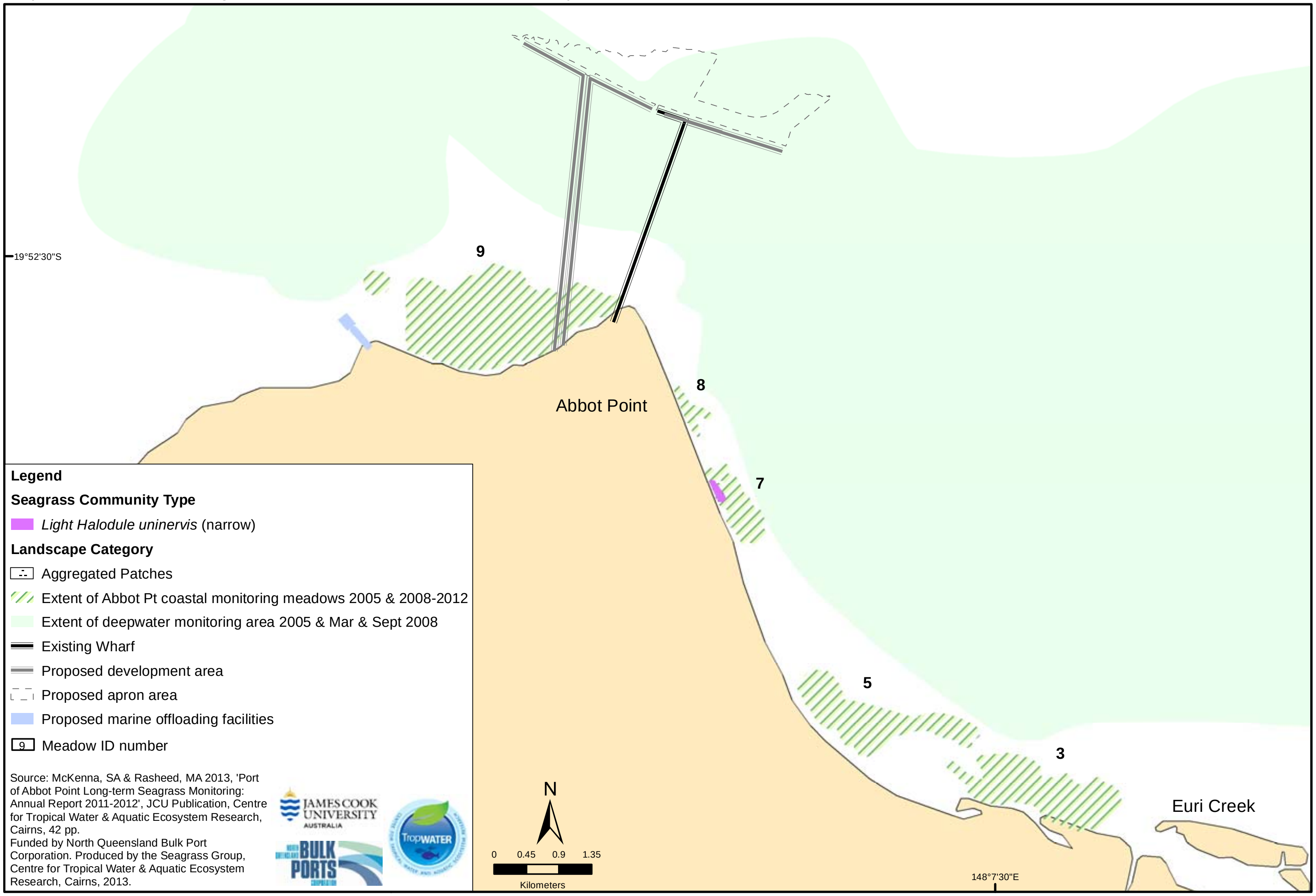
** - No visibility at any of the monitoring sites; Biomass calculations approximate only: Biomass derived from calculation of shoot counts converted to biomass based on biomass and shoot relationships of similar meadow and species composition

NP – No seagrass present in monitoring blocks

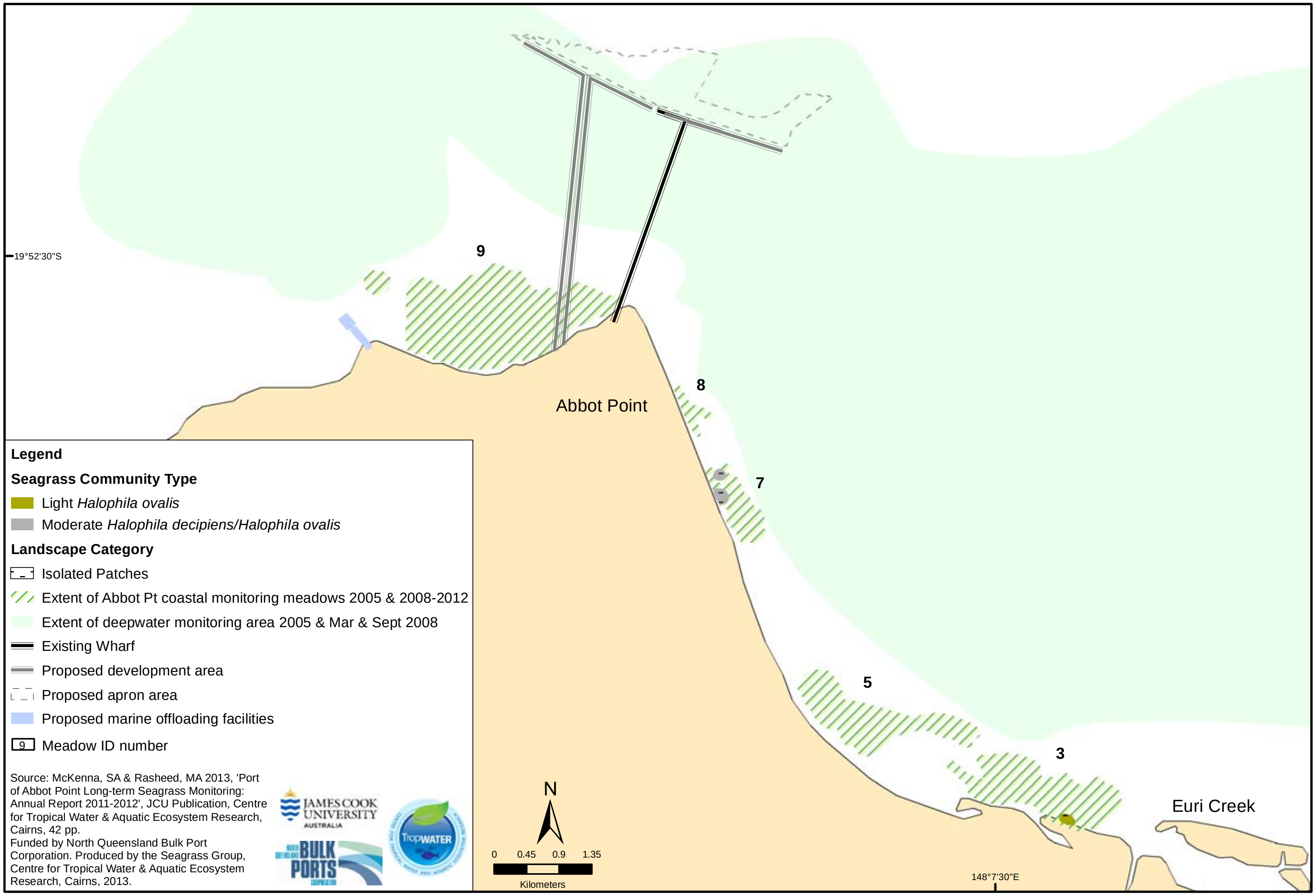
A.3 Seagrass Distribution Maps

Coastal monitoring meadow community type, landscape category and distribution within the Port of Abbot Point, September 2011 – September 2012: Maps 2-5.

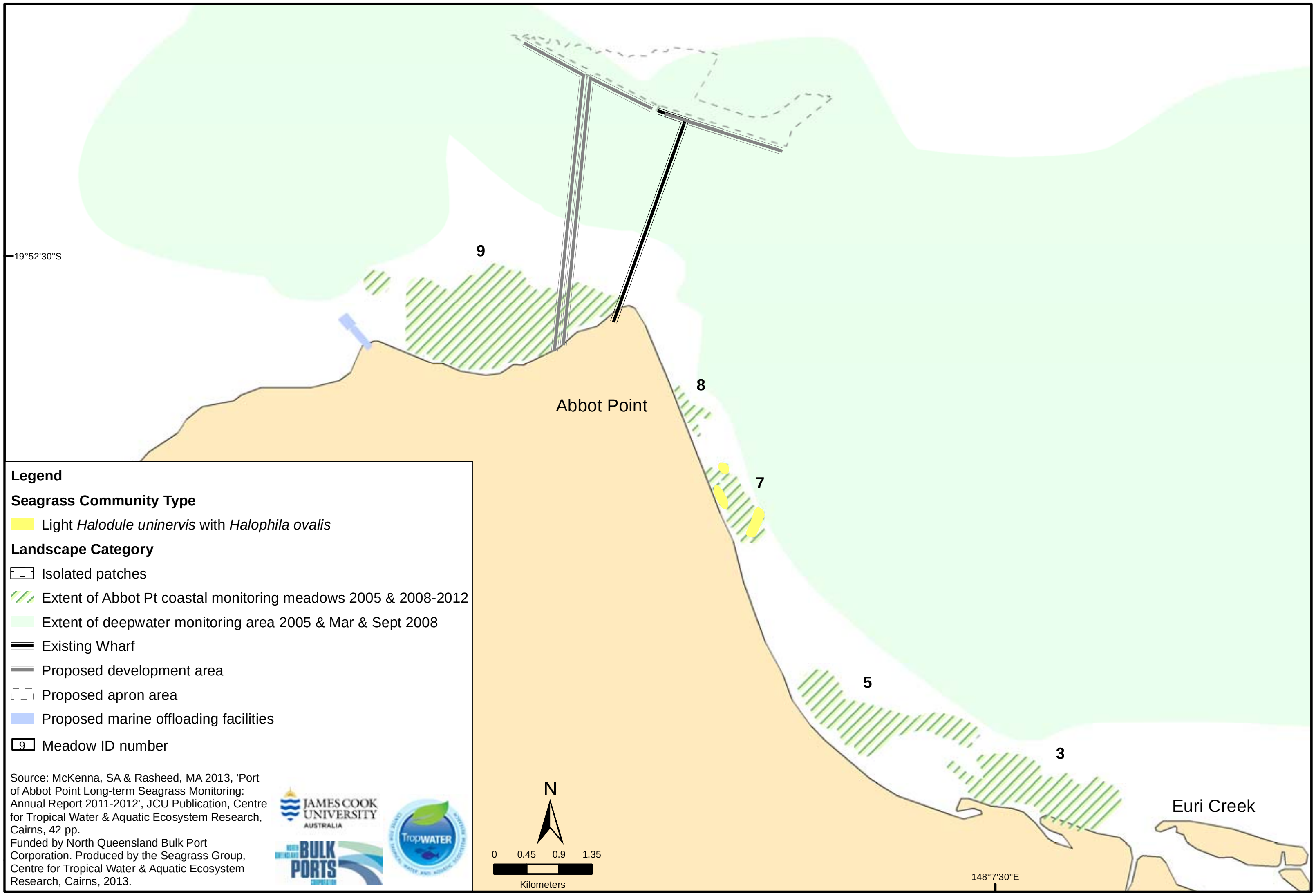
Map 2. Coastal monitoring meadows in the Port of Abbot Point September 2011



Map 3. Coastal monitoring meadows in the Port of Abbot Point February 2012



Map 4. Coastal monitoring meadows in the Port of Abbot Point June 2012



Map 5. Coastal monitoring meadows in the Port of Abbot Point September 2012