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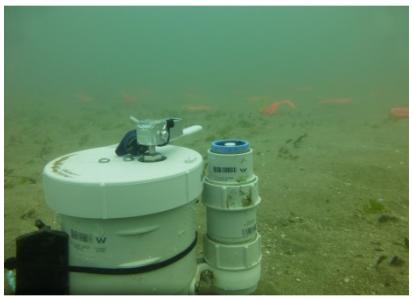
PORT OF ABBOT POINT LONG-TERM SEAGRASS MONITORING:

ANNUAL REPORT 2012 - 2013

McKenna SA & Rasheed MA

Report No. 13/44

March 2014



PORT OF ABBOT POINT LONG-TERM SEAGRASS MONITORING: ANNUAL REPORT 2012-2013

A Report for North Queensland Bulk Ports Corporation (NQBP)

Report No. 13/44

March 2014

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KEY FINDINGS

1. Seagrasses have been monitored quarterly at Abbot Point since 2008 with additional broader regional seagrass surveys conducted in 2008 and 2013.
2. After 18 months of recovery deep water seagrass underwent declines through 2013 following Tropical Cyclone Oswald and associated rainfall, high winds and flooding.
3. Inshore monitoring meadows have yet to show substantial recovery but in 2013 there were some initial signs of recovery with small amounts of *Halodule uninervis* present at two of the inshore meadows.
4. The density of deep water seagrass in the broader port limits dramatically declined in the 2013 baseline surveys compared with the last regional baseline surveys conducted in 2008. Similarly the density of seagrass at inshore meadows in the broader region declined from dry season 2008 to dry season 2013.
5. The total extent of all seagrass meadows in the broader Abbot Point area declined by 60% between the 2008 and 2013 wet season surveys. However by the 2013 dry season survey, total meadow area had increased again to be similar to the 2008 dry season.
6. The first ever recorded occurrence of *Halophila tricostata* in the Abbot Bay/Bowen area was made in the September 2013 baseline survey.
7. The broader scale baselines in 2013 have found meadows of the key inshore species *Halodule uninervis* and *Zostera muelleri* near to Abbot Point that could provide a means of recovery for Abbot Point meadows through dispersal of seeds and other propagules.
8. Light (Photosynthetically Active Radiation) monitoring indicated that during the seagrass growing season in the second half of 2013, the amount of light available was favourable for seagrass growth at both inshore and offshore sites. While some seagrass recovery was observed the lack of recovery at other meadows was likely due to a lack of available propagules (seeds, fragments, adult plants).
9. 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 need to be considered in conjunction with future developments associated with port expansions in formulating management strategies to protect seagrasses.
10. Assessments of seagrass seed banks and their viability will be a key addition to the monitoring program in 2014 to understand their resilience to impacts and potential for recovery.

IN BRIEF

Seagrasses have been monitored quarterly in the Port of Abbot Point since 2008. Each quarter seagrass monitoring meadows representing the range of different seagrass community types found in the Abbot Point area are mapped and assessed for changes in area (inshore meadows only), biomass (density) and species composition. In addition to monitoring meadow assessments, in 2013 all seagrasses within the broader port limits were re-mapped as an update to the wet and dry season baseline surveys last conducted in 2008.

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 (Figure 1). Similar declines to seagrasses were also seen in other areas of tropical eastern Queensland including Cairns, Mourilyan Harbour, Townsville and Gladstone.

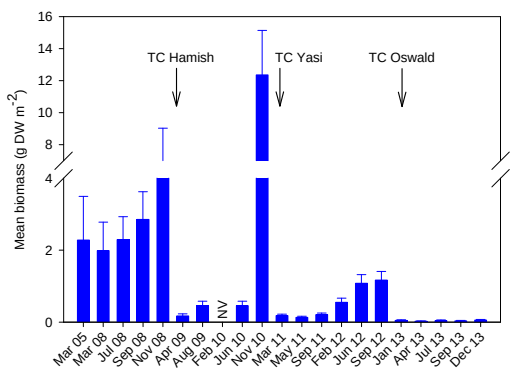


Figure 1. Mean biomass (gDWm^{-2}) of Abbot Point offshore seagrass monitoring sites from 2005 to 2013 (NV – no visability at deep water sites)

Despite encouraging signs of deep water seagrass recovery after TC Yasi, deep water seagrass declined in density again through 2013 following Tropical Cyclone Oswald and associated rainfall, high winds and flooding (Figure 1). In contrast, since April 2013, three of the five coastal monitoring meadows have had seagrass present, and although still dominated by the colonising *Halophila* species, small amounts of *Halodule uninervis* have returned to a couple of the meadows.

Mapping of deep water seagrass density in the broader port limits reflected the results found in the quarterly deep water monitoring surveys. The density of deep water seagrass in the broader port limits dramatically declined in the 2013 baseline surveys compared with the last seasonal baseline surveys conducted in 2008. Similarly the density of seagrass at inshore meadows declined from dry season 2008 to dry season 2013. This decline at inshore meadows correlated with a change in meadow species composition. By 2013 there was a reduction in the amount of larger species; *Halodule uninervis* and *Zostera muelleri* present in the meadows, and a higher dominance of the smaller *Halophila* species at the inshore meadows.

In terms of mapped area, the total extent of all seagrass meadows in the broader Abbot Point area combined, declined by 60% between the 2008 and 2013 wet season surveys (Map 1). This loss in meadow area was mainly due to the loss of some of the larger offshore meadows on the western side of Abbot Point and also the loss of the inshore monitoring meadows. By the 2013 dry season survey, total meadow area in the broader Abbot Point area had increased to values similar to those seen in the 2008 dry season.

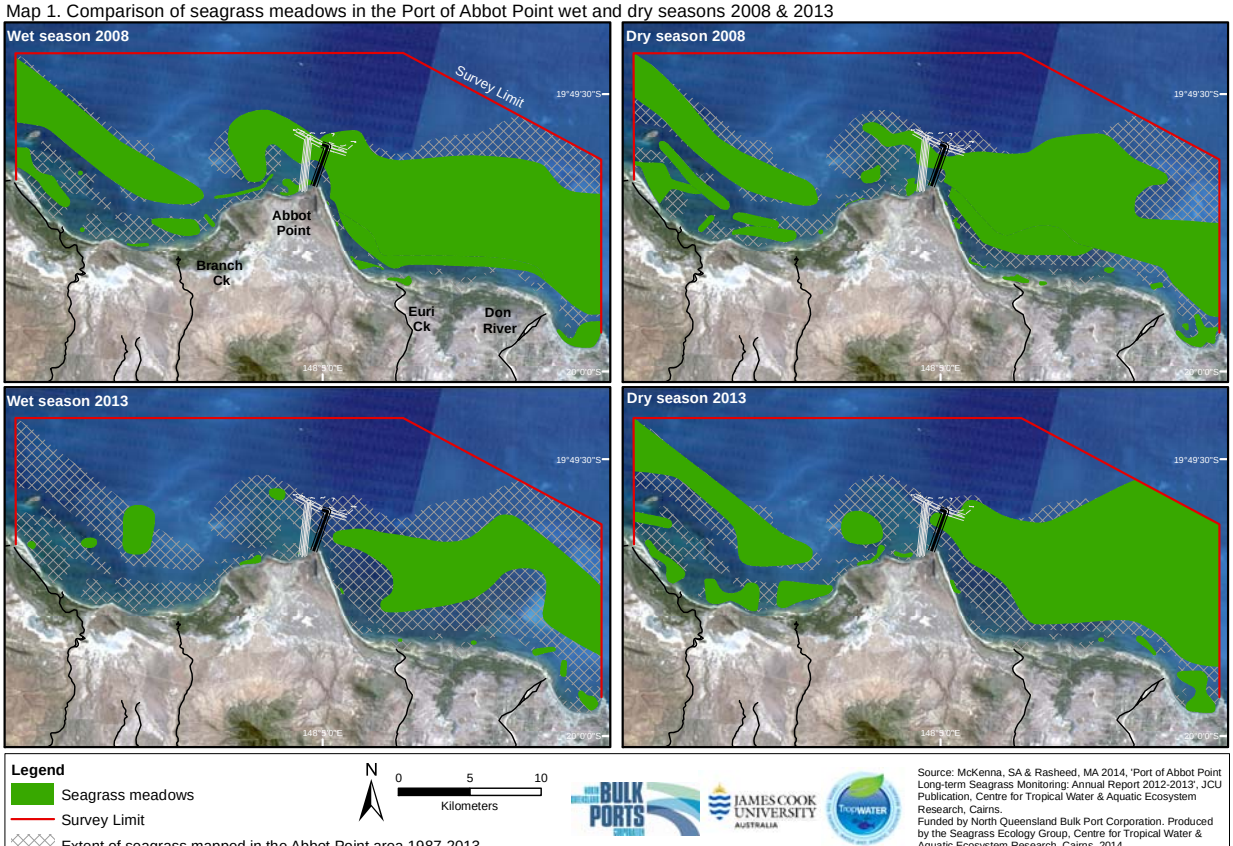
Monitoring of light (Photosynthetically Active Radiation) available to seagrasses around Abbot Point during 2013 indicates that light availability was likely to be favourable for seagrass growth, particularly in the latter half of the year when mean PAR at monitoring sites was higher, coinciding with the seagrass growing season, compared to available PAR the beginning of the year. The amount of PAR available to seagrasses in the Abbot Point area was similar and comparable to the light environments at other areas of deep water seagrass where PAR is monitored including Green Island off Cairns and Lizard Island in the northern Great Barrier Reef.

Multiple seagrass declines over the last 5 years are likely to have left a legacy of reduced resilience of seagrasses to further impacts. The cumulative impacts of natural stressors when combined with future developments associated with port expansions have the potential to impact seagrasses. Several initiatives have been included in the monitoring program or are soon to be added 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. In addition during 2014, assessments of seed banks and viability, and reproductive capacity will be added to the program so that appropriate management thresholds are developed to maintain the ability of seagrasses to grow and continue to recover.

The Abbot Point seagrass monitoring program forms part of a broader Queensland program that examines condition of seagrasses in the majority of Queensland commercial ports and is a component of James Cook University's (JCU) broader seagrass assessment and research program. Seagrasses in Western Cape York, the Torres Strait and the Gulf of Carpentaria were generally in a good condition which is in stark contrast to seagrasses on the east coast of Queensland that were severely impacted by unfavourable climate events and cyclones and remained in a vulnerable condition in 2013/14 such as Mourilyan Harbour, Cairns, and Townsville. For full details of the Queensland ports seagrass monitoring program see www.jcu.edu.au/portseagrassqld.

Map 1. Comparison of seagrass meadows in the Port of Abbot Point wet and dry seasons 2008 & 2013



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1 INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem services including coastal protection, support of fisheries production, nutrient cycling and particle trapping (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 (McLeod et al. 2011; Fourqurean et al. 2012; Macreadie et al. 2013). Seagrass meadows show measurable responses to changes in water quality, making them ideal candidates for monitoring the long-term health of marine environments (Dennison et al. 1993; Abal and Dennison 1996; Orth et al. 2006).

1.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program has been established in the majority of Queensland commercial ports. The program was developed by the Seagrass Ecology Group at James Cook University's Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) (Formally part of Fisheries Queensland/DAFF) in partnership with the various Queensland port authorities. While each location is funded separately and they have a range of requirements for use of the information, a common methodology and rationale is utilised to provide a network of seagrass monitoring locations throughout the state (Map 2).

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

A strategic long-term assessment and monitoring program for seagrasses in port locations provides mangers and regulators with the key information to ensure that seagrasses and ports can co-exist as well as information to plan and implement port development and maintenance programs that will have a minimal impact on seagrasses. In addition, as an excellent integrator of impacts to water quality, seagrasses provide an ideal indicator of overall marine environmental health of the port (Dennison et al. 1993). The program also provides an ongoing assessment of many of the most threatened seagrass communities in the state.

The program not only delivers key information for the management of port activities to minimise impacts on seagrasses but has also resulted in significant advances in the science and knowledge of tropical seagrass ecology. It has been instrumental in developing tools, indicators and thresholds for the protection and management of seagrasses and an understanding of the drivers of tropical seagrass change. It provides a measure of the marine environmental health of the ports as well as feeding into regional assessments of the status of seagrasses.

For more information on the program and reports from the other monitoring locations see www.jcu.edu.au/portseagrassqld

1.2 Abbot Point Seagrass Monitoring Program

North Queensland Bulk Ports Corporation (NQBP) in partnership with the Seagrass Ecology Group at TropWATER have been engaged in a seagrass assessment and monitoring program at Abbot Point since 2008, with the program currently ongoing. This program has involved four baseline surveys (two each in 2008 & 2013) of the marine habitat within the port limits, manipulative experimental research of the seagrass at the port, long-term monitoring of representative seagrass meadows at inshore coastal and

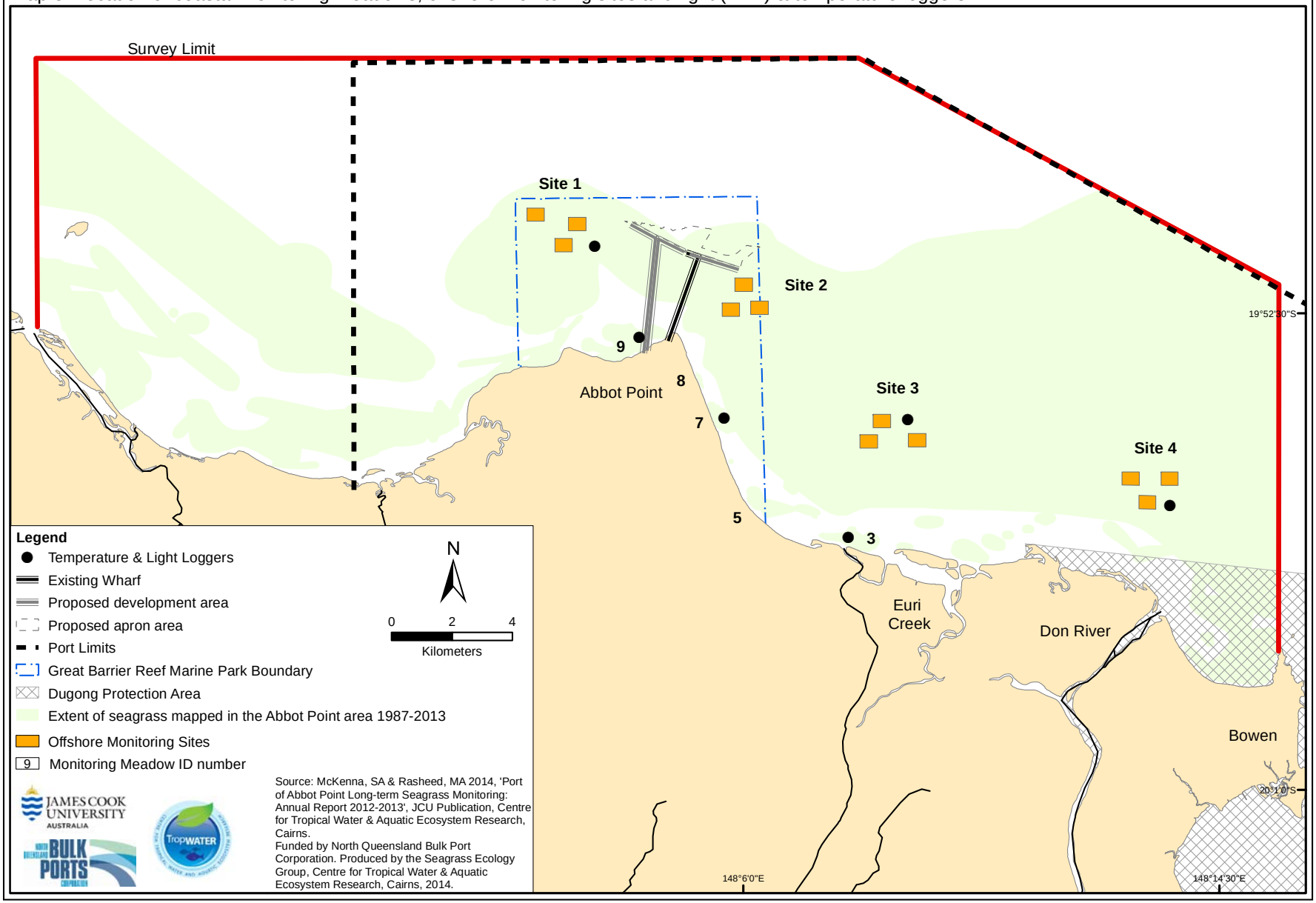
offshore areas, and light (Photosynthetically Active Radiation (PAR)) and temperature assessments at the seabed (McKenna et al. 2008; Unsworth et al. 2010; Mckenna & Rasheed 2013; Rasheed et al. 2014) (Map 3). The long-term monitoring areas represent the range of seagrass communities within the port 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) (Map 3). Quarterly monitoring of seagrass habitat within the port has continued since 2008.

The program was developed to aid in the management of planned port expansions and to minimise potential impacts of port activities on seagrass habitats, and to assess the long-term condition and trend of this important fisheries habitat. Seagrass monitoring surveys satisfy environmental monitoring requirements as part of the port's long-term dredge management plan and are used by management agencies to assess the status and condition of seagrass resources in the region. The monitoring program also forms part of Queensland's network of long-term monitoring sites of important fish habitats in high risk areas.

This report updates the results of long-term seagrass monitoring for assessments between September 2012 and December 2013. The report also presents the results of the two whole of port baseline surveys conducted in March and September 2013. The objectives of the long-term seagrass monitoring program of the Port of Abbot Point were to:

1. Compare results of baseline and quarterly 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.

Map 3. Location of coastal monitoring meadows, offshore monitoring sites and light (PAR) & temperature loggers



2 SAMPLING APPROACH AND METHODS

There were three components to the Abbot Point seagrass program in 2012-2013:

1. Quarterly assessments of established monitoring meadows;
2. Wet and dry season updated baseline mapping of seagrass within the broader port limits;
3. Light (PAR) and temperature assessments at the seabed.

2.1 Quarterly assessment of established monitoring meadows & the 2013 Baseline surveys

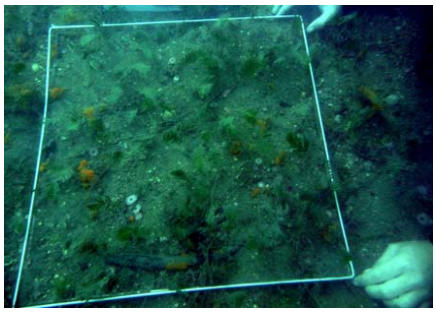
From the results of the baseline surveys in 2008 (McKenna et al. 2008), five coastal meadows and four offshore areas were identified as suitable for long-term seagrass monitoring (Map 3). Monitoring meadows were representative of the range of seagrass communities identified in the 2008 baseline surveys and were also located in areas considered ideal sensitive receptor sites for assessing seagrass condition during and after port activity and development.

Seagrass monitoring in the Abbot Point area has been conducted quarterly (weather dependent) since May 2008. 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.

In addition to the quarterly monitoring surveys, two major surveys of coastal and offshore seagrass habitat within the broader port limits were conducted in 2013, updating the previous 2008 baseline surveys. The 2008 and 2013 baseline surveys were conducted in the wet season (March) and dry season (September) in order to capture seagrasses at their likely seasonal extremes of distribution and abundance.

Methods for assessing inshore and offshore seagrasses in the monitoring and the baseline surveys followed those established for the Abbot Point seagrass 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 an underwater CCTV camera system were used to survey coastal and offshore areas for seagrass (see McKenna et al. 2008 for full description). At each survey site, seagrass habitat observations included seagrass species composition, above-ground biomass, percent algal cover, depth below mean sea level (MSL), sediment type, time and position (GPS). The percent 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 with CCTV mounted camera system and free-divers to measure seagrass biomass and species composition.

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).
- ***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 1. Nomenclature for community types in the Port of Abbot Point 2008-2013

Community type	Species composition
Species A	Species A is 90-100% of composition
Species A with Species B	Species A is 60-90% of composition
Species A with Species B/Species C	Species A is 50% of composition
Species A/Species B	Species A is 40-60% of composition

Table 2. Density categories and mean above-ground biomass ranges for each species use in determining seagrass community density in the Port of Abbot Point 2008-2013

Density	Mean above ground biomass (g DW m^{-2})				
	H. uninervis (narrow)	*H. ovalis* *H. decipiens*	*H. uninervis* (wide) *C. serrulata/rotundata*	*H. spinulosa* *H. tricostata*	*Z. muelleri*
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 3). Mapping precision estimates ranged from 20m for small 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.

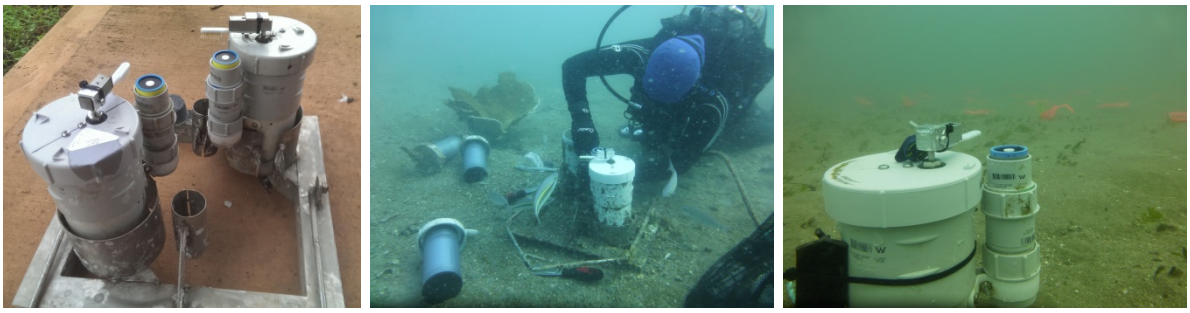
Table 3. Mapping precision and methodology for seagrass meadows in the Port Abbot Point 2008-2013

Mapping precision	Mapping methodology
20-50m	Subtidal meadow boundaries determined from free diving surveys; Relatively high density of survey sites; Recent aerial photography aided in mapping.
60-400m	Subtidal meadow boundaries determined from free diving and underwater CCTV and sled tows; Moderate to high density of survey sites; Recent aerial photography aided in mapping.
500m	Larger subtidal meadows with boundaries determined from underwater CCTV and sled tows; All meadows subtidal; Relatively low density of survey sites.

2.2 Light and temperature assessments

Maximum daily water temperature (°C) and irradiance (Photosynthetically Active Radiation (PAR) mol m^{-2} day^{-1}) conditions within the seagrass meadows at Abbot Point have been assessed at three inshore coastal meadows and three offshore sites since September 2011 using custom built benthic data logging stations (Map 3). Each logging station consisted of a stainless steel frame which held up to two PAR loggers (Odyssey Integrated Light loggers Model Z412) with supporting electronic wiper units, and an autonomous iBTag temperature logger. Loggers recorded temperature and PAR within the seagrass canopy every 15 minutes. Loggers were exchanged and downloaded approximately every 90 days. The electronic wiper unit fitted to each PAR logger automatically cleaned the optical surface of the sensor every 15 minutes to prevent marine organism fouling.

These environmental parameters were collected along with existing sources of daily weather data (rainfall, river flow and the amount of cloud in the sky) 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 & temperature loggers deployed at Abbot Point

2.3 Statistical analysis

For each monitoring meadow one-way ANOVAs were initially attempted to compare seagrass above-ground biomass between surveys, however, due to the massive declines and the large numbers of "zero" results the data at each meadow and offshore monitoring site failed the assumptions of normality and homogeneity of variance despite using several data transformations. For this report data were pooled for all deep water sites and then also for all inshore sites and analysed to assess change in biomass over time. As seagrass recovery continues in future surveys a re-assessment of statistical analyses approaches will be performed and meadow by meadow analysis reinstated when appropriate.

Pooled data for offshore seagrass above-ground biomass was compared between dates with a generalised linear mixed-effects model (GLM) in the statistical package program R (R Core Team, 2013). We used R (R Core Team, 2013) and *lme4* (Bates et al. 2012) to perform a linear mixed effects analysis of the relationship between biomass and time. Due to the repeated sampling of each site, we held site as a random factor to account for any collinearity in the data. As fixed effects we entered year and month, and the interaction between the two into the model. Biomass data was square root transformed. A 'null' model was set up and then all other models with the fixed effects as factors were run. Visual inspection of residual plots did not reveal any obvious deviations from homoscedasticity or normality. P-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. The significant model with the lowest AIC number was selected as the most appropriate model to describe the data. Using the *multcomp* package (Hothorn et al. 2008) in R, multiple comparisons of

means using Tukey Contrasts with a Holm adjustment (sequentially compares the lowest p-value with a Type I error rate that is reduced for each consecutive test), was then used to determine significant differences in biomass between surveys. Detailed statistical results are presented in Appendix 1.1.

Pearson's product-moment correlation coefficients were used to examine relationships between PAR and cloudy days and PAR and river flow at each light monitoring site. PAR data and cloudy day data at five of the six monitoring sites was square root transformed, while river flow data at four monitoring sites was log transformed. Non-parametric rank correlations between PAR and river flow were conducted for monitoring meadow 9 as data did not conform to parametric assumptions despite transformation.

3 RESULTS

Eight seagrass species have been identified within the Abbot Point region since broad scale surveys of the area began in 1987 (Figure 2). Of particular note in this report was the presence of *Halophila tricostata* in Abbot Bay in the September 2013 baseline survey (Figure 2). This is the first record of this species in the Abbot Point/Bowen region. The species has previously been recorded at coastal sites between the Hinchinbrook Channel and Upstart Bay where it was found in water 1.4-20 m deep (Coles et al. 1987; Kuo et al. 1993; Coles et al. 1998).

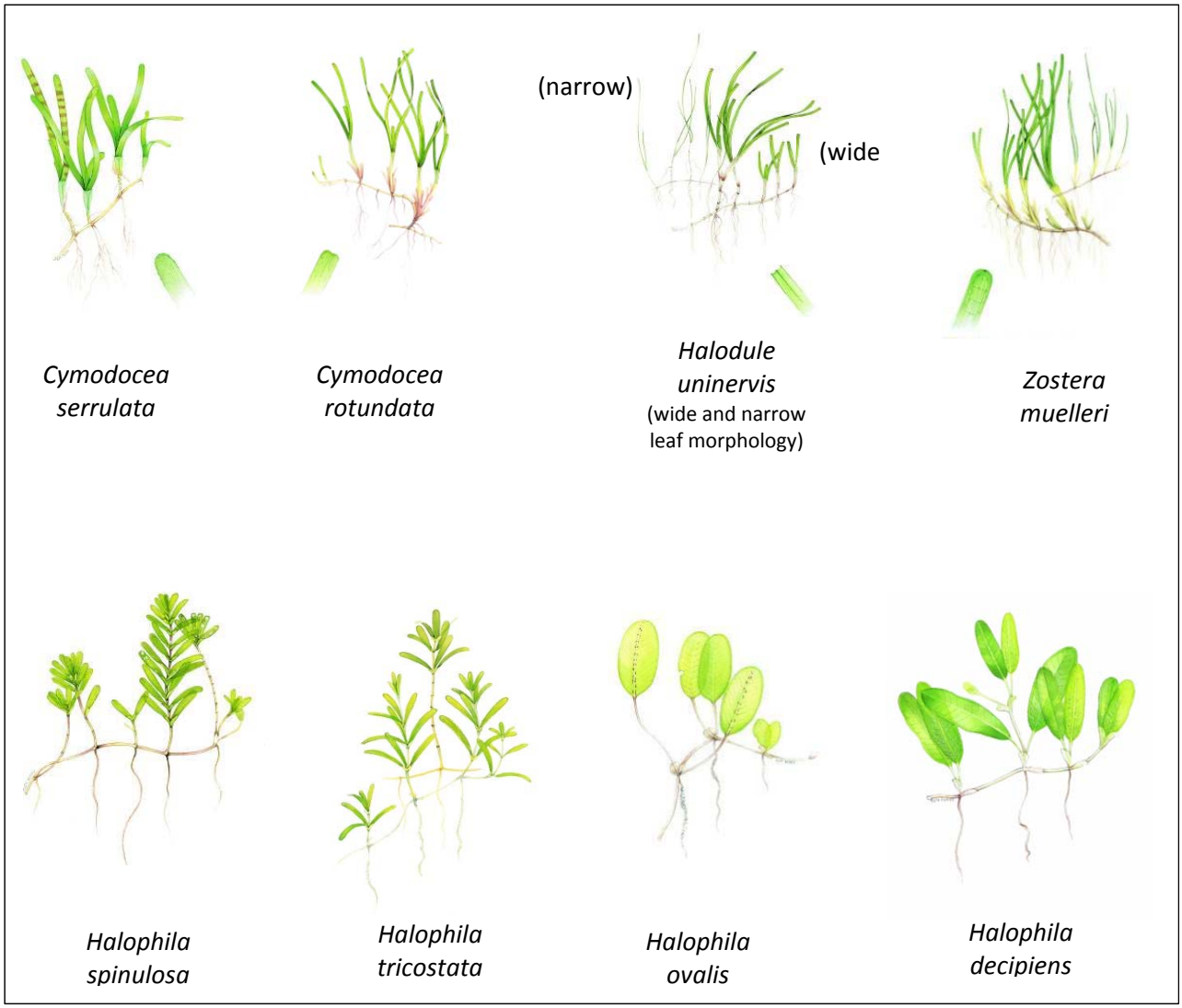


Figure 2. Seagrass species identified in the Abbot Point/Bowen region.

3.1 Quarterly Assessments of Established Monitoring Meadows and Sites

3.1.1 Seagrass species, distribution, abundance and changes in the monitoring meadows

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 from winter-early summer; a trend consistent with observations of seagrasses throughout Queensland (Figures 3-11; Appendices A.1–A.2). Following the summer of

2010/11, significant losses in density and distribution of seagrasses at both inshore and offshore monitoring sites were observed. There was evidence of seagrass recovery at some of the deep water monitoring sites following these climatic events between March 2011 and September 2012. However seagrass biomass at the offshore monitoring sites has again declined since the January 2013 survey (Figures 8-11; Appendix A.1). By April 2013 these declines were statistically significant ($p < 0.05$) compared to biomass in June and September 2012 (Appendix A.1). These declines may have been a result of the impacts of high winds and flooding associated with Tropical Cyclone Oswald. TC Oswald passed inland of the Abbot Point area on approximately January 24th 2013 and produced severe weather over nearly all of eastern Queensland (BOM 2013). Destructive winds of up to 140 km/h were measured at Hay Point (200km south of Abbot Point) with flooding occurring across much of eastern Queensland (BOM 2013).

The coastal inshore monitoring meadows have not undergone any significant recovery since the La Niña-related events of 2010/11 and severe Tropical Cyclone (TC) Yasi, however three of the five coastal monitoring meadows did have small amounts of seagrass present between April 2013 and December 2013 (Figures 3-7; Appendices A.2). Of particular note is the presence of *H. uninervis* in a couple of the inshore monitoring meadows.

Coastal Monitoring Meadows

Prior to the La Niña-related events of 2010/11 and severe TC Yasi the inshore monitoring meadows at Abbot Point were highly variable in distribution and biomass between monitoring events. These meadows generally consisted of low biomass, isolated to aggregated patches of seagrass dominated by *H. uninervis*, although Meadow 3 west of Euri Creek was traditionally dominated by *Z. muelleri* and was the only location this species was recorded in the Abbot Point area (Figures 3-7). In this monitoring program (2008-2013) seagrass above-ground biomass when present in the coastal monitoring meadows has ranged from 0.005 g DW m^{-2} to 8.91 g DW m^{-2}, while the area of individual meadows when present have ranged from 1.2 ha to 127.54 ha (Figures 3-7; Appendices A.2).

In March 2011, following the 2010/2011 floods and TC Yasi, four of the five coastal monitoring meadows were absent. Meadow 7 dominated by *H. 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. Seagrass was also absent at all meadows in the January 2013 survey (Figures 3-7). By April 2013 seagrass had re-emerged in three of the five monitoring meadows, and although the seagrass was dominated by the colonising *H. ovalis* species, small amounts of *H. uninervis* was present at two inshore monitoring meadows and may represent the beginnings of some recovery (Figures 3, 5 & 7).

For the first time since November 2010 a small patch of *Z. muelleri* was found in Meadow 3, however this patch had again disappeared in a recent survey (March 2014 data will be part of next report) (Figure 3). Seed-bank assessments conducted in Meadow 3 during 2012 found no *Z. muelleri* seeds, parts of seeds or pericarps (outer casing of seed) in any sediment cores, indicating the *Zostera* seed-bank in Meadow 3 is either extremely low density or non-existent. The appearance of this patch of *Z. muelleri* in December 2013 may have been the result of recruitment of a floating fragment or seeds dispersed from outside the area.

While the presence of *Halophila ovalis* in coastal meadows is an encouraging sign care should be taken when interpreting the graphs in the following pages as representing recovery. *Halophila ovalis* is a colonising species and true recovery of these coastal meadows would only be achieved with a major return of *Halodule uninervis* and *Zostera muelleri*.

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 (Figures 8-11; Appendix A.2). From March 2011, biomass had slowly been

increasing at three of the four offshore monitoring sites (Sites 2-4), which was a positive sign of recovery and resilience to disturbance. By January 2013 however, seagrass at the offshore monitoring sites underwent declines again and have remained at very low densities (Figures 8-11; Appendix A.1 & A.2). These declines coincided with destructive winds and flooding from TC Oswald that passed by the Abbot Point region in January 2013.

Changes in species composition since the 2010/2011 floods and TC Yasi has been varied at offshore monitoring sites. At Site 1 to the west of the port facilities there was a sudden shift from what was traditionally a *H. uninervis* dominated site, to 100% cover by *H. spinulosa* in March 2011, the first survey after the floods (Figure 8). Since the March 2011 survey seagrass was absent at this site until January 2013 where *H. spinulosa* and *H. ovalis* had re-emerged in low densities and persisted until July 2013 (Figure 8). Seagrass has been absent at the site since then.

Seagrass at Site 2 remained dominated by *H. spinulosa* immediately following the floods (March 2011), however, by May 2011 species composition had shifted to another pioneering species *H. decipiens* (Figure 9). Since May 2011 the proportion of biomass made up by *H. decipiens* has gradually decreased with *H. spinulosa* becoming the dominant species again throughout 2012 and 2013.

Species composition at offshore monitoring sites 3 and 4 has remained relatively consistent throughout the monitoring program with *H. spinulosa* generally the dominant species, and *H. ovalis* and *H. decipiens* making up the rest of the species composition at these sites (Figures 10 & 11). Interestingly, *Cymodocea serrulata* re-appeared in September 2012 at Site 3 (1% of species composition). This was the first time this species had been found in any of the offshore monitoring areas since March 2011, and the first time this species had been present at Site 3 since August 2009 (Figures 10 & 11). As a higher light requiring species this may have been an indication of a general improvement in the light environment in deeper areas of Abbot Point at the time. *Cymodocea serrulata* has not been found at any monitoring site since September 2012.

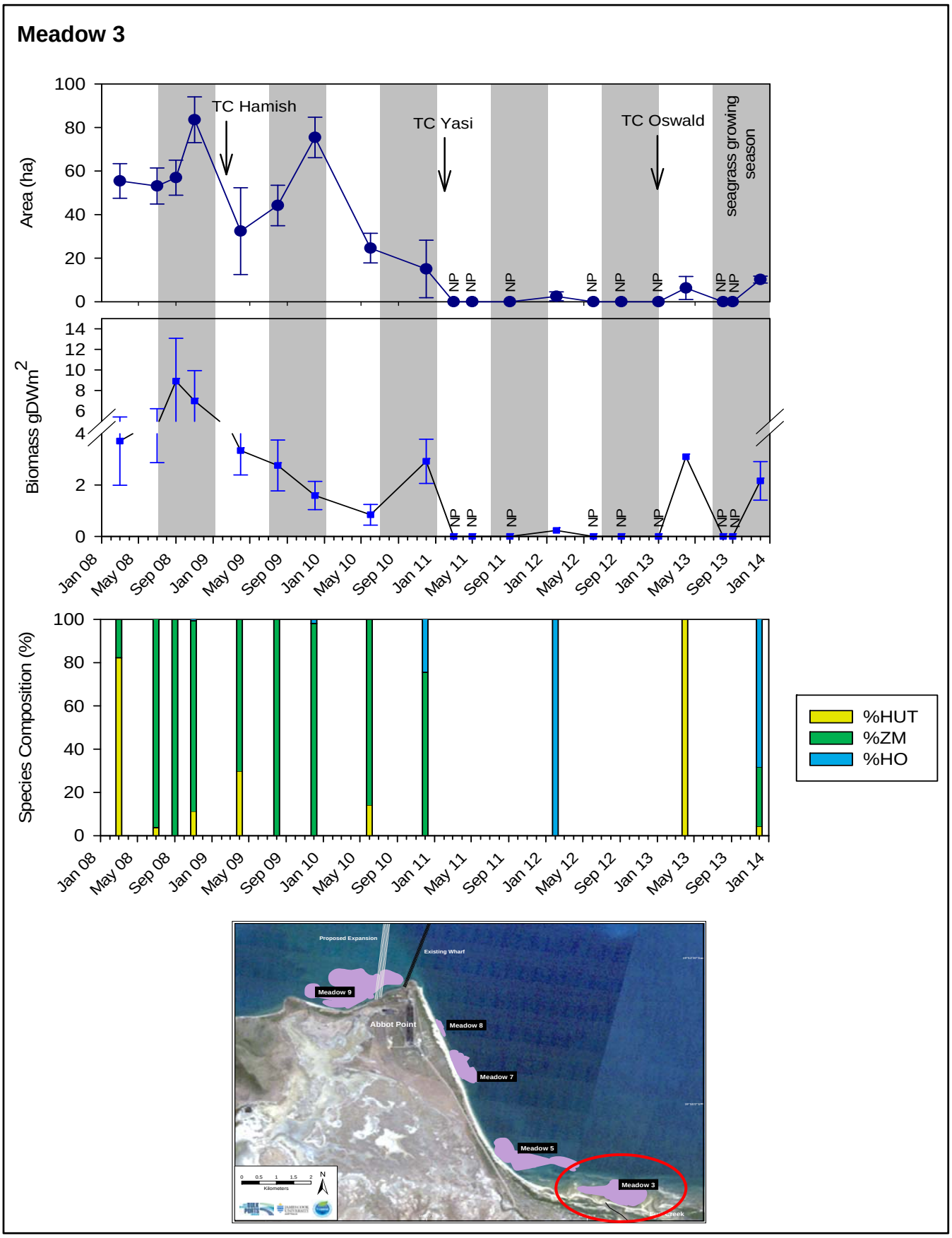


Figure 3. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 3.

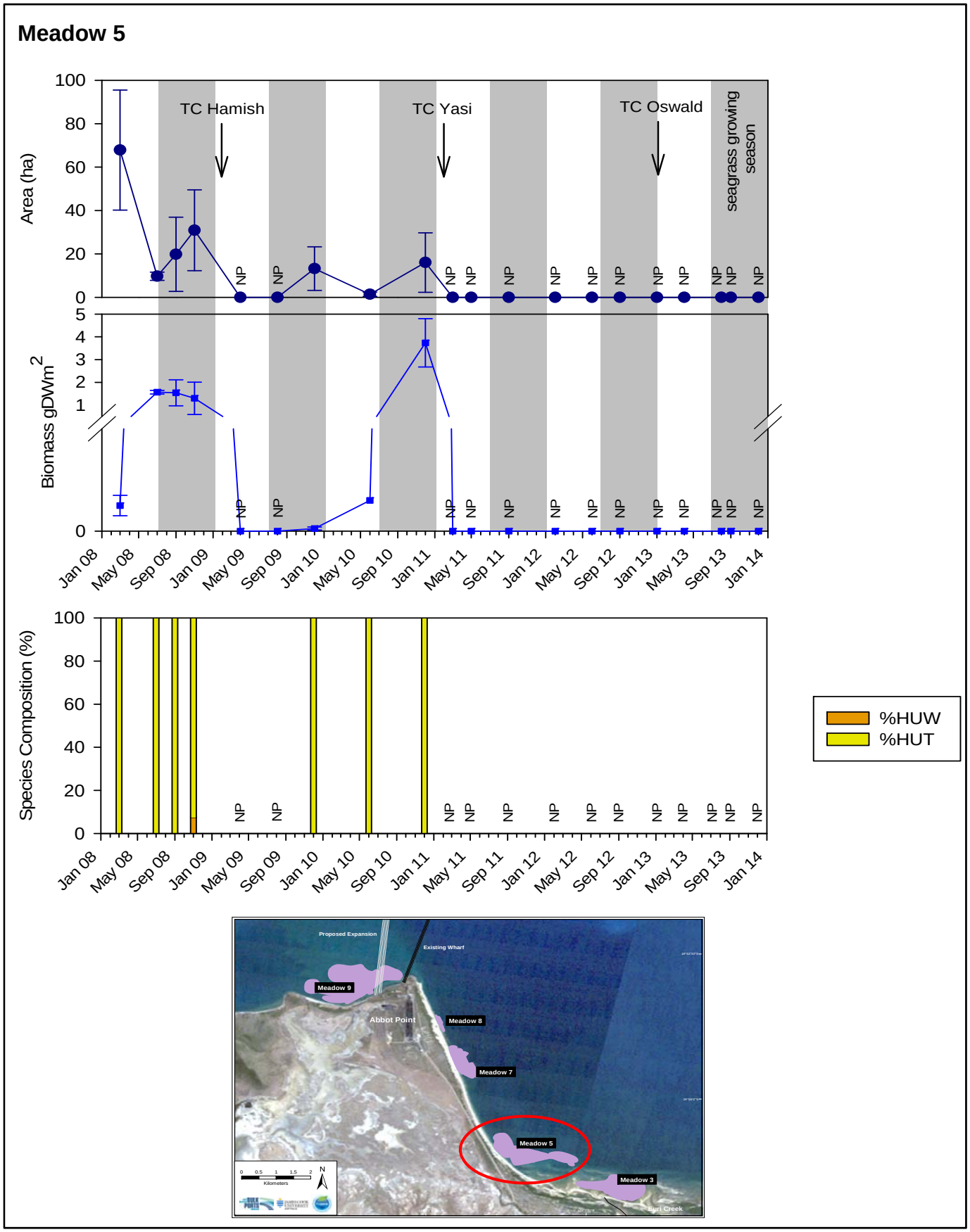


Figure 4. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 5.

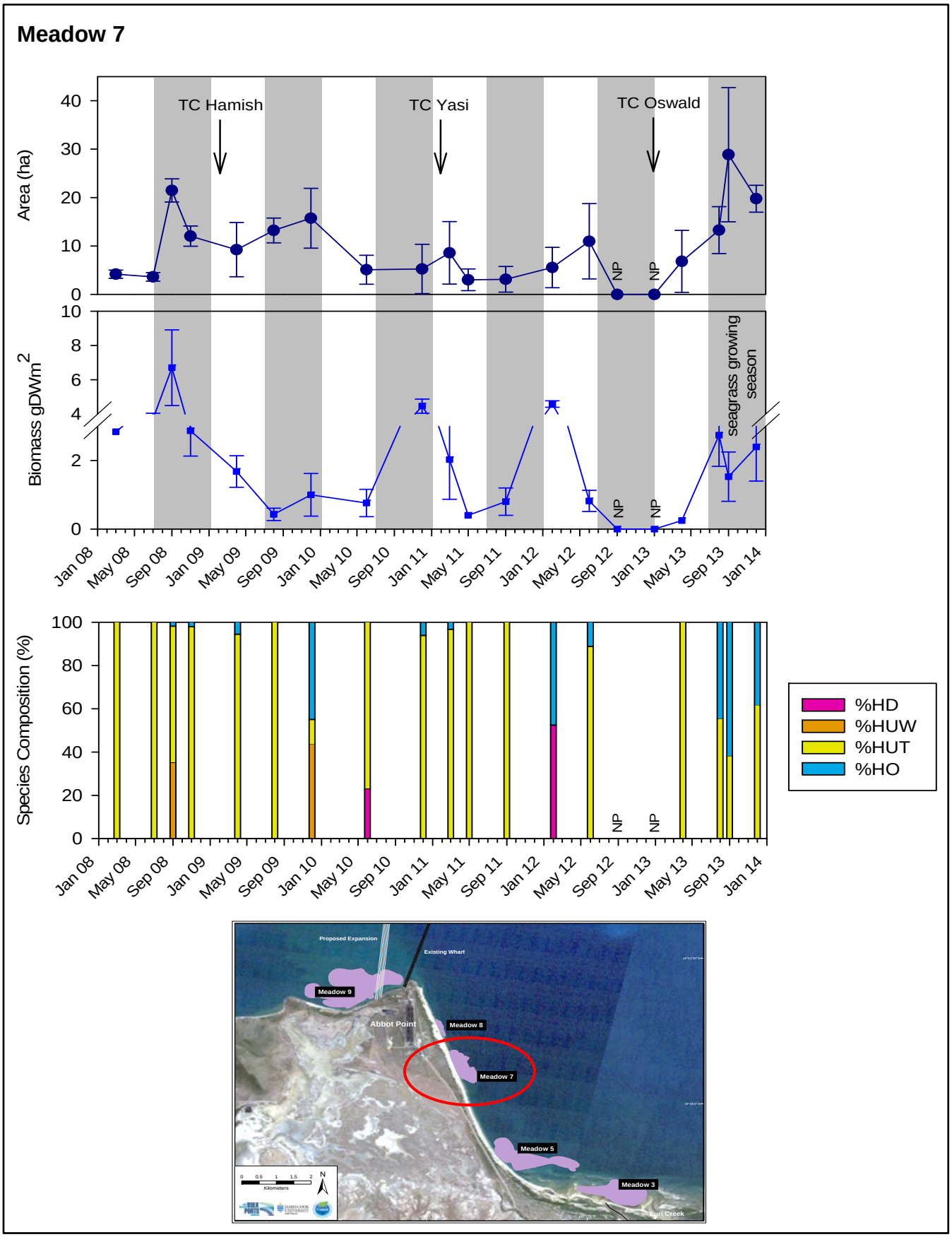


Figure 5. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 7.

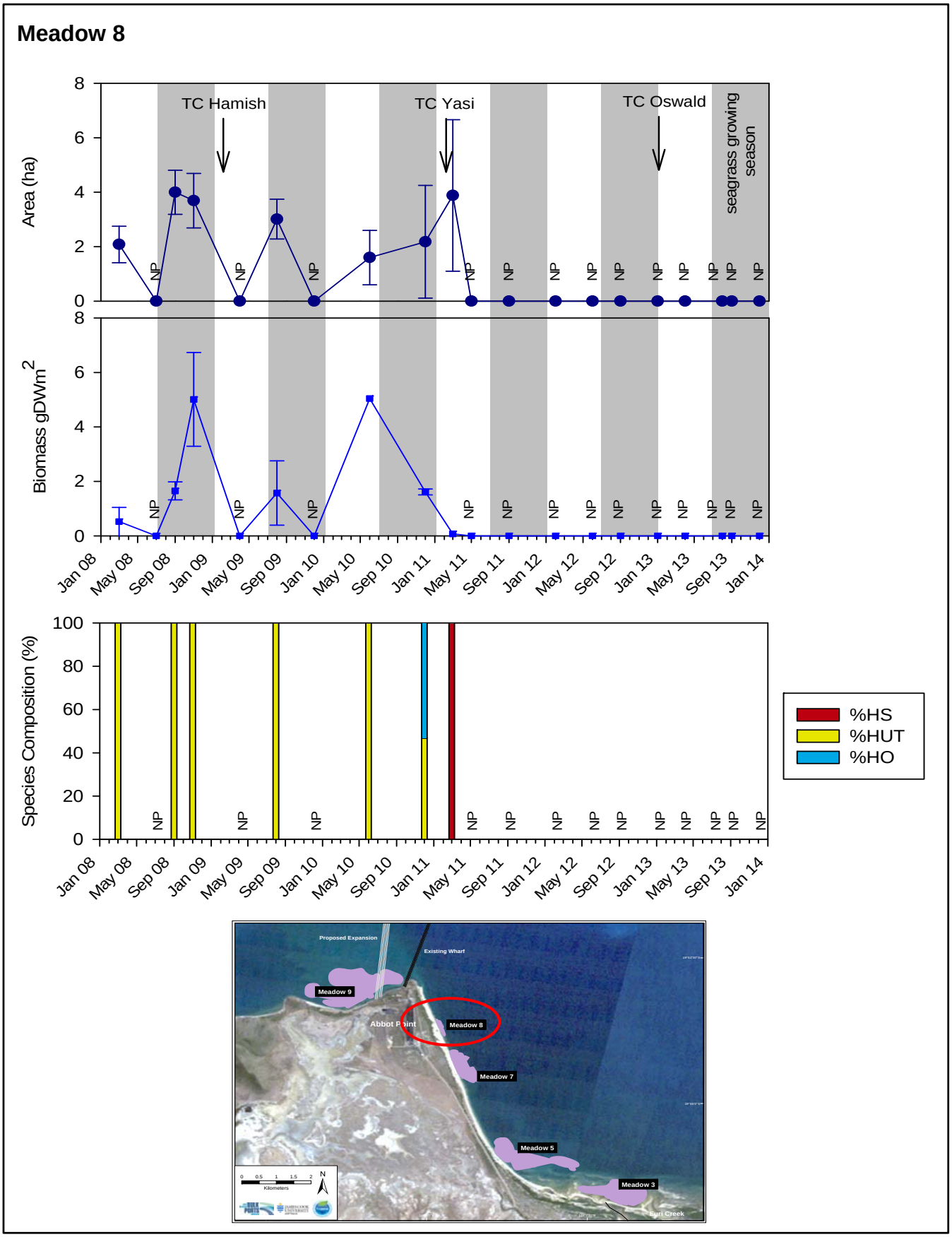


Figure 6. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 8.

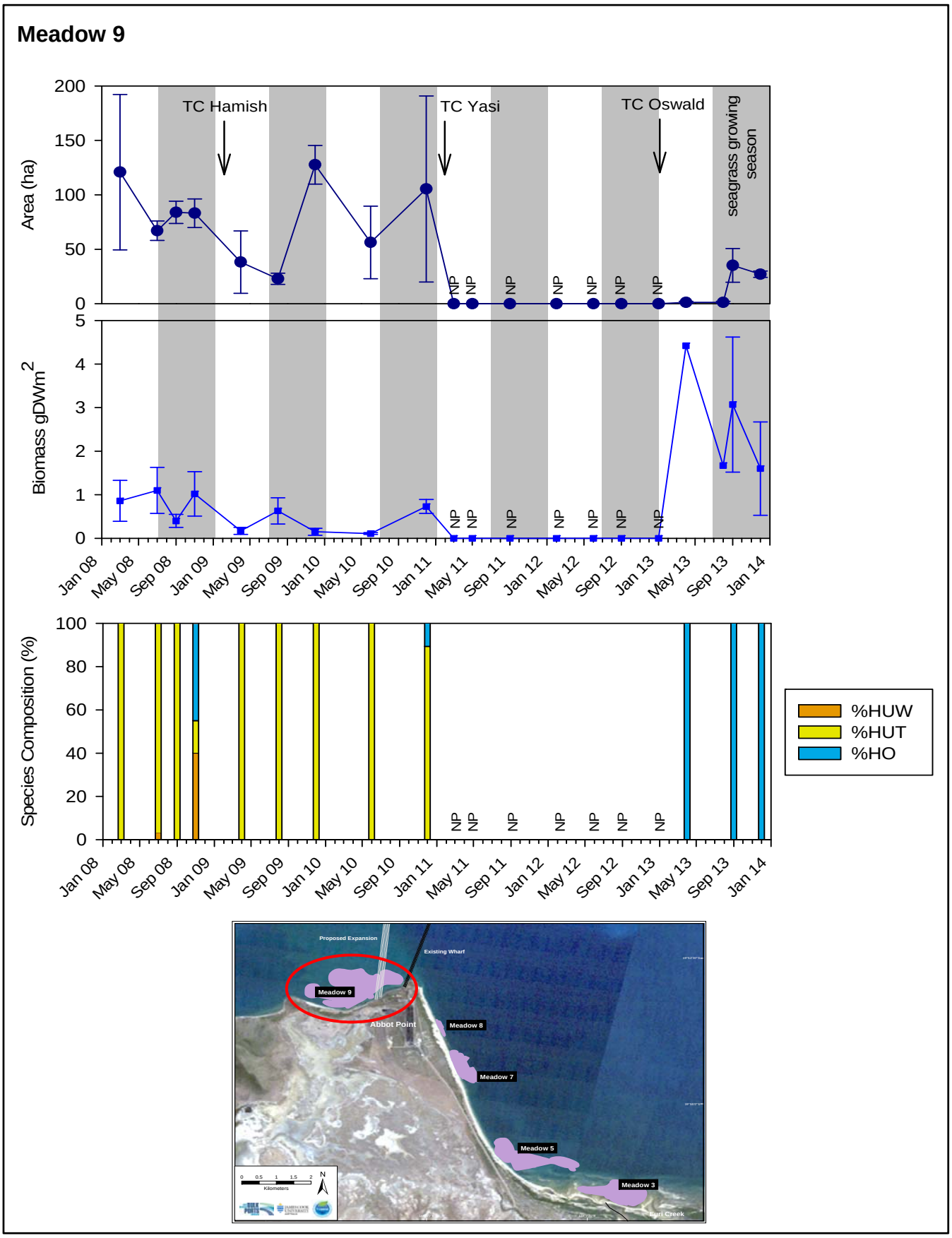
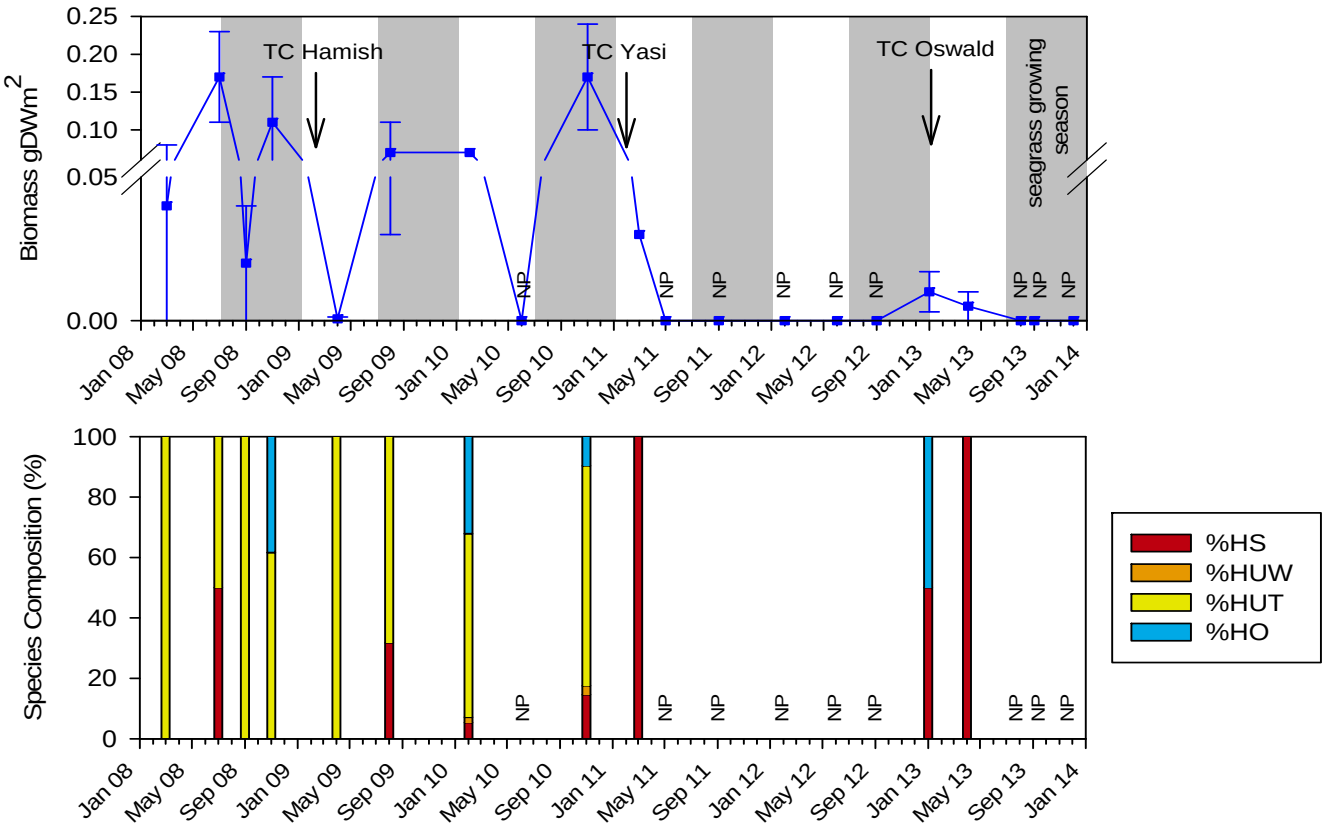


Figure 7. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 9.

Offshore Site 1



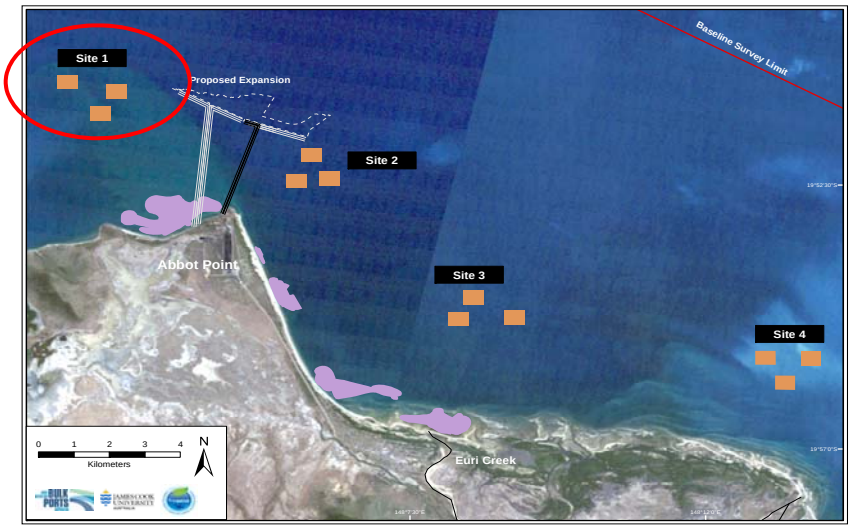
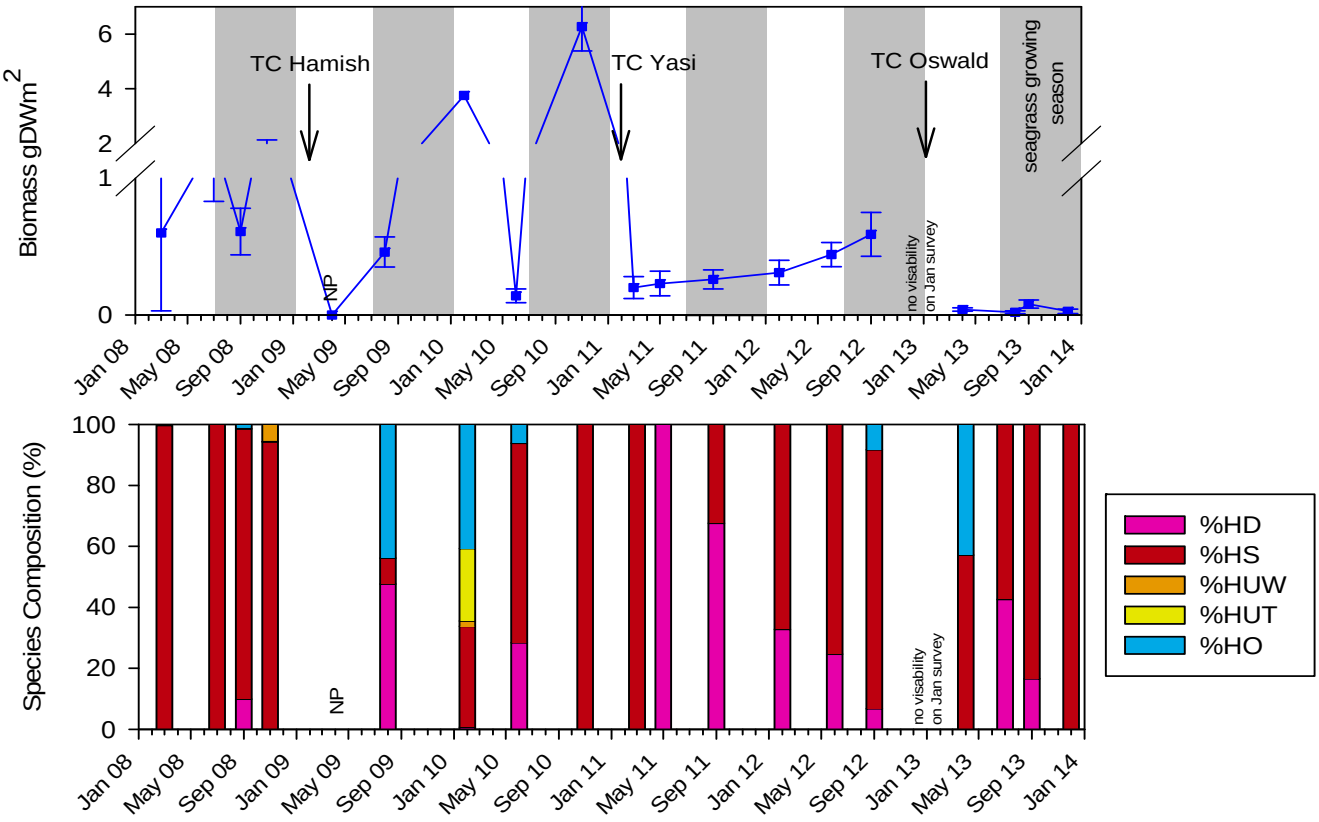


Figure 8. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at offshore monitoring Site 1.

Offshore Site 2



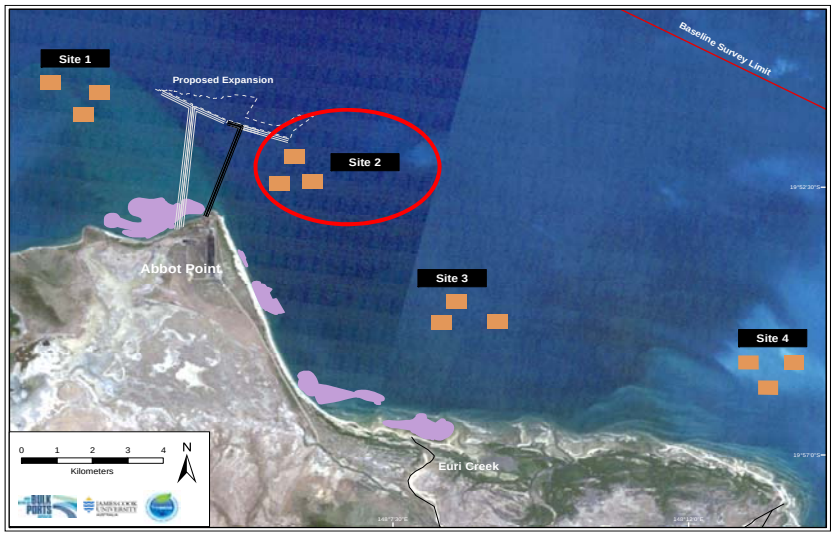
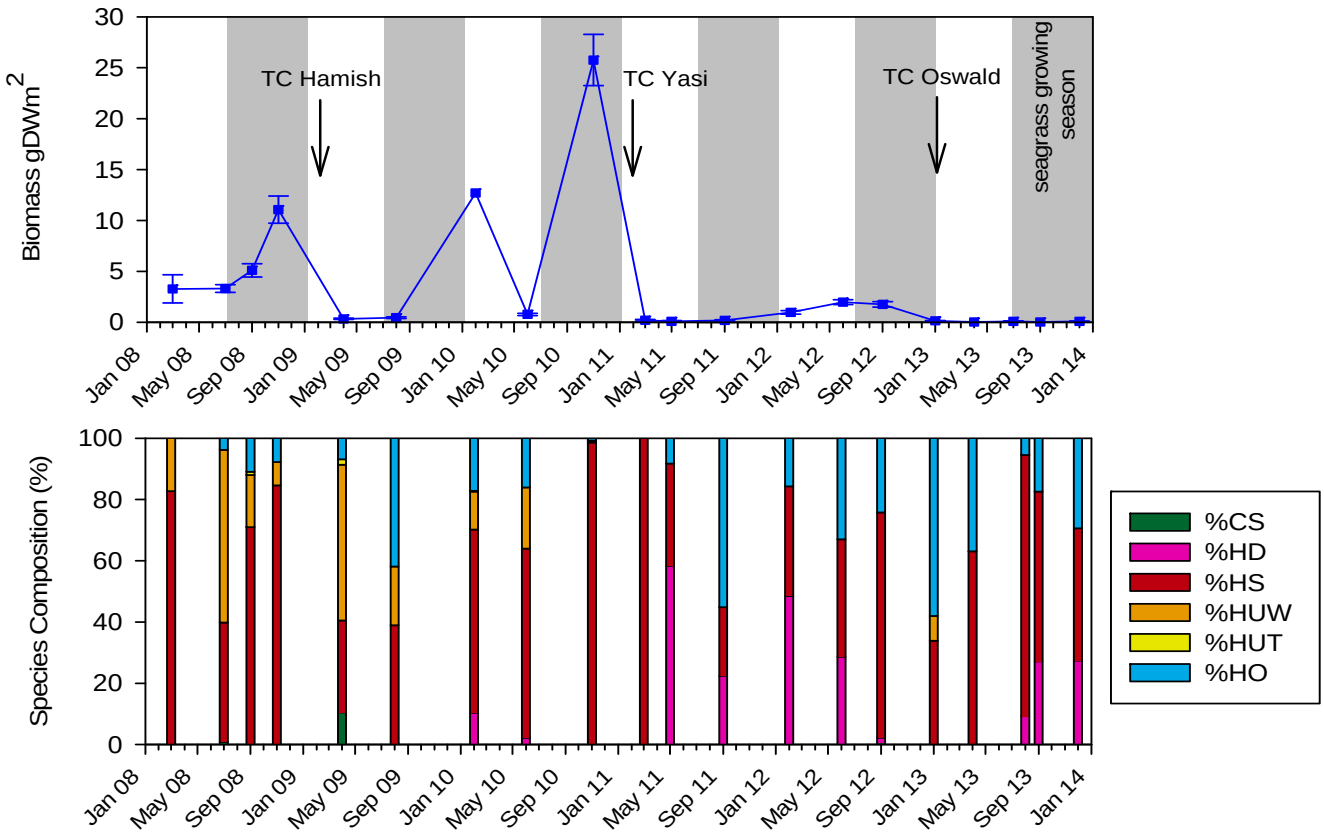


Figure 9. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at offshore monitoring Site 2.

Offshore Site 3



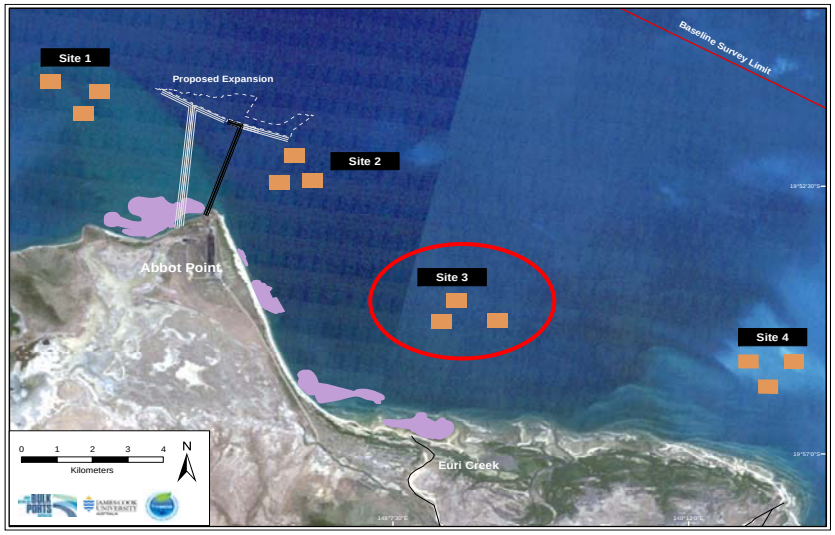
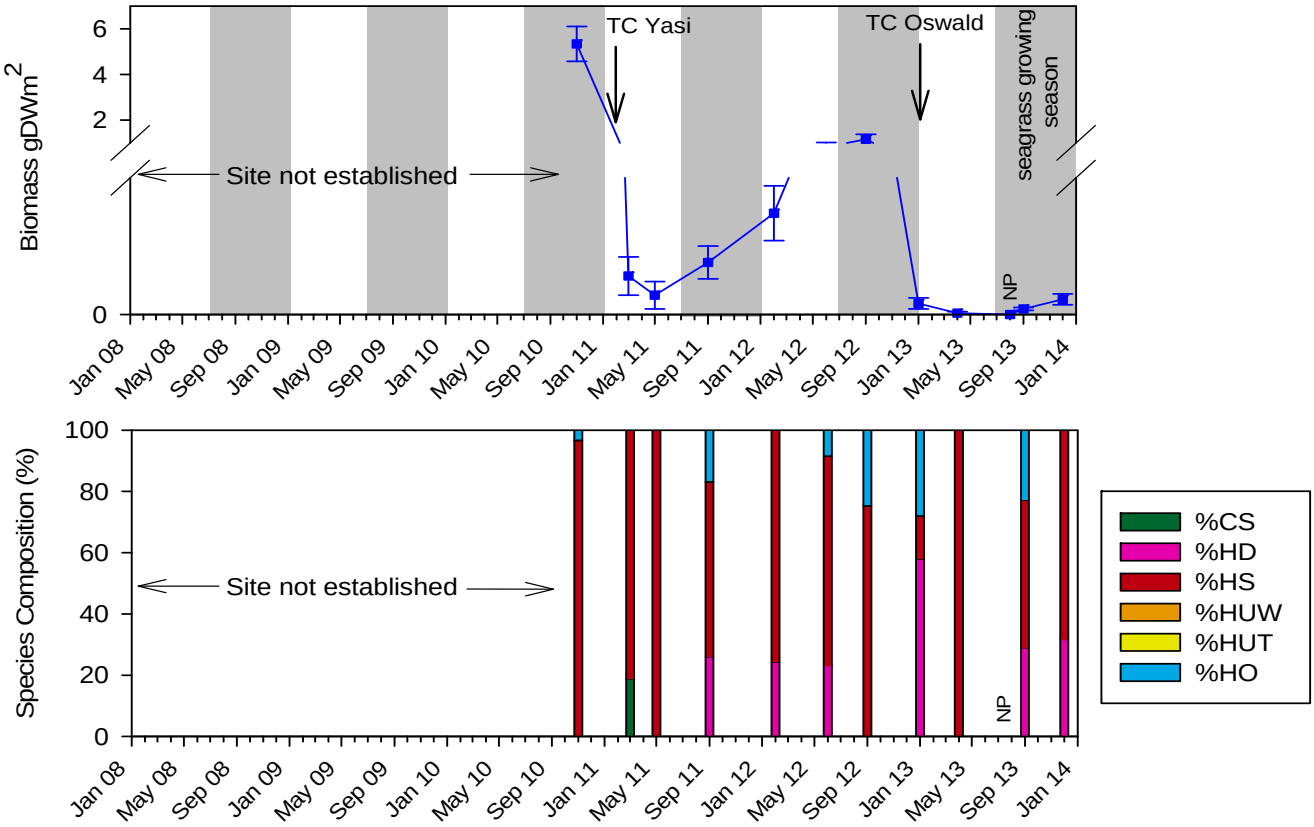


Figure 10. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at offshore monitoring Site 3.

Offshore Site 4



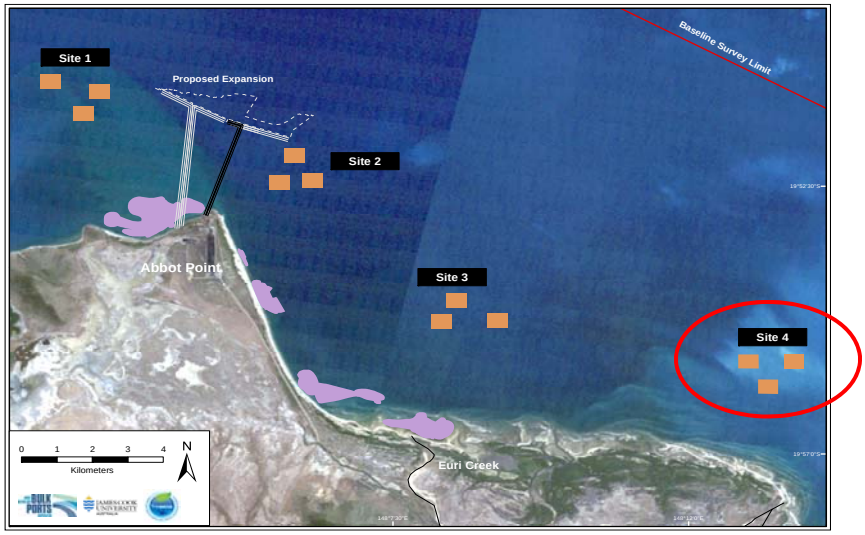


Figure 11. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at offshore monitoring Site 4.

3.2 Seagrass within the Broader Port of Abbot Point – Baseline surveys

Seagrass was first mapped within the Abbot Point port limits during broad-scale surveys of the east coast of Queensland in 1987 (Coles et al. 1992). In 2005, NQBP commissioned a more detailed study of the seagrass, algae and benthic macro invertebrate communities in the vicinity of the existing port facilities (Rasheed et al. 2005). As part of the current seagrass program at Abbot Point and in preparation for potential port expansion NQBP again engaged TropWATER to carry out wet and dry season baseline surveys of seagrass habitat in 2008 (McKenna et al. 2008). Results of those surveys found extensive areas of inshore and offshore seagrass meadows (20,803 ha) covering the region from Eliot River/Camp Island to Queens Bay, to a distance of approximately 10km offshore (see McKenna et al. 2008 for details) (Map 4). In order to update this baseline and periodically provide a region wide assessment of seagrass condition, wet season and dry season surveys of the entire area were again conducted in 2013. These surveys also identified extensive areas of coastal and offshore seagrass habitat; approximately 19,416 ha of seagrass habitat was mapped in the 2013 dry season survey (Map 4).

3.2.1 Seagrass species, distribution, abundance and changes in the 2013 baseline surveys

A total of 369 and 377 habitat characterisation sites were surveyed in the 2013 wet season and dry season baseline surveys respectively. Similar to the 2008 surveys, seagrass occurred in a strip of small meadows adjacent to the coast and in three large offshore meadows (Map 4). Seagrass was widely distributed throughout the area including the proposed port expansion area.

Halophila spinulosa dominated the deeper sub-tidal areas while *H. uninervis* tended to dominate the coastal meadows in the wet season. In the dry season, there was a change in species composition at many of the same inshore meadows where *Halophila* species tended to be the dominant species, not *H. uninervis*. The majority of the meadows found in both surveys (wet & dry seasons 2013) were of low to moderate density. The moderate density meadows were not located within the footprint or modelled dredge plume of the proposed port development (Map 4). Seagrass was found to a maximum depth of 17.4m below MSL in the wet season and 27.6m below MSL in the dry season (Map 4).

The location of seagrass meadows was generally similar between the two seasonal surveys in 2013, however there was a distinct difference in the total area of seagrass habitat mapped between the wet and dry seasons (Map 4; Figure 12). A total of 8,212 ± 3776 ha of seagrass habitat was mapped in the wet season, while there was 19,419 ± 6,094 ha mapped in the dry season. Much of this increase was due to the re-emergence of seagrass in the dry season at offshore and inshore areas on the western side of the Abbot Point wharf (Map 4). Although there was a marked difference in the total seagrass area mapped between the two surveys, the biomass remained similar for both inshore and offshore meadows (Figure 12).

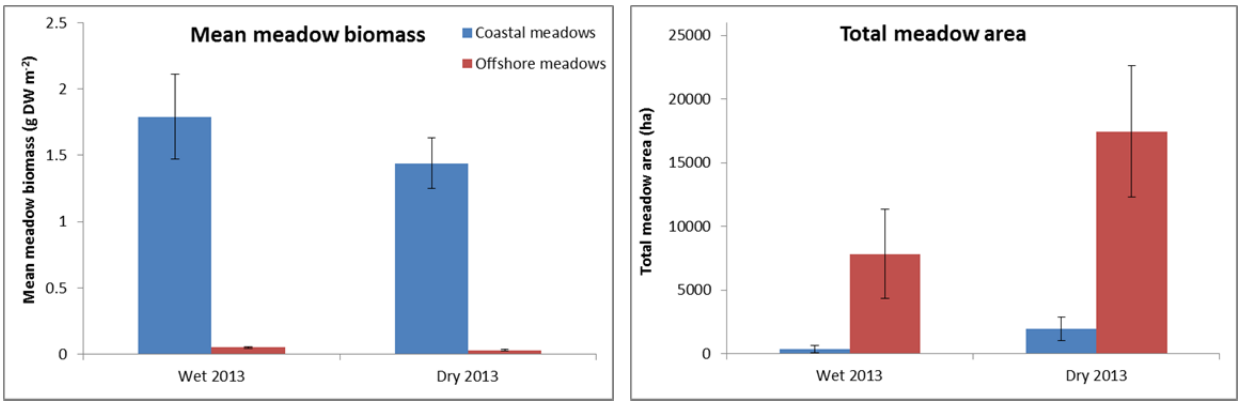
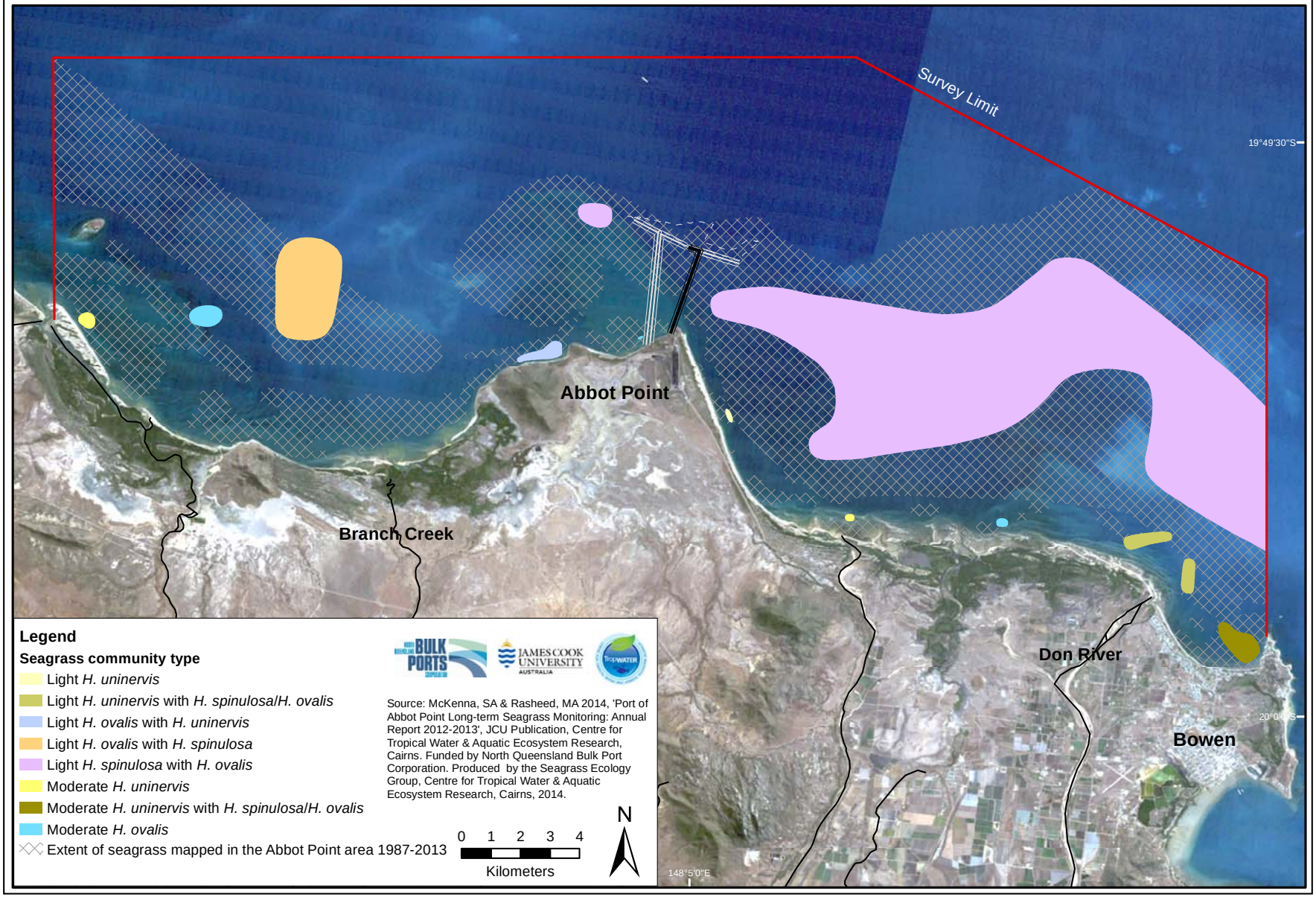
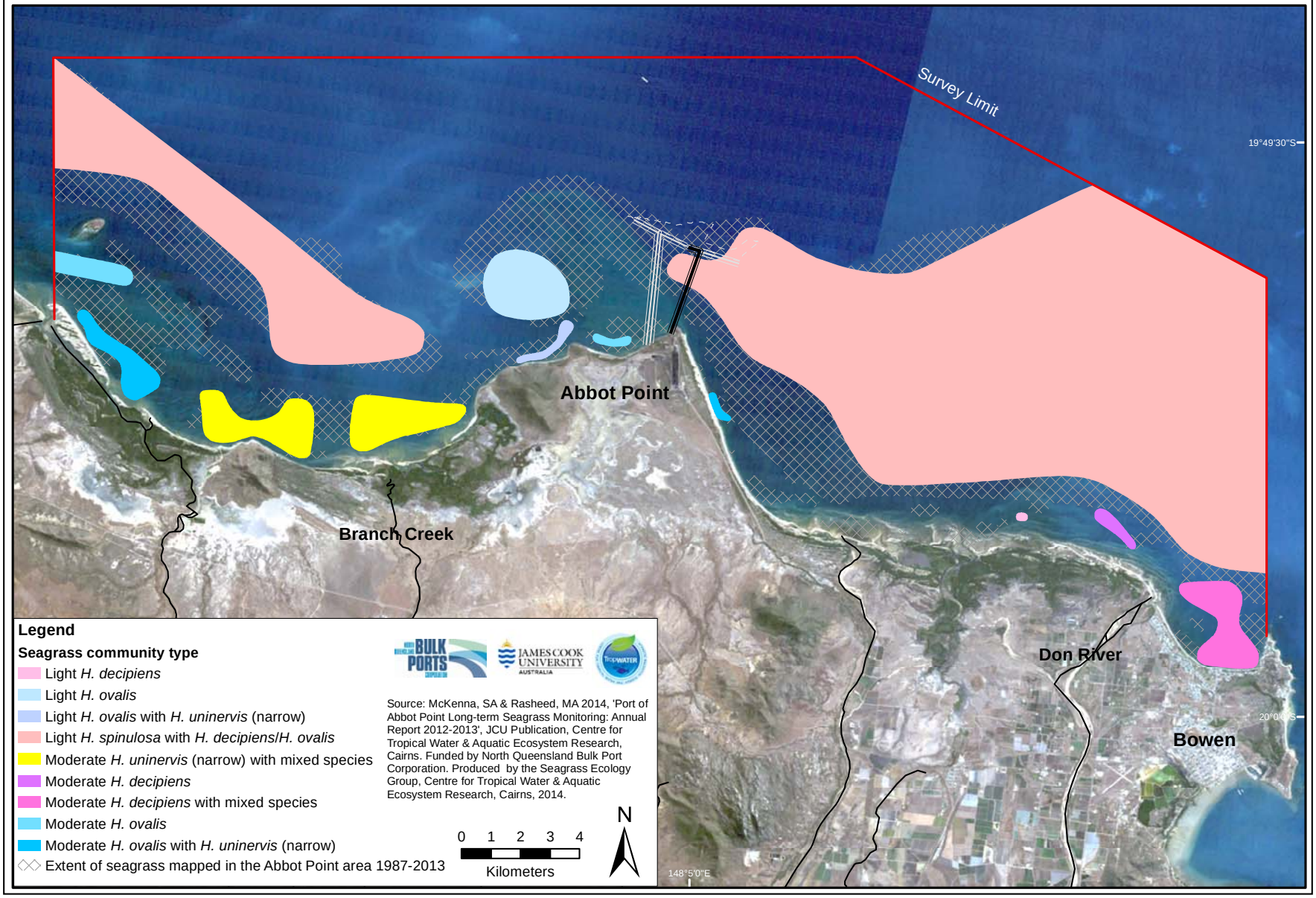


Figure 12. Mean meadow biomass (g DW m^{-2}) and total meadow area (ha) for all coastal and offshore seagrass meadows pooled.

Map 4. Seagrass meadow community types and location in the Port of Abbot Point April 2013



Map 5. Seagrass meadow community types and location in the Port of Abbot Point September 2013



3.2.2 Comparison with previous whole of port baseline surveys

As reported above there have been four (1987, 2005, wet & dry season 2008) previous surveys of seagrass encompassing the entire Abbot Point region. The 1987 survey only examined coastal seagrass. The 2005 survey (see Rasheed et al. 2005) was done in the wet season at the same scale and intensity as the present baseline surveys although it covered a smaller section of the port limits. The 2008 and 2013 baseline surveys were part of the current seagrass monitoring program at Abbot and are therefore directly comparable to the 2013 surveys. These surveys were conducted during the seasonal extremes; the wet season and dry season, to gain an understanding of the seasonal variation in seagrass meadows within the Abbot Point region.

Overall the location and species composition of coastal and offshore seagrass meadows have been similar between all baseline surveys. *H. uninervis* has generally been the dominant species at inshore meadows while *H. spinulosa* has dominated offshore seagrass meadows. Of note was the presence of *Halophila tricostata* in the September 2013 baseline survey in the large offshore meadow near Camp Island. This species was not found in any of the previous surveys. There was also the loss of the *Z. muelleri* meadow near Euri Creek between the 2008 and 2013 surveys. This meadow was consistantly present at Euri Creek until the La Niña-related events of 2010/11 and severe TC Yasi in February 2011 that impacted the area.

The biomass (density) of inshore meadows mapped in the broader Abbot Point area was similar between the 2008 wet season (1.36 ± 0.03 g DW m^{-2}) and 2013 wet season (1.79 ± 0.32 g DW m^{-2}) surveys. In the latter half of the year, seagrass biomass was slightly higher in 2008 (2.76 ± 0.74 g DW m^{-2}) compared to 2013 (1.44 ± 0.19 g DW m^{-2}) (Figure 13). This correlated with a change in species composition of meadows between surveys where there was a reduction in the larger species such as *H. uninervis* and *Z. muelleri*, and a higher dominance of the smaller *Halophila* species in the meadows.

In contrast to meadow density total meadow area of the inshore meadows was similar in the dry seasons of 2008 and 2013, but between the wet season surveys coastal meadow area had declined by 75% from 2008 to 2013. This was mainly due to the loss of some of the bigger offshore meadows on the western side of the Abbot Point wharf.

Mapping of deep water seagrass density in the broader port limits found that the density of deep water seagrass dramatically declined between 2008 and 2013. In the wet season of 2008 the offshore meadows had an above ground biomass of 2.75 ± 0.7 g DW m^{-2} while in 2013 this biomass had declined to 0.05 ± 0.008 g DW m^{-2} (Figure 13). Similarly comparing the dry season surveys, the offshore meadows in 2008 had a combined meadow biomss of 3.77 ± 1.02 g DW m^{-2} while in 2013 it was 0.03 ± 0.006 g DW m^{-2} (Figure 13).

Total meadow area of the offshore meadows was different between the 2008 and 2013 wet seasons with offshore meadow area declining by approximately 11,482 ± 2,660 ha (60%) from 2008 to 2013 (Figure 13). By the dry season of 2013 total meadow area had recovered to be similar to that in 2008, however biomass remained lower.

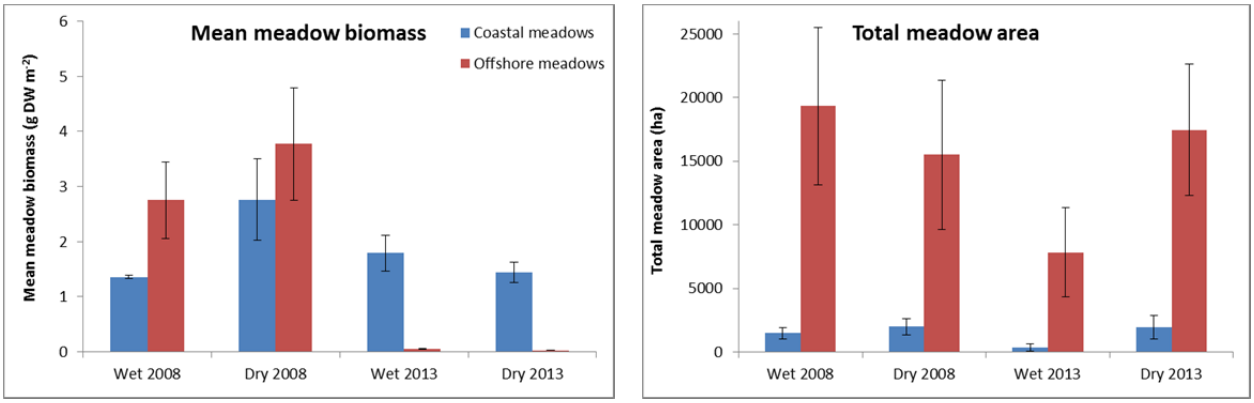
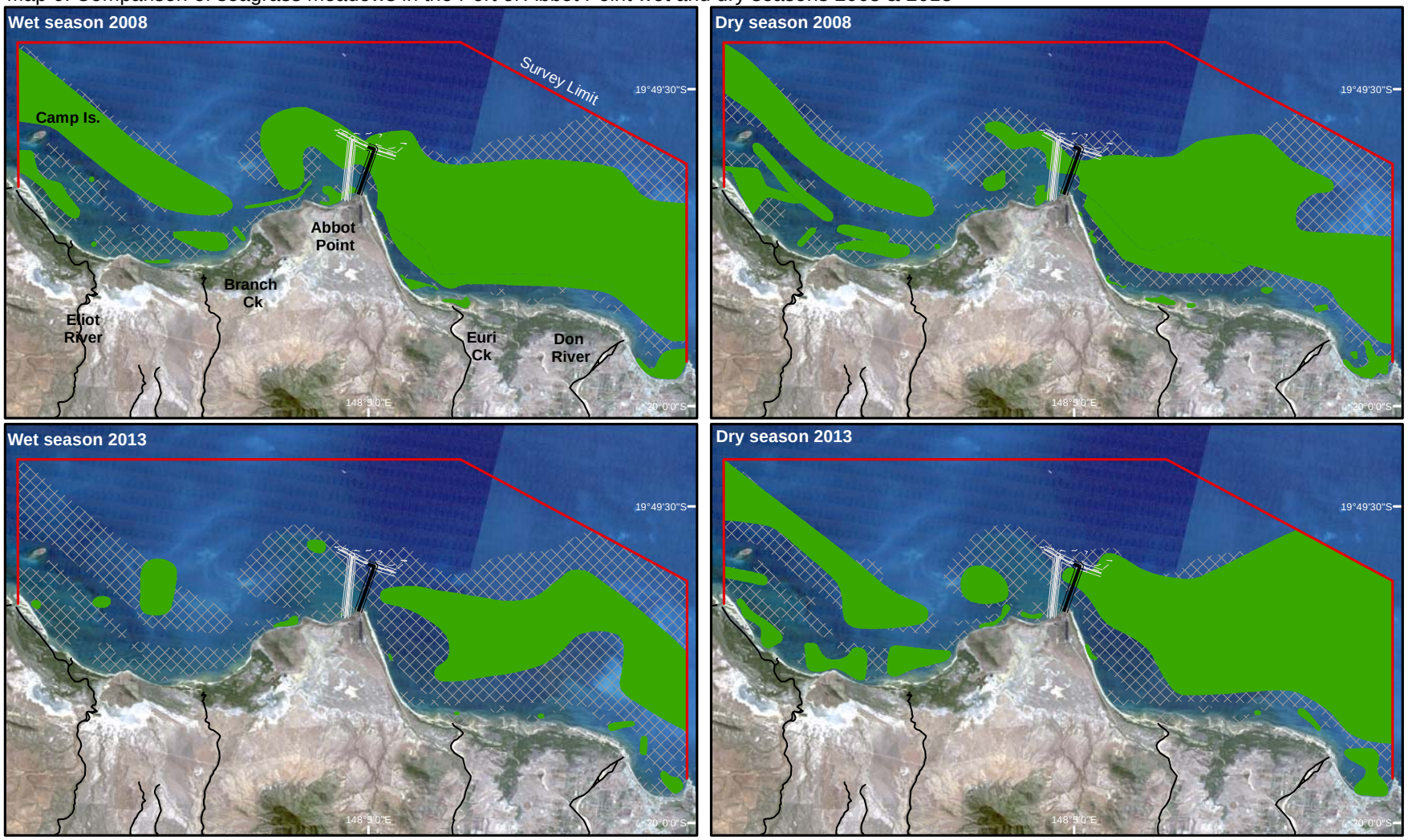


Figure 13. Mean meadow biomass (g DW m^{-2}) and total meadow area (ha) for all coastal and offshore seagrass meadows pooled in 2008 and 2013.

Map 6. Comparison of seagrass meadows in the Port of Abbot Point wet and dry seasons 2008 & 2013



Legend

- Seagrass meadows
- Survey Limit
- Extent of seagrass mapped in the Abbot Point area 1987-2013

N

0 5 10

Kilometers

Source: McKenna, SA & Rasheed, MA 2014, 'Port of Abbot Point Long-term Seagrass Monitoring: Annual Report 2012-2013', JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns.

Funded by North Queensland Bulk Port Corporation. Produced by the Seagrass Ecology Group, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns, 2014.

3.3 Light (PAR) And Temperature Assessments

Available light (PAR) was higher at inshore monitoring meadows (0 to 35.8 mol m^{-2} d^{-1}) compared to the offshore monitoring sites (0 to 12 mol m^{-2} d^{-1}) (Figures 15 & 16). Available light decreased significantly with increasing cloud cover and river flow from the Don River (Table 4), and light also varied seasonally; generally greater in the dry season and lower in the wet season. For example at the shallowest site (Meadow 3 at Euri Creek) mean available light was approximately 74% and 82% greater in the 2011 and 2012 dry seasons compared the corresponding wet seasons. Similarly, at the deepest monitoring site (Site 4), mean available light was 62% and 100% greater in the 2011 and 2012 dry seasons compared the corresponding wet seasons

Throughout the dry season, decreases in available light correlated with high cloud cover when there was no rainfall (Table 4). For example at Meadow 3 the shallowest of the monitoring meadows, during late November/early December 2013 it can be seen that there was a period of high cloud cover and correlating decreases in PAR (Figure 15).

The amount of available light at deep water seagrass meadow sites at Abbot Point was similar and comparable to the light environments at both Green Island off Cairns, and Lizard Island in the northern Great Barrier Reef where similar deep water seagrass meadows occur (Chartrand et al. 2014).

Table 4. Correlations for PAR, Cloudy Days and River Flow. Pearson's product-moment correlation coefficients (r) are presented, and the 95% confidence intervals are presented in the parenthesis ( ). Statistically significant correlations (*p < 0.05; **p < 0.01; ***p < 0.001) and corresponding confidence intervals are in bold.

Variable	Cloudy days	River Flow
PAR (Meadow 3)	**-0.41*** (-0.48 — -0.35)**	**-0.55*** (-0.61 — -0.50)**
PAR (Meadow 7)	**-0.38*** (-0.44 — -0.31)**	**-0.31*** (-0.38 — -0.23)**
PAR (Meadow 9)	**-0.32*** (-0.39 — -0.25)**	**-0.15*** (-0.21 — -0.08)**
PAR (Offshore 1)	**-0.18*** (-0.25 — -0.11)**	**-0.20*** (-0.27 — -0.13)**
PAR (Offshore 3)	**-0.33*** (-0.40 — -0.26)**	**-0.25*** (-0.35 — -0.20)**
PAR (Offshore 4)	**-0.23**8 (-0.30 — -0.15)**	**-0.11** (-0.19 — -0.03)**

PAR and cloudy days data were square root transformed and river flow data was log or log+1 transformed.
For meadow 9 PAR and river flow correlations were done on ranks.

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 (Figures 15 & 16). The maximum instantaneous water temperature recorded at the seabed at any of the sites was 34.2°C in September 2012 at coastal Meadow 3 (Euri Creek) (Figure 15). This corresponded with a spike in PAR (30.6 mol m^{-2} d^{-1}) and a midday low tide of 0.52m. 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 (Figure 16). Generally water temperatures at deeper sites were similar to the coastal sites except that they didn't have the extreme peaks during low tides. Maximum daily water temperatures in the coastal meadows ranged between 19.6 – 34.2°C, and 19.7 – 31.1°C for the deeper monitoring sites (Figures 15 & 16).

Some initial equipment reliability issues and people tampering with equipment once deployed resulted in missing light data during the first 12 months of the program. Subsequent improvements to the design of

equipment and establishing dual PAR and temperature loggers at each of the logging monitoring sites has provided greater data integrity and reduced data loss.

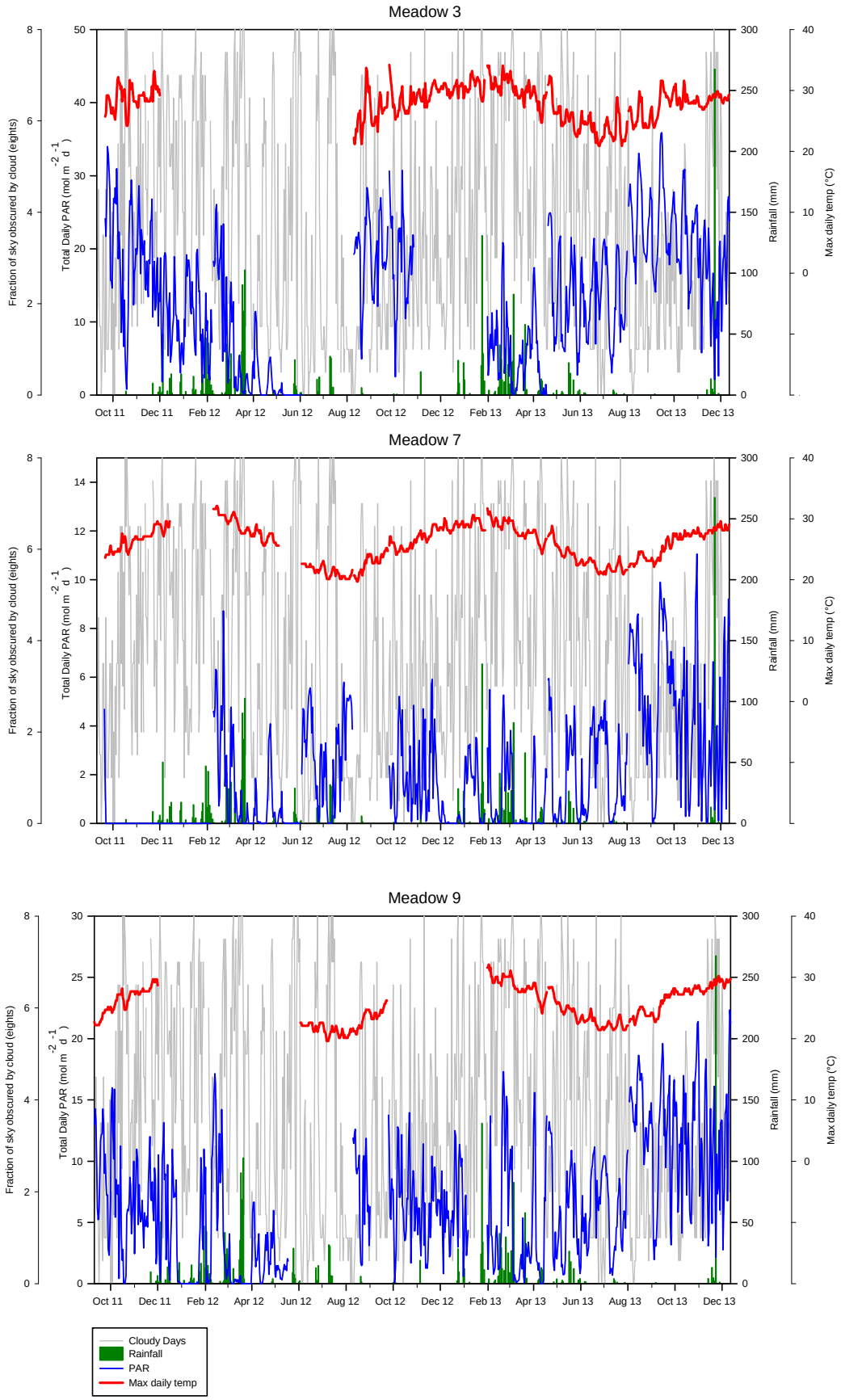


Figure 14. Total daily PAR (mol $m^{-1}day^{-1}$), maximum daily water temperature (°C), daily rainfall (mm) and fraction of sky obscured by cloud (measured in eighths/oktas) at the Abbot Point inshore monitoring sites, September 2011-December 2013.

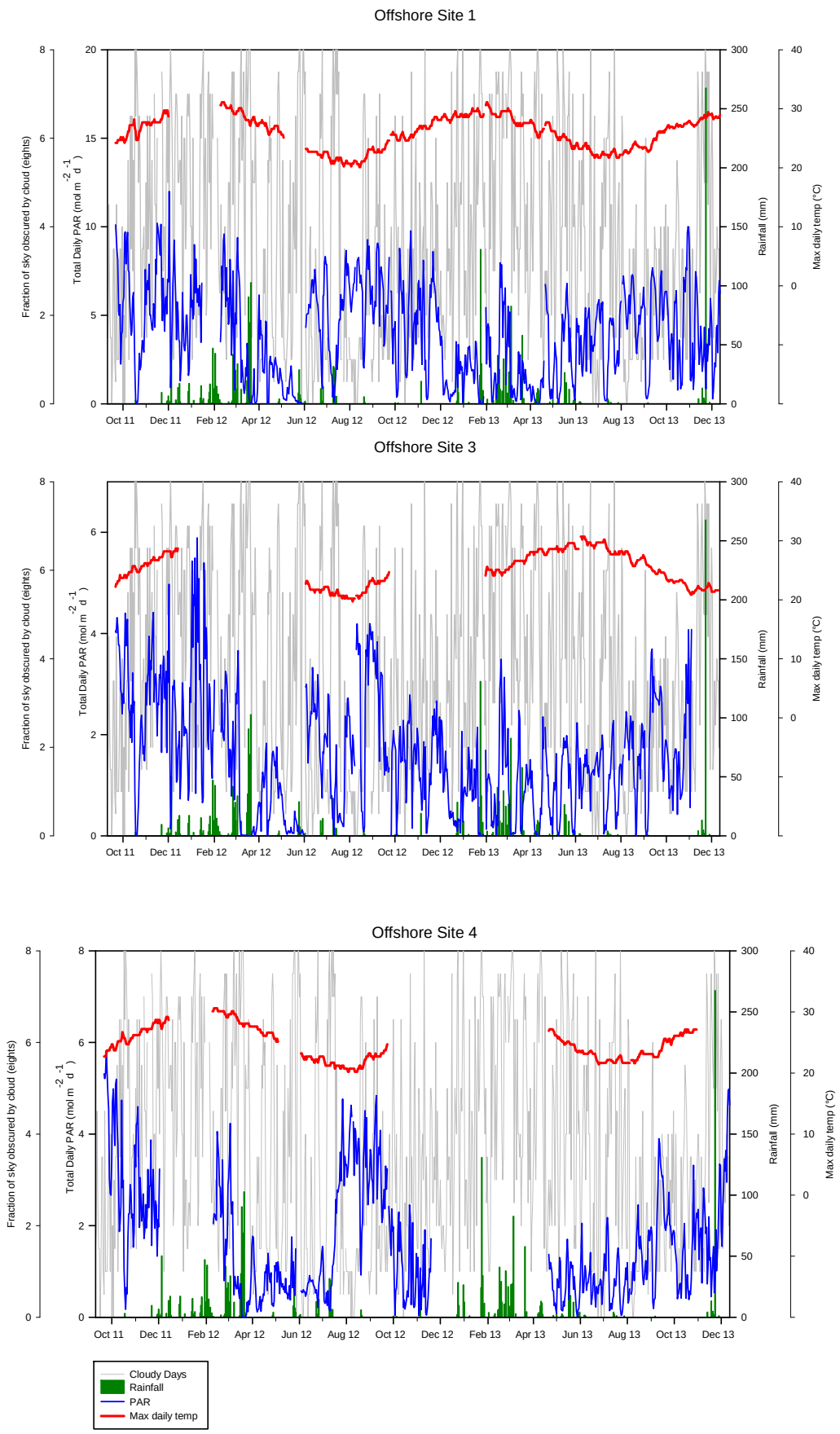


Figure 15. Total daily PAR (mol $m^{-1}day^{-1}$), maximum daily water temperature (°C), daily rainfall (mm) and fraction of sky obscured by cloud (measured in oktas/eighths) at the Abbot Point offshore monitoring sites, September 2011-December 2013.

3.4 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 La Niña system which ran from July 2010 to June 2011 and Tropical Cyclone Oswald in January 2013 (BOM 2013). TC Oswald had little impact on its initial landfall at Kowanyama on the western Cape York Peninsula on January 22nd 2013, but the remnant low moved southwards and produced severe weather over nearly all of eastern Queensland during the following week (BOM 2013). Destructive winds of up to 140 km/h were recorded at Hay Point near Mackay (200km south of Abbot Point).

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 16). Since April 2011, rainfall in the Bowen area has generally remained below average, with the exception of a couple of months in the 2012 and 2013 wet season (March 2012, January, March, May & November 2013). Rainfall in July 2012 (the dry season) was also above the long-term average. Total annual rainfall in Bowen in 2012 and 2013 was near to the long-term average (Figure 16 inset).

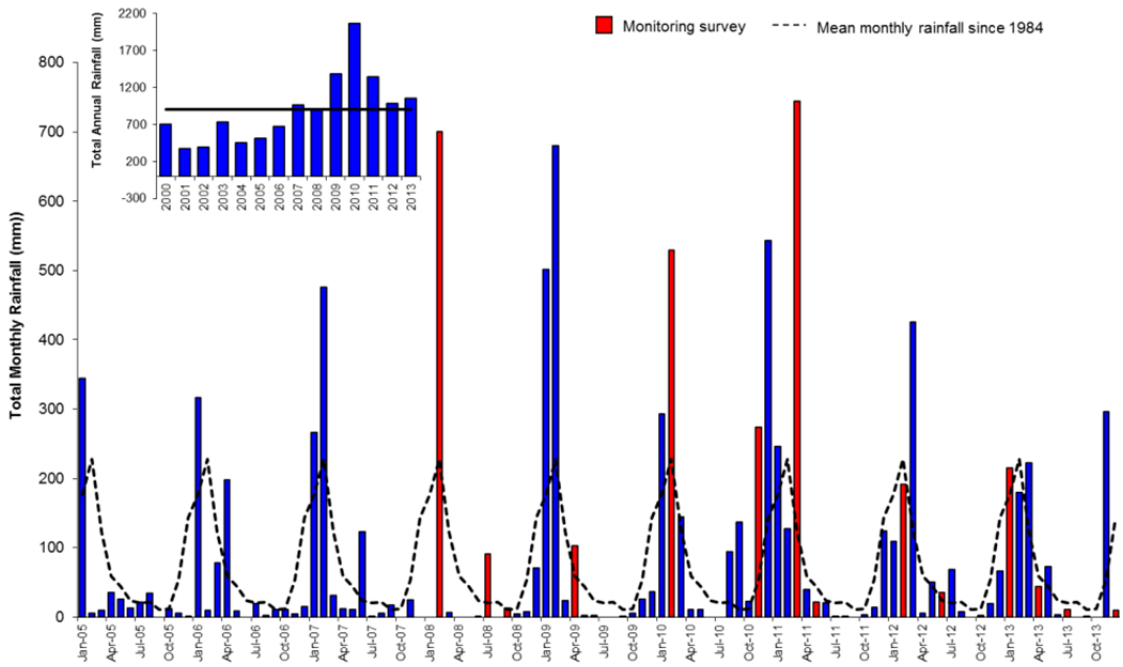


Figure 16. Total monthly rainfall (mm) from January 2005 to December 2013 and (inset) total annual rainfall from 2000 to 2013 for the Bowen area. Data source www.bom.gov.au (Station #33257).

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 November 2011, with 2011 having the highest total annual river flow since 1991 (Figure 17). River flow remained below the long-term average until March 2012 when it peaked to nearly five times the long-term monthly river flow average. River flow then generally remained below the long-term average until January 2013 where high flows coincided with TC Oswald (Figure 17). Total annual river flow was below the long-term average in 2013.

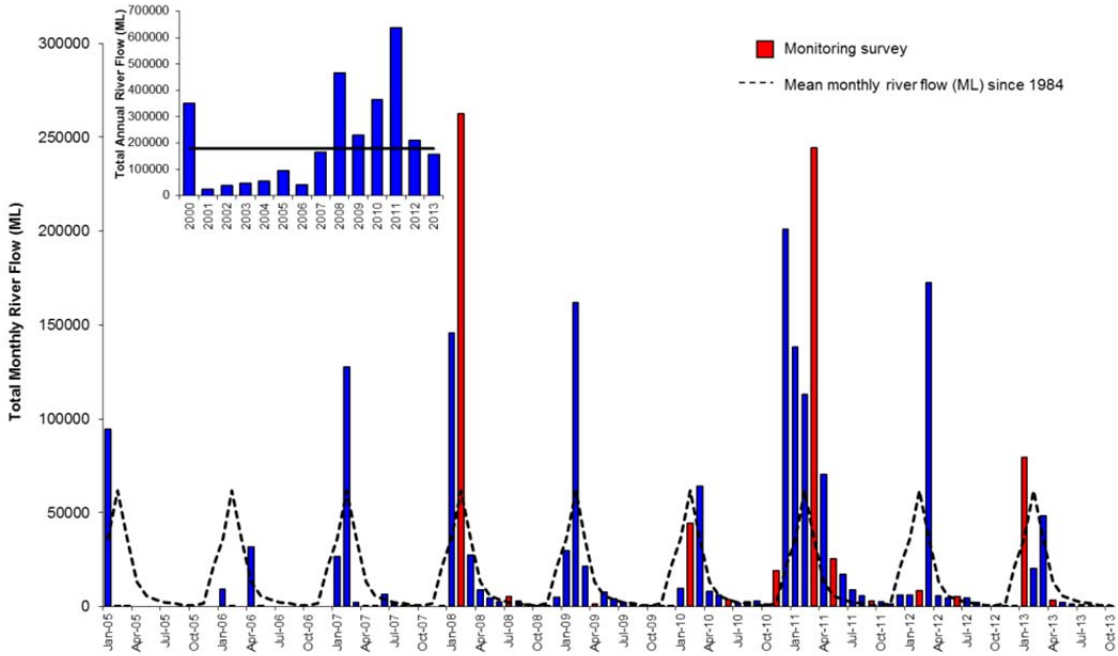


Figure 17. Total monthly river flow from January 2005 to October 2013 and (inset) total annual river flow from 2000 to 2013 for the Don River. **NB**: Annual value for 2013 is January 2013 to October 2013 only. Data source: www.ehp.qld.gov.au (Station #121003A).

Mean cloud cover

Cloud cover is measured visually by estimating the fraction (in eighths or oktas) of the dome of the sky covered by cloud (BOM 2013). A completely clear sky is recorded as zero okta, while a totally overcast sky is 8 oktas. The presence of any trace of cloud in an otherwise blue sky is recorded as 1 okta, and similarly any trace of blue in an otherwise cloudy sky is recorded as 7 oktas (BOM 2013). Cloudy days have been presented in this report as the amount of cloud in the sky can affect how much available light (PAR) is reaching the sea floor. As expected the number of cloudy days was higher in the wet season at the beginning and end of 2013 (Figure 18). The highest number of clear days was recorded between September and October 2013.

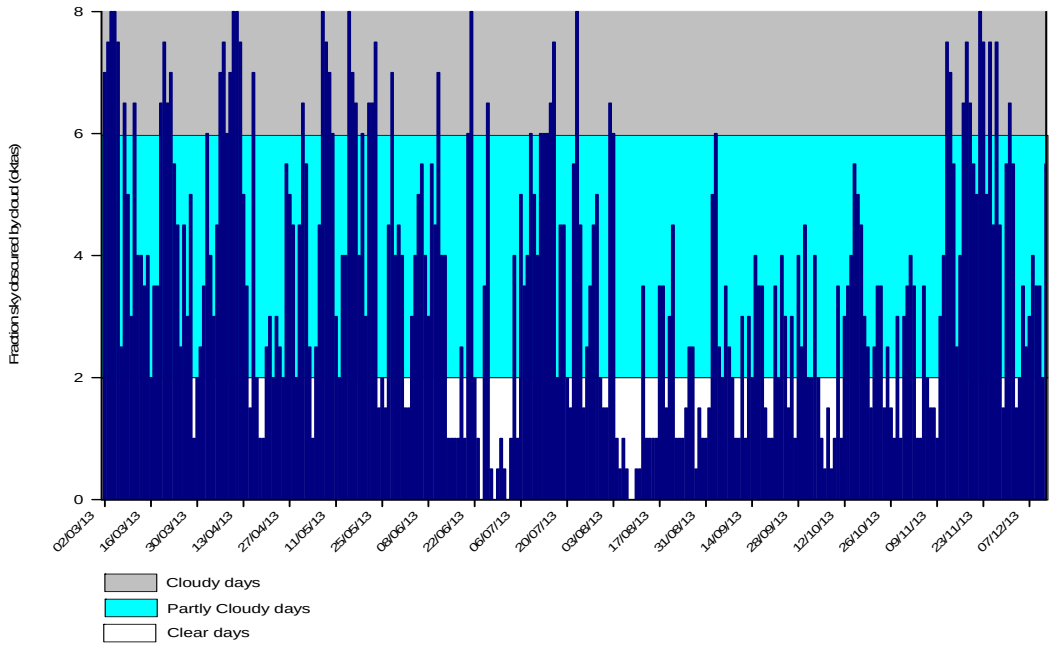


Figure 18. Mean number of clear and cloudy days between March and December 2013 (0 = clear day; 8 = cloudy day). Data source www.bom.gov.au (Station #33257).

4 DISCUSSION

Significant losses of seagrass density and distribution at Abbot Point were observed following major climate events including Tropical Cyclone Hamish (March 2009), the 2010/11 La Niña events, Tropical Cyclone Yasi (February 2011), and Tropical Cyclone Oswald (January 2013). Between TC Hamish and TC Yasi inshore and offshore seagrasses were able to recover to some degree. However, since the 2010/11 La Niña and TC Yasi related losses, recovery of seagrass primarily occurred at the deep water Abbot Point monitoring sites, with limited to no recovery in the inshore monitoring meadows. Deep water seagrass recovery was once again stalled after TC Oswald in early 2013, and seagrass at the inshore monitoring sites continued to show only limited signs of initial recovery.

Recent studies at Abbot Point have shown that deep water seagrasses have the capacity to recover after repeated significant climate events (Rasheed et al. 2014); however multiple years of seagrass decline are likely to leave a legacy of reduced resilience of seagrasses to further impacts. As a result seagrasses may be more susceptible to wet season conditions and additional major impact events compared to previous years. In other north Queensland seagrass monitoring locations such as Mourilyan Harbour and Cairns repeated impacts have led to sustained losses of seagrasses and in the case of Mourilyan recovery remains unlikely to occur for key meadows without some form of assisted restoration (Jarvis et al. 2014; York et al. 2014).

Seagrass recovery from disturbance can occur through both sexual (seeds) and asexual (rhizome extension or vegetative fragmentation) mechanisms. At Abbot Point coastal meadows dominated by *H. uninervis* are likely to have a strong reliance on asexual reproduction for recovery from losses, while the deep water *Halophila* species can recover quickly (3 months) from experimental disturbance through a combination of sexual and asexual reproduction (Rasheed et al. 2014). *Halophila* species are well adapted for recovery once conditions become favourable after disturbance (McMillan 1991; Hammerstrom et al. 2006) and typically produce large seed banks; 134 - 13,500 m^{-2} (McMillan 1988; Hammerstrom et al. 2006) from which recovery can occur. A *Halophila* seed bank at Abbot Point has been previously quantified, however multiple years of recovery and decline may have depleted offshore *Halophila* seed banks, with adult plants potentially putting more energy into shoot and/or rhizome growth and not into sexual reproduction (producing flowers, fruits & seeds) (Erftmeijer and Stapel 1999; Hammerstrom et al. 2006). In addition, the viability of the seed bank, defined as the ability of seeds to germinate (Fenner and Thompson 2005), decreases over time unless it is replenished. As a consequence there may be fewer viable seeds remaining in the sediment reducing potential seedling recruitment for the next growing season, and subsequently delaying recovery. Until deep water seagrasses have recovered, and the seed bank is re-stocked, seagrass colonising deep water areas may be increasingly vulnerable to further disturbance events (Rasheed et al. 2014).

In order to better establish the ability of seagrasses at Abbot Point to recover and their changing levels of resilience over time it is planned to add regular seed bank assessments and viability testing of the seeds to the monitoring program during 2014.

The shallow inshore meadows previously comprised of *H. uninervis* and *Z. muelleri* have not shown substantial recovery in the 33 months following TC Yasi. In manipulative field experiments, these meadows were unable to recover when all adult plants were removed due to the near absence of seeds for these species in the shallow seagrass meadow seed banks (*Z. muelleri* 0 ± 0 seeds m^{-2}; *H. uninervis* 5 ± 2 seeds m^{-2}) The production of seed banks for these species appears to be highly site and location specific, with many other meadows in Queensland capable of forming large seed banks, including in Townsville (7000 seeds m^{-2}) (McKenzie et al. 2010) and Gladstone (700–900 seeds m^{-2}) (McCormack et al. 2012), while other locations had seed banks similar to Abbot Point (Rasheed 2004; McCormack et al. 2012; Jarvis et al. 2013). The likely high reliance of *Halodule uninervis* and *Zostera muelleri* on asexual reproduction for recovery (Rasheed 2004; Rasheed et al. 2014), 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 which in other locations can take more than 10 years (Kirkman 1978; Birch and Birch 1984; Hyland et al. 1989; Poiner et al. 1989; Campbell and McKenzie 2004).

It was discussed in the 2012 annual report that 'the recovery of the shallow coastal meadows via seed or vegetative fragment dispersal from outside the study area was also likely to be limited, with the nearest substantial meadows that could provide *Halodule* and *Zostera* propagules being at Upstart Bay, 50 Kilometres to the north'. We now know as a result of the 2013 baseline surveys that there are some small *H. uninervis* meadows on both the western and eastern side of the Abbot Point wharf, and there is a relatively large *Z. muelleri* meadow between the Bowen Marina and Tug Boat wharf (pers. obs.). Although the abundance and distribution of these *H. uninervis* and *Z. muelleri* meadows in the broader port area has declined since the 2008 baseline surveys, these meadows may provide a potential source from which recovery of the inshore meadows could occur through propagules dispersal. However, the effects of distance and the influence of environmental conditions on propagule dispersal (via seeds and/or fragments) for these species are still poorly understood.

Halodule seeds are formed under the sediment and neutrally or negatively buoyant possibly limiting dispersal (Hall et al. 2006; Kendrick et al. 2012), while *Zostera* can producing floating reproductive shoots capable of dispersing 20-300 km (Reusch et al. 2000; Harwell and Orth 2002). In addition Hall et al. (2006) found that floating fragments of *Halodule wrightii* were capable of remaining viable up to four weeks, allowing time for dispersal at relatively large distances (i.e. kilometres). Therefore, the potential scale of dispersal is limited by hydrodynamic processes as well as viability for many seagrass species (Harwell and Orth 2002; Hall et al. 2006; Kendrick et al. 2012).

In combination with the availability of propagules to help with recovery, other processes associated with flooding and storm impacts also have the potential to influence seagrass recovery including light, salinity, nutrients and sediment chemistry (Carlson et al. 1994; Lirman & Cropper 2003; Campbell & McKenzie 2004; Ralph et al. 2007; Chartrand et al. 2012; Collier et al. 2012a & b; Collier et al. 2014; Petus et al. 2014). The 2012 annual report and Rasheed et al. (2014) discussed in detail the importance of light as a major factor in determining seagrass growth, and in combination with the physical disturbances associated with TC Yasi, light reduction was likely a major contributor to the observed declines in seagrasses at Abbot Point after TC Yasi. In tropical regions seagrass genera such as *Zostera* and *Halodule* have significantly greater light requirements (Grice et al. 1996; Bach et al. 1998; Longstaff and Dennison 1999; Longstaff 2003; Collier et al. 2009a & b; Collier et al. 2012b) than *Halophila* (Udy and Levy 2002; Fourqurean et al. 2003; Freeman et al. 2008). At Abbot Point it has been the higher light requiring species; *Zostera muelleri* and *Halodule uninervis* that have been most negatively impacted by disturbance.

While light reduction may have played an important role in the observed seagrass decline, it is unlikely that light availability was a major contributor to the lack of recovery observed at the inshore meadows at Abbot Point, particularly in the Euri Creek *Z. muelleri* meadow. At this meadow mean daily PAR in the 2011/2012 and 2012/2013 growing seasons (July to January) was 15.38 mol m^{-2} d^{-1} and 18.85 mol m^{-2} d^{-1} respectively, and did not fall below light thresholds developed for shallow intertidal *Z. muelleri* meadows in Gladstone Harbour of 6 mol m^{-2} d^{-1} sustained over a minimum period of two weeks for longer than 4 days (Chartrand et al. 2012). This suggests that in the Abbot Point growing seasons light was likely above the minimum requirement for seagrass growth. The fact that *Zostera* has been unable to recover is probably due to the lack of available propagules previously discussed (seeds or remaining adult plants). This meadow was completely lost after the 2010/2011 floods and cyclones, and no seeds were found in the seed bank for this meadow.

At times light available to the coastal *H. uninervis* meadows during 2012 and 2013 (Meadows 7 & 9) has been less favourable with levels regularly below the thresholds thought to be required for the species to maintain positive growth for extended periods of up to 30 days (5.2 mol m^{-2} d^{-1}) (Collier et al. 2012b). However during the growing season between August and December 2013 light conditions had improved and remained above these minimum levels. These improved light conditions coincided with the return of *H.*

uninervis to some of the meadows. Similar to the coastal *Z. muelleri* meadow the lack of recovery of *H. uninervis* in some coastal sites despite good light conditions was likely due to the lack of propagules from which recovery could occur following the complete loss of meadows.

Implications for Port Management

Multiple years of climate induced seagrass decline are likely to have left a legacy of reduced resilience to to further impacts. Results of the latest surveys indicate that at least three of the five inshore monitoring meadows may be showing initial signs of recovery, while the offshore seagrass meadows have declined since January 2013 after positive signs of recovery through 2011 and 2012. One of the benefits of conducting the 2013 baseline surveys was that the surveys described *H. uninervis* meadows in the broader Abbot Point area and we know that *Z. muelleri* is present in Bowen Harbour. These meadows may be potential sources for inshore seagrass meadow recovery through dispersal of seeds and fragments, and may be vital to maintaining the long-term health of the Abbot Point seagrass meadows.

Considering the state of seagrass resilience will be important in managing potential impacts of future port activities and developments especially considering the generally reduced state of resilience for most meadows following recent climate events. 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. A key addition to the program during 2014 will be an examination of the seed bank density and the viability of seagrass seeds as part of monitoring which will provide critical information on the continuing resilience of seagrasses and their ability to recover from stresses

The current monitoring program at Abbot Point provides a sound basis for developing effective local light management triggers for both the offshore and coastal seagrass meadows that are appropriate to the ecological requirements of local seagrass species. Light data currently being collected at Abbot Point combined with regular assessments of seagrass change provide a good framework to develop a light based management approach, although some additional *in situ* or laboratory based experimental research may be required to further refine these targets.

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A APPENDICES

A.1 Statistical Analysis

Results of multiple Comparisons of Means using Tukey Contrasts with a Holm adjustment (sequentially compares the lowest p-value with a Type I error rate that is reduced for each consecutive test) comparing mean above-ground seagrass biomass at the offshore monitoring sites (all site data pooled). Cells marked with a "Yes" indicates a significant difference in biomass ($p < 0.05$) between comparison surveys and cells marked "No" indicates no significant difference in biomass between surveys.

P<0.05

Sampling Time	Mar-05	Mar-08	Jul-08	Sep-08	Nov-08	May-09	Aug-09	Jun-10	Nov-10	Mar-11	May-11	Sep-11	Feb-12	Jun-12	Sep-12	Jan-13	Apr-13	Aug-13	Sep-13	Dec-13
Mar-05																				
Mar-08	No																			
Jul-08	No	No																		
Sep-08	No	No	No																	
Nov-08	Yes	Yes	Yes	No																
May-09	No	No	No	Yes	Yes															
Aug-09	No	No	No	No	Yes	No														
Jun-10	No	No	No	No	Yes	No	No													
Nov-10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes												
Mar-11	No	No	Yes	Yes	Yes	No	No	No	Yes											
May-11	No	No	Yes	Yes	Yes	No	No	No	Yes	No										
Sep-11	No	No	No	Yes	Yes	No	No	No	Yes	No	No									
Feb-12	No	No	No	No	Yes	No	No	No	Yes	No	No	No								
Jun-12	No	No	No	No	Yes	No	No	No	Yes	No	No	No	No							
Sep-12	No	No	No	No	Yes	No	No	No	Yes	No	No	No	No	No						
Jan-13	No	No	Yes	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No					
Apr-13	No	No	Yes	Yes	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	No				
Aug-13	No	No	Yes	Yes	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	No	No			
Sep-13	No	No	Yes	Yes	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	No	No	No		
Dec-13	No	No	Yes	Yes	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	No	No	No	No	

A.2 Abundance and Distribution Comparisons 2005 - 2012

1. Mean above-ground biomass (g DW m^{-2}) of coastal monitoring meadows within the Port of Abbot Point, March 2005, February 2008 – December 2013.

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
Jan 13	NP	NP	NP	NP	NP
Apr 13	3.10 ± 0 (1)	NP	0.25 ± 0 (1)	NP	4.42 ± 0 (1)
Jul 13	NP	NP	2.74 ± 0.91 (5)	NP	1.67 ± 0 (1)
Sept 13	NP	NP	1.53 ± 0.72 (4)	NP	3.07 ± 1.55 (3)
Dec 13	2.16 ± 0.75 (3)	NP	2.40 ± 1 (4)	NP	1.60 ± 1.07 (3)

NP – No seagrass present in meadow

2. Area (ha) of coastal monitoring meadows within the Port of Abbot Point, March 2005, February 2008 – December 2013.

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**
Jan 13	NP	NP	NP	NP	NP	**NP**
Apr 13	6.28 ± 5.3	NP	6.81 ± 6.4	NP	1.2 ± 1	**14.29 ± 12.7**
Jul 13	NP	NP	13.27 ± 4.84	NP	1.23 ± 1.02	**14.5 ± 5.86**
Sept 13	NP	NP	28.86 ± 13.86	NP	35.11 ± 15.47	**63.97 ± 29.33**
Dec 13	10.19 ± 1.6	NP	19.76 ± 2.79	NP	27.08 ± 2.89	**57.03 ± 7.28**

NP – No seagrass present in meadow

3. Mean above-ground biomass (g DW m^{-2}) of offshore monitoring sites in the Port of Abbot Point, March 2005, February 2008 – December 2013.

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)*
Jan 13	0.01 ± 0.009 *(Halophila spinulosa Halophila ovalis)*	NV	0.14 ± 0.03 *(Halophila spinulosa Halophila ovalis)*	0.04 ± 0.02 *(Halophila decipiens)*
Apr 13	0.01 ± 0.009 *(Halophila spinulosa)*	0.04 ± 0.01 *(Halophila spinulosa)*	0.03 ± 0.02 *(Halophila spinulosa)*	0.01 ± 0.009 *(Halophila spinulosa)*

Jul 13	NP	0.02 ± 0.01 *(Halophila spinulosa)*	0.09 ± 0.05 *(Halophila spinulosa)*	NP
Sept 13	NP	0.08 ± 0.03 *(Halophila spinulosa)*	0.02 ± 0 *(Halophila spinulosa)*	0.02 ± 0.01 *(Halophila spinulosa)*
Dec 13	NP	0.03 ± 0.02 *(Halophila spinulosa)*	0.09 ± 0.03 *(Halophila spinulosa)*	0.06 ± 0.02 *(Halophila spinulosa)*

* - 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

NV – No visability at site