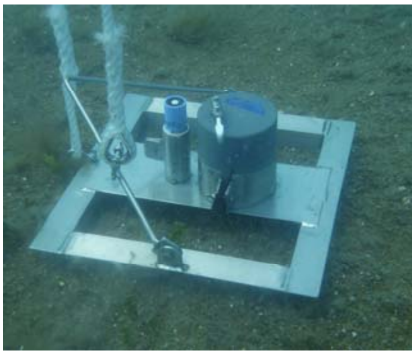
Department of Employment, Economic Development and Innovation

Port of Abbot Point Long-Term Seagrass Monitoring:

Update Report 2008-2011



McKenna, SA. & Rasheed, M.A.

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EXECUTIVE SUMMARY

This report summarises the results of the coastal and deepwater seagrass monitoring program conducted between June 2010 and September 2011 at the Port of Abbot Point. The report also discusses the status of light and temperature assessments, and recovery experiments that have been included as part of the monitoring program in the Port. The seagrass monitoring program at Abbot Point was developed in 2008 following two baseline assessments of the marine habitat within the port limits.

Seagrasses at Abbot Point were highly dynamic, changing as a function of season, and further influenced by extreme weather events during the life of the study. Seagrass biomass and distribution was generally lowest at the end of the wet season and greatest in the late dry season, a trend consistent with observations of seagrasses throughout Queensland.

Results of the latest survey indicate that seagrasses at Abbot Point are in a vulnerable state. Significant losses of density and distribution of seagrasses at Abbot Point were observed after the November 2010 survey, particularly in the coastal monitoring meadows. The La Niña events of 2010/11 combined with severe Tropical Cyclone Yasi are the most likely factors that caused these significant losses. Consecutive above average wet seasons since late 2009 have also potentially left seagrasses with substantially reduced resilience to further stressors. The cumulative impacts of natural stressors, combined with a potential increased level of impact from future port activities and development, places these seagrasses at a heightened risk.

Seagrasses at Abbot Point have the potential to recover, however this recovery is dependent upon the species present and the availability of seed reserves. Studies at Abbot Point between 2008 and 2010 found that *Halophila spinulosa*, the dominant seagrass species 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 simulated disturbance, relying on asexual propagation making them more vulnerable to longer term impacts should widespread loss occur.

The seagrass monitoring and research program findings demonstrate the importance of developing effective management strategies for future developments that may potentially disturb the local water quality (particularly light availability) at Abbot Point. Water quality management linked to the local ecological requirements of seagrasses will help ensure the resilience of seagrasses in the area during planned large scale capital works in the port. This monitoring program provides the basis for such assessments which will be critical should the current vulnerable state of seagrasses continue.

BACKGROUND

In 2008 North Queensland Bulk Ports Corporation (NQBP) commissioned the Marine Ecology Group (MEG) through the Department of Employment, Economic Development and Innovation (DEEDI) to develop and conduct a seagrass assessment and experimental program for the Port of Abbot Point. This program involved two baseline surveys of the marine habitat within the port limits and experimental research of the seagrass at the port beginning in February 2008 (Map 1; Table 1). The goal of the program was to provide key information to aid in selecting the most sound port development options that have minimal impacts on the marine environment, and to also act as a foundation for the development of suitable management strategies to protect seagrasses based on their resilience and capacity for recovery. The studies conducted at Abbot Point since 2008 have assisted with the state and commonwealth agency consultation regarding the Multi Cargo Facility (MCF) project. The baseline assessments were also used to establish a longer term monitoring strategy for seagrasses within the port environment.

The baseline surveys in 2008 mapped more than 20,000 hectares of deepwater and coastal seagrass communities within the port limits (Map 1) (McKenna et al. 2008). The survey area contained a variety of species and meadow types ranging from low biomass coastal *Halodule uninervis* meadows to higher biomass, deep water *Halophila spinulosa* meadows. The experimental program conducted between 2008 and 2010 found that seagrass meadows at Abbot Point are very productive and are comparable with many productive marine and terrestrial ecosystems worldwide (Unsworth et al. 2010). The productivity of these seagrasses was found to provide habitat and food for a range of important fauna, with many species of economically important *Penaeid* prawns utilising the seagrass meadows of Abbot Point. This is in addition to the presence of a range of endangered and migratory megafauna such as dugong, turtle and humpback whales observed in proximity to the port. Seagrasses also provide other ecosystem services including nutrient and carbon trapping and cycling, sediment and bank stabilisation, and the primary productivity that underpins much of the coastal marine ecosystem (Costanza et al. 1997; Hemminga and Duarte 2000; Kennedy and Björk 2009).

The experimental program also found Abbot Point seagrasses had some level of resilience to stress, however this varied with species and community type and will be dependent upon the continued availability of seed reserves in the future (Unsworth et al. 2010). Species such as *Halophila spinulosa* had a high capacity for recovery through the use of seed reserves in the sediment, however, shallow nearshore species such as *Halodule uninervis* failed to recover quickly from simulated disturbance, relying on asexual propagation. As a result *Halodule uninervis* is considered more vulnerable to longer term impacts should widespread loss occur.

The seagrass assessment and experimental program at Abbot Point formed the basis of a monitoring strategy to aid in the management of dredge related impacts and to assess the long term condition and trend for this fisheries habitat. Quarterly monitoring of selected coastal seagrass meadows and selected offshore sites has continued since 2008 and NQBP has commissioned the Marine Ecology Group to continue these quarterly assessments until May 2013. Further recovery experiments will also be carried out to complete our understanding of key seagrass communities that may be affected by port developments at Abbot Point. New to the program is the assessment of light and temperature within the seagrass canopy. These assessments will help relate changes in the Abbot Point seagrass meadows to the major seasonal drivers of change.

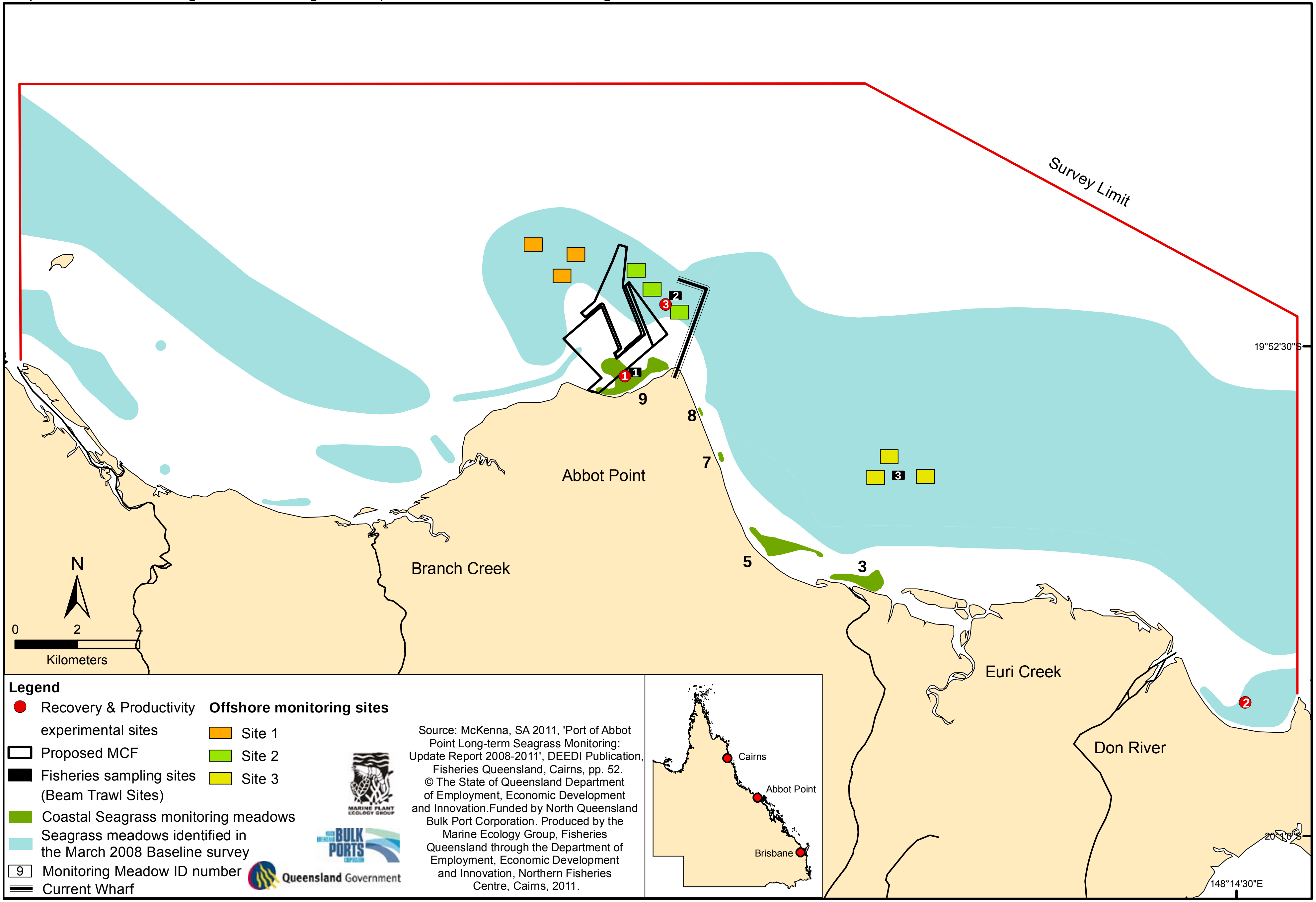
Abbot Point seagrass meadows are subject to a range of potential anthropogenic and natural threats reducing their resilience to cumulative impact. The available information indicates that future developments that may potentially disturb the local water quality (particularly light availability) at Abbot Point need to be carefully managed to ensure the longer term viability of seagrasses.

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

1. Compare results of baseline and seasonal monitoring events to assess any changes in seagrass distribution and abundance in relation to natural events or human induced port and catchment activities;
2. Establish the capacity for recovery of key seagrass meadow types likely to be affected by the proposed developments;
3. Relate changes measured in seagrass meadows to light and temperature data collected;
4. 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 quarterly coastal and deepwater seagrass surveys from 2008-2011 as well as the status of the light and temperature measurements and recovery experiments.

Map 1. Location of Seagrass Monitoring and Experimental sites & 2008 Seagrass Distribution in the Port of Abbot Point



METHODS

Sampling Approach & Methodology

The seagrass program at Abbot Point has three components, (1) quarterly assessments of established monitoring meadows, (2) quarterly assessments of the capacity for recovery for the species *Zostera capricorni*, and (3) light and temperature assessments in the seagrass canopy.

1. Quarterly Assessment of Established Monitoring Meadows

From the results of the baseline surveys in 2008 (McKenna et al. 2008), five coastal meadows and three offshore areas were identified as suitable for long-term seagrass monitoring (Map 1). In November 2010, an additional offshore monitoring site was added to the program, while offshore Site 2 was moved to the eastern side of the current wharf at the request of NQPB due to potential development and dredge operations in the immediate area (Map 2). The addition of Site 4 was to add another "reference" site away from proposed development. These monitoring sites were selected because they represented the full range of seagrass species and habitat types present in the Port of Abbot Point. They also form key sensitive receptor sites for assessing seagrass condition during the dredging operation and post dredging recovery.

These monitoring meadows have been assessed approximately quarterly (weather dependent) since May 2008 with the last monitoring survey occurring in September 2011 (Table 1). Quarterly assessments were used to better establish within and among year variation of seagrasses prior to, during and after the planned MCF dredging project.

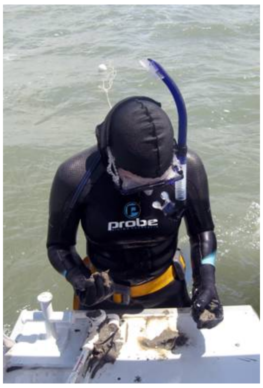
Methods for assessing the coastal seagrass monitoring meadows and offshore monitoring sites were the same as those already established for the program at Abbot Point (see McKenna et al. 2008 & Unsworth et al. 2010). Standard methodology applied at Abbot Point and throughout Queensland allows for direct comparison of local seagrass dynamics with the broader region.

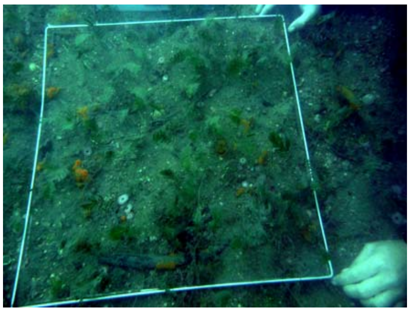
A. Coastal Monitoring

Coastal sampling sites were assessed by divers. Sites were located along transects perpendicular to the shoreline extending approximately 1 km offshore with random sites used to measure continuity of bottom habitat between transects. Sampling intensity was approximately 20m to 100m intervals along each transect. Transects continued to the seaward edge of any seagrass meadows encountered.

At each survey site, seagrass meadow characteristics, including seagrass species composition, above-ground biomass, percent algal cover and sediment type were determined from three random placements of a 0.25 m^2 quadrat. The percent cover of other major benthos at each site was also recorded as well as time, depth below mean sea level (MSL) and position (GPS).

Seagrass biomass (above-ground) was determined using a "visual estimates of biomass" technique (see Kirkman 1978 and Mellors 1991). This technique involves an observer ranking seagrass biomass in the field in three random placements of a 0.25m^2 quadrat at each site. Ranks are made in reference to a series of quadrat photographs of similar seagrass habitats for which the 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 recorded by GPS were assessed by free divers to measure seagrass biomass and species composition to characterise the coastal habitat.

B. Offshore Monitoring

Within each of the four offshore sites, three replicate blocks were randomly selected to monitor, with three 100 metre transects randomly sampled within each block. The start and finish of each transect was recorded using a Global Positioning System (GPS) accurate to ± 5m.

Offshore sites were surveyed using a CCTV camera system, with real-time monitor; this was towed from the research vessel '*Pearl Bay*'. At each sampling site, the camera system was towed for 100 metres at drift speed (approximately one knot). Footage was observed on a TV monitor and recorded. The camera was mounted on a sled that incorporates a sled net 600mm width and 250mm deep with a net of 10mm-mesh aperture. Surface benthos was captured in the net (semi-quantitative bottom sample) and used to confirm seagrass, algal and benthic macro-invertebrate habitat characteristics and species observed on the monitor. A Van Veen grab was used to confirm sediment type. This method has been used extensively by the MEG for deepwater benthic surveys in the Ports of Abbot Point, Hay Point, Mackay and Gladstone (Rasheed et al. 2001; Rasheed et al. 2003; Rasheed et al. 2005), as well as throughout the Great Barrier Reef Lagoon and other locations off the Queensland coast (Coles et al. 1996; Coles et al. 2009). The technique ensured a large area of seafloor was integrated at each site so that patchily distributed seagrass and benthic life that typifies deepwater habitats in the region could be detected.

Data recorded at each site included:

1. ***Seagrass species composition*** – Seagrass identifications in the field and from video according to Kuo and McComb (1989). Species composition measured from the sled net sample and from the video screen when species are distinct.

2. ***Seagrass biomass*** – Estimates of seagrass biomass from video images using a calibrated visual estimates technique adapted from Mellors (1991). This involves making random video grabs from the digital videotape with the constraint that visibility is acceptable for the selection. A visual estimate of above-ground biomass was made by an observer viewing the screen. All observers calibrated to a standard set of video images that have been harvested and measured.

3. ***Algae*** – Presence/absence, algae type and percent cover were identified according to Cribb (1996). Percent cover was estimated from the video grab. Algae type was grouped into 5 taxa:

- ***Erect Macrophytes*** - macro algae with an erect growth form and high level of cellular differentiation e.g. *Sargassum, Caulerpa* and *Galaxaura* species
- ***Erect Calcareous*** - algae with erect growth form and high level of cellular differentiation containing calcified segments e.g. *Halimeda* species
- ***Filamentous*** - thin thread like algae with little cellular differentiation.
- ***Encrusting*** - algae growing in sheet like form attached to substrate or benthos e.g. coralline algae.
- ***Turf Mat*** - algae that forms a dense mat or turf on the substrate.

4. ***Sediment type*** – A 0.0625m^2 Van Veen grab was used to obtain a sediment sample at each site. Grain size categories were then identified visually as; shell grit, rock, gravel shell grit, rock, gravel (>2000µm), coarse sand (>500µm), sand (>250µm), fine sand (>63µm) and mud (<63µm).

5. ***Site location*** – by GPS including weather conditions at the time of sampling

Offshore video sampling sled, and sorting benthic samples from the sled net

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*** – point 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.

2. Seagrass Capacity for Recovery

Key aspects of seagrass recovery, productivity, resilience and fisheries value were examined at three seagrass meadows in Abbot Point between 2008 and 2010 (Map 1). The studies provided information on how these meadows are likely to respond to development related disturbance by quantifying aspects of their ecological and fisheries values (see Unsworth et al. 2010).

Information collected to date has formed the basis for assisting in the development of appropriate triggers and mitigation strategies to minimise impacts to seagrass habitat as well as assisting in prioritising seagrass areas for protection. There were three major components to the experimental investigations at Abbot Point:

1. Capacity for seagrass recovery
2. Seagrass productivity
3. Fisheries value of Abbot Point seagrasses

A new recovery site was to be established in the coastal *Zostera capricorni* monitoring meadow (3) located near Euri Creek (Map 2) with assessments to continue until 2013. Meadow 3 is an intertidal to shallow subtidal seagrass community that was not included in the original experimental program at Abbot Point due to logistical issues with accessing the site when the program began. With the extension and expansion of the seagrass assessment program at Abbot Point, collecting information on the capacity for recovery for this seagrass meadow will complete the baseline information of all key meadow types present in the Abbot Point Area. This recovery site will be sampled quarterly in conjunction with the long-term coastal and offshore monitoring aspects of the program.

The recovery site in meadow 3 was to be established in August 2011. Since March 2011 however, seagrass has been absent in this meadow so the recovery experiment has therefore not begun and results will not be discussed in this report. Once seagrass returns to the meadow quarterly assessments of recovery can begin.

3. New to the Program - Light and Temperature Assessments

To enhance the quarterly monitoring surveys light and temperature loggers were deployed at six sites in September/October 2011; three in coastal meadows and three in offshore meadows (Map 2). Knowledge of the background relationships that exist between seagrass and local environmental variables is critical for estimating and managing future environmental risk from the proposed development.

There are a range of environmental factors that potentially affect seagrasses however light and temperature are of particular importance. The majority of seagrass meadows in the area may be light limited for much of the year due to naturally high levels of turbidity. Such marginal conditions can be further aggravated by port activities such as dredged related turbidity plumes leading to elevated stress and mortality (Erftemeijer & Lewis 2006). The effects of changing light (photosynthetically active radiation or PAR), turbidity and temperature can vary both according to species and site. It is therefore necessary to collect this information for the unique seagrass community types present to provide better baseline information to interpret seagrass change.

Results from the temperature and light loggers at Abbot Point will not be discussed in this report as no data has been collected. First collection of logger data will occur in November 2011 at the time of the next quarterly monitoring survey.

Statistical Analysis

To determine differences in seagrass biomass of individual meadows, an equal variance test was completed to determine the best fit test statistic for the analysis. If the data passed the equal variance test (i.e. Bartlett's), a simple one-way Analysis of Variance (ANOVA) was conducted in SigmaPlot v.11.0. Where data failed the equal variance test, a Behrens-Fisher test was used (Zar 1999). The Behrens-Fisher is a two-tailed t test that uses a weighted degrees of freedom due to the unequal variances among the groups being tested.

The test statistic is:

$$t' = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

and the degrees of freedom is calculated as

.

$$\nu' = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2 - 1}}$$

Since the majority of the data did not follow a normal distribution, an α level of 0.01 was used to minimise the possibility of recording a type 1 error (Underwood 1997). Detailed results are presented in Appendix 1.

Map 2. Location of Established Monitoring Meadows, Temperature & Light Loggers and Proposed Experimental Site.

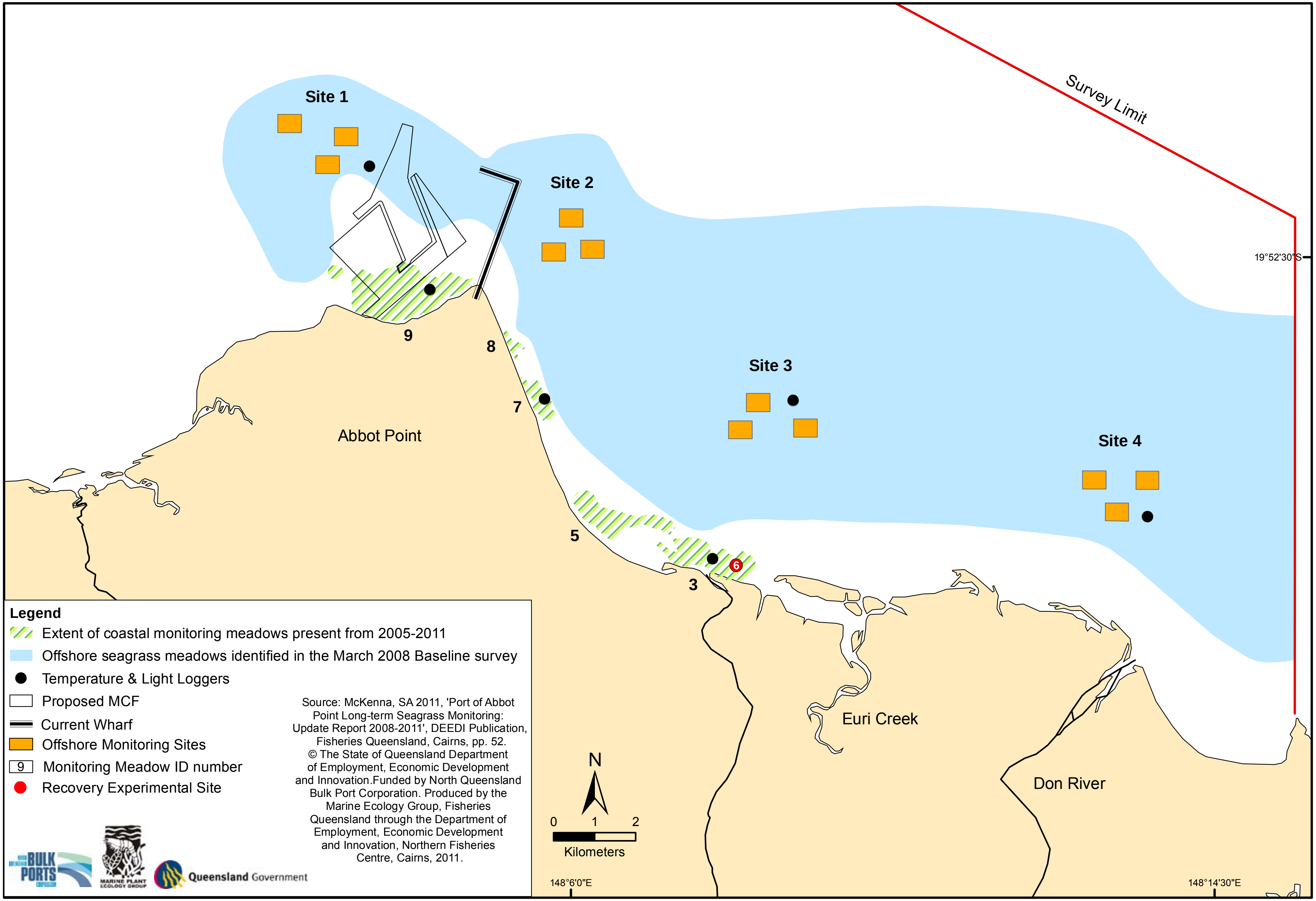


Table 1. Timeline of sampling events

Seagrass Monitoring Schedule											
Task	**Feb/ Mar 2008**	**May 2008**	**July 2008**	**Aug/ Sept 2008**	**Nov 2008**	**April 2009**	**May 2009**	**Aug 2009**	**Dec 2009**	**Feb 2010**	**Jun 2010**
Baseline surveys of entire area of interest	✓			✓							
Coastal and offshore monitoring			✓	✓	✓	✓		✓	✓ Coastal meadows only	✓ Offshore meadows only	✓
Recovery experiments	Identify sites	✓ *	✓**	✓	✓***		✓	✓****			
Productivity experiments	✓ Identify sites	✓		✓	✓						
Seed bank and flowering sampling			✓	✓	✓	✓	✓	✓		✓	
Fisheries sampling (beam trawling)				✓	✓	✓		✓			

*Experimental Recovery Sites 1 & 2 only Established
**Recovery Site 3 established; Site 2 not sampled due to poor weather
***Ceased shoot counts at Recovery Site 1 as quadrats were becoming too eroded for the experiment to be effective.
****Only Recovery Site 3 surveyed

Note: Future sampling events are weather dependent and may vary slightly from the timeline below.

Table 1 cont. Timeline of sampling events

Seagrass Monitoring Schedule cont.											
Task	**Nov 2010**	**Feb 2011**	**May 2011**	**Aug 2011**	**Nov 2011**	**Feb 2012**	**May 2012**	**Aug 2012**	**Nov 2012**	**Feb 2013**	**May 2013**
Baseline surveys of entire area of interest											
Coastal and offshore monitoring	✓ Establish offshore site 4 & move site 2	✓ **(march)**	✓	✓ **(sept)**	✓	✓	✓	✓	✓	✓	✓
Recovery experiments				✓ **Meadow 3*******	✓ **Meadow 3**	✓ **Meadow 3**	✓ **Meadow 3**	✓ **Meadow 3**	✓ **Meadow 3**	✓ **Meadow 3**	✓ **Meadow 3**
Productivity experiments											
Seed bank and flowering sampling				✓ **Meadow 3*******	✓ **Meadow 3**	✓ **Meadow 3**	✓ **Meadow 3**	✓ **Meadow 3**	✓ **Meadow 3**	✓ **Meadow 3**	✓ **Meadow 3**
Fisheries sampling (beam trawling)											

*****Recovery site unable to be established due to no grass being present

Note: sampling events are weather dependent and may vary from the timeline below.

RESULTS

1. Quarterly Assessment of Established Monitoring Meadows

Seagrass species, distribution, abundance and changes

Following the February/March 2008 baseline survey, there have been 11 quarterly monitoring surveys conducted between July 2008 and September 2011. Seven seagrass species (from three families) have been identified within the Abbot Point port limits (Table 3) (Rasheed et al. 2005; McKenna et al. 2008; Unsworth et al. 2010). The majority of seagrass meadows were patchy and variable in density with *Halophila spinulosa* dominating the deeper subtidal areas, and *Halodule uninervis* dominating the inshore areas. The 11 monitoring surveys have shown that seagrasses at Abbot Point are highly dynamic, changing as a function of season and influenced by major weather events (Figures 1-4; Appendix 1-3).

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 1-4; Appendix 2-4). Since the November 2010 survey, however, there have been major declines of seagrass in coastal and offshore areas at Abbot Point (Figures 1-4; Appendix 1-3). Many of the coastal monitoring meadows have been absent since the March 2011 survey and where meadows were present, the meadow consisted of only an isolated patch of seagrass. Seagrass had been consistently present throughout the potential port facility expansion area through all seasons until March 2011 (Figures 1-4; Appendix 2-4).

A. Coastal Monitoring Meadows

The maximum distribution that the coastal monitoring meadows have covered throughout the program is 270.13 ha (Map 3). The majority of the coastal meadows consisted of isolated to aggregated patches of seagrass and were primarily dominated by *Halodule uninervis* (Appendix 3). The exception was meadow 3 west of Euri Creek, which was dominated by *Zostera capricorni* (Figures 1a & b; Appendix 3).

The coastal monitoring meadows at Abbot Point have been highly variable in distribution and biomass between monitoring events, with some meadows becoming absent for periods of time, typically at the end of the wet season (Figures 1a & b; Appendix 1-3). Since the March 2011 survey, four of the five coastal monitoring meadows have been absent, representing a loss of ~ 267 ha of seagrass. As of the September 2011 survey, the distribution of seagrass in the coastal monitoring meadows was 3.12 ha (Map 3, Figures 1a & b).

Seagrass in the coastal monitoring meadows generally increased in above-ground biomass and distribution in late spring/summer of each year. The above-ground biomass of seagrass in all meadows ranged from negligible (<0.01g DW m^2) where individual shoots of seagrass were present (meadow 5) to 8.91 ± 4.17g DW m^2 for the *Zostera capricorni* meadow at Euri creek in its peak (Figures 1a & b; Appendix 1-3). Seagrass distribution in the meadows ranged from 1.4 ha (meadow 5) to 127.5 ha at meadow 9 (Figures 1a & b; Appendix 1-3). This meadow, located in the footprint of the potential port facility expansion area on the western side of the existing wharf, was consistently the largest meadow of the five coastal monitoring meadows over time (Map 3, Figures 1a & b, Appendix 1-3).

The species composition of the coastal monitoring meadows has been mostly stable throughout the monitoring program (Figures 1a & b). Of note however, are some changes that have occurred in meadows 3, 9 and 8 in recent surveys. These three meadows had substantially more *Halophila ovalis* in the species composition leading up their absence in March 2011. Meadow 8 underwent a species shift from being dominated by *Halodule uninervis* until June 2010, then *Halophila ovalis* /

Halodule uninervis dominated in November 2010, to only consisting of *Halophila spinulosa* in March 2011 (Figure 1a). *Halophila spinulosa* has not been found coastally near Abbot Point in the current monitoring program, however, the species was regularly found in small densities at experimental recovery site 2 at Queens Bay, which was at a similar depth to meadow 8 (Map 1) (Unsworth et al. 2010).

B. Offshore Monitoring

Similar to the coastal meadows, above-ground biomass at the offshore monitoring sites has been highly variable between surveys, with seagrass at some of the sites being absent for periods of time (Figures 2a & b, Appendix 1 & 2C). Seagrass density at these offshore sites generally reached a maximum in late spring/summer while declines in biomass generally occurred at the end of the wet season (Figures 2a & b, Appendix 1 & 2C). There was a significant increase in density at all offshore sites in November 2010 when above-ground biomass was at the highest recorded for all sites since monitoring began, after which major declines in seagrass occurred (Figures 2a & b, Appendix 1 & 2C).

The deepwater monitoring sites have been more species rich and more variable in species composition with respect to season compared to the coastal meadows. Site 3 has been the most species rich area of Abbot Point with six species of seagrass identified at the site (Figures 2a & b). Species diversity in the offshore areas of Abbot Point was high compared with surveys of similar port areas in the region such as Mackay (2 species) and Hay Point (4 species) (Rasheed et al. 2001; Thomas et al. 2011).

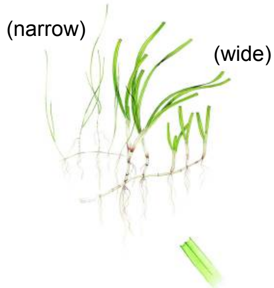
The greatest density of seagrass has consistently been found at Site 3 (Figure 2b, Appendix 1 & 2C). Mean above-ground biomass at this site has ranged from 0.10 ± 0.06 g DW m^2 in May 2011 to a moderate cover of seagrass at 25.76 ± 2.52 g DW m^2 in November 2010 (Figure 2b, Appendix 1 & 2C). *Halodule uninervis* contributed a significant proportion of the species composition at this site until November 2010, after which only species of the genera *Halophila* have been present.

In contrast, the lowest density offshore area has consistently been Site 1, located closest to the potential port facility expansion area (Figure 2a, Appendix 1 & 2C). The average above-ground biomass across all surveys at Site 1 was a sparse 0.06 ± 0.02 g DW m^2. *Halodule uninervis* had dominated Site 1 until the March 2011 survey when only *Halophila spinulosa* was present (Figure 2b, Appendix 1 & 2C). Seagrass has been absent in this monitoring area three times, June 2010, May 2011 & September 2011 (Figure 2b, Appendix 1 & 2C).

Seagrass at offshore monitoring Site 2 has been absent once (April/May 2009) throughout the program (Figure 2a, Appendix 1 & 2C). Seagrass above-ground biomass varied between 0.14 ± 0.05 g DW m^2 in winter 2010 to 6.27 ± 0.89 g DW m^2 in spring 2010 at this site (Figure 2b, Appendix 1 & 2C). These changes in biomass have been reflected in shifts of the species composition observed at Site 2. In surveys where biomass has been very low, *Halophila ovalis* and *Halophila decipiens* has contributed to larger portions of the species composition at the site, while at times when biomass has been higher, *Halophila spinulosa* contributed the majority of the species composition (Figure 2b, Appendix 1 & 2C).

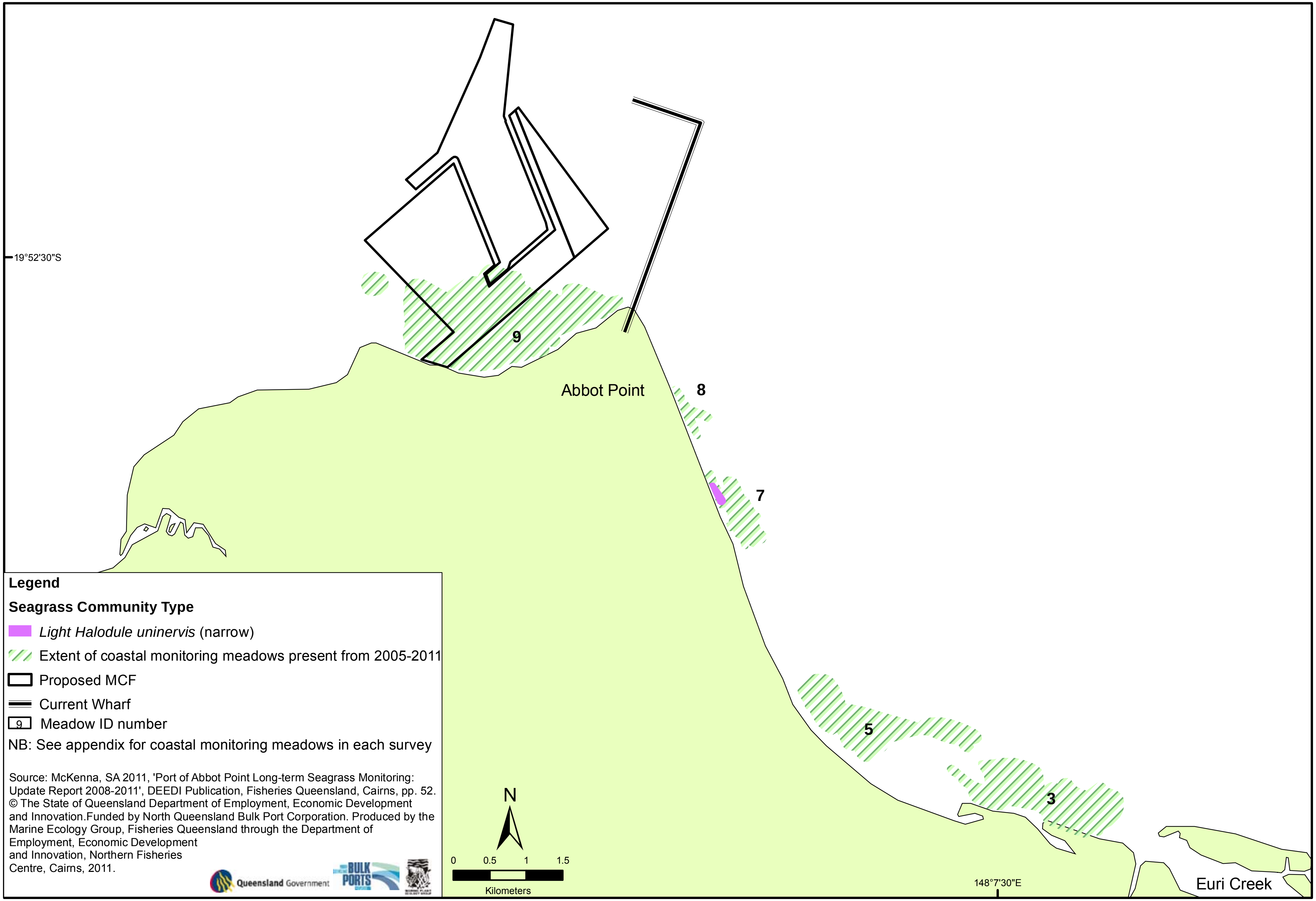
Site 4, established in November 2010 was found to be dominated by *Halophila spinulosa* (Figure 2b, Appendix 1 & 2C). The dominant habitat at this site was rock/rubble with areas of reef. Mean above-ground biomass at this site ranged from 5.34 ± 0.76 g DW m^2 in November 2010 to 0.07 ± 0.05 g DW m^2 in May 2011(Figure 2b, Appendix 1 & 2C).

Table 3. Seagrass species found within the Port of Abbot Point, March 2005, February 2008-September 2011.

Family	Species			
CYMODOCEACEAE Taylor	*Cymodocea serrulata* (R.Br.) Aschers and Magnus		*Halodule uninervis* (wide and narrow leaf morphology) (Forsk.) Aschers. in Boissier	
	*Cymodocea rotundata**			
ZOSTERACEAE Drummortier	*Zostera capricorni* Aschers.			
HYDROCHARITACEAE Jussieu	*Halophila decipiens* Ostenfield		*Halophila ovalis* (R. Br.) Hook. F.	
	Halophila spinulosa (R. Br.) Aschers. in Neumayer			

**Cymodocea rotundata* only identified in the March 2005 Baseline survey

Map 3. Maximum Distribution of Coastal Monitoring Meadows & Distribution of seagrass in September 2011



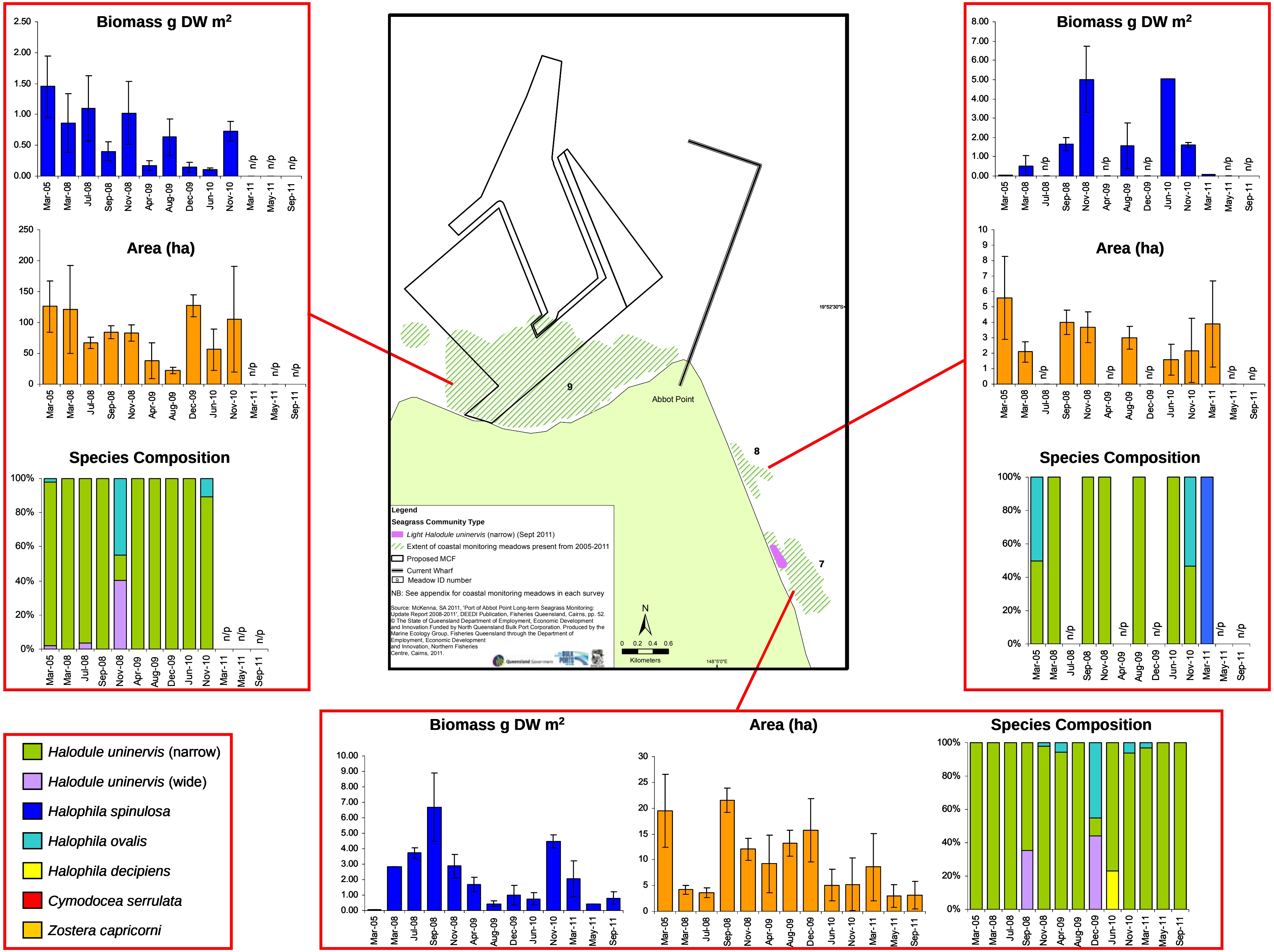


Figure 1a. Changes in meadow biomass, area and species composition for the coastal monitoring meadows 7, 8 & 9 from March 2005, March 2008 - September 2011. NP – seagrass not present.

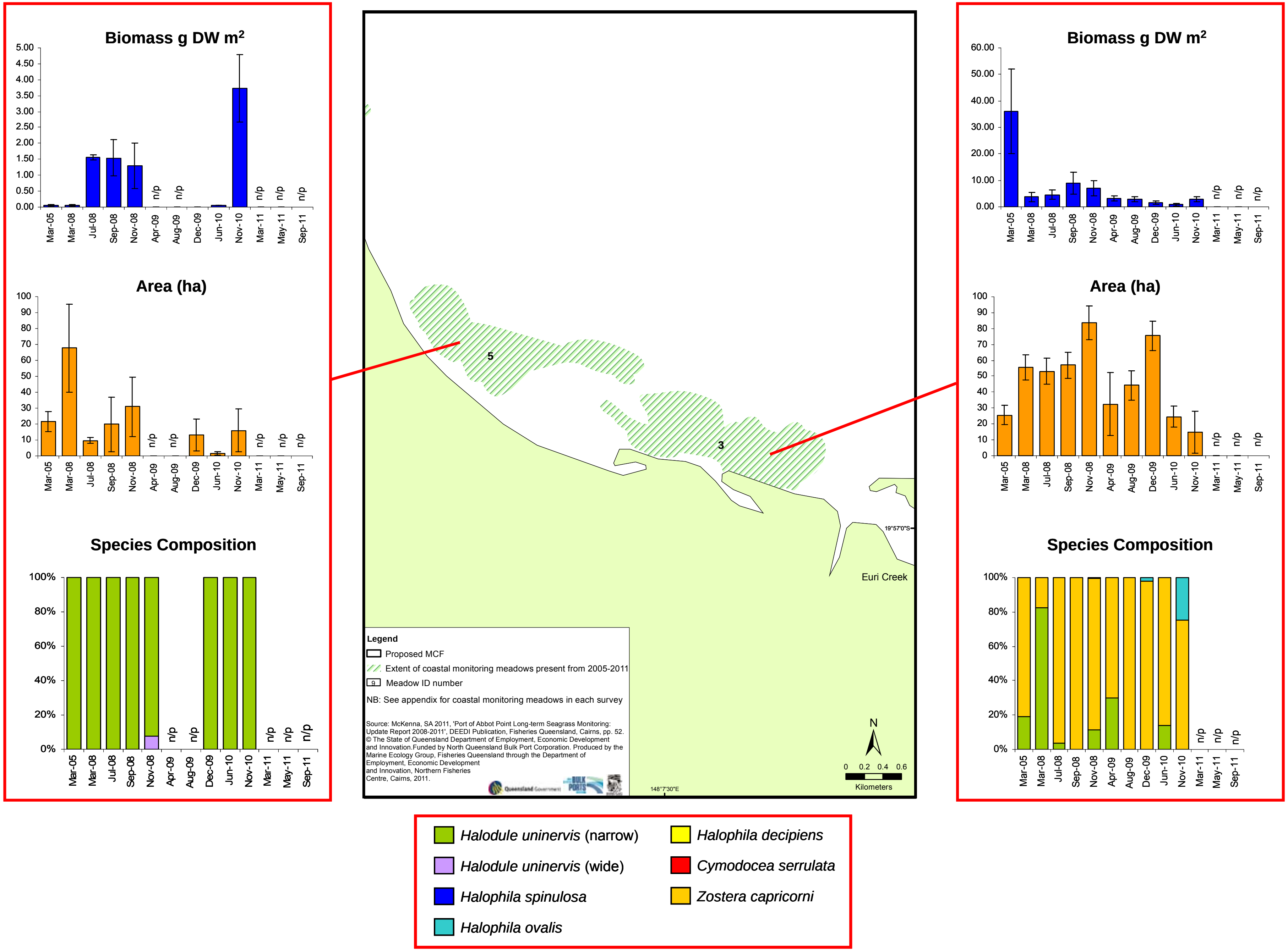


Figure 1b. Changes in meadow biomass, area and species composition for the coastal monitoring meadows 3 & 5 from March 2005, March 2008 - September 2011. NP – seagrass not present.

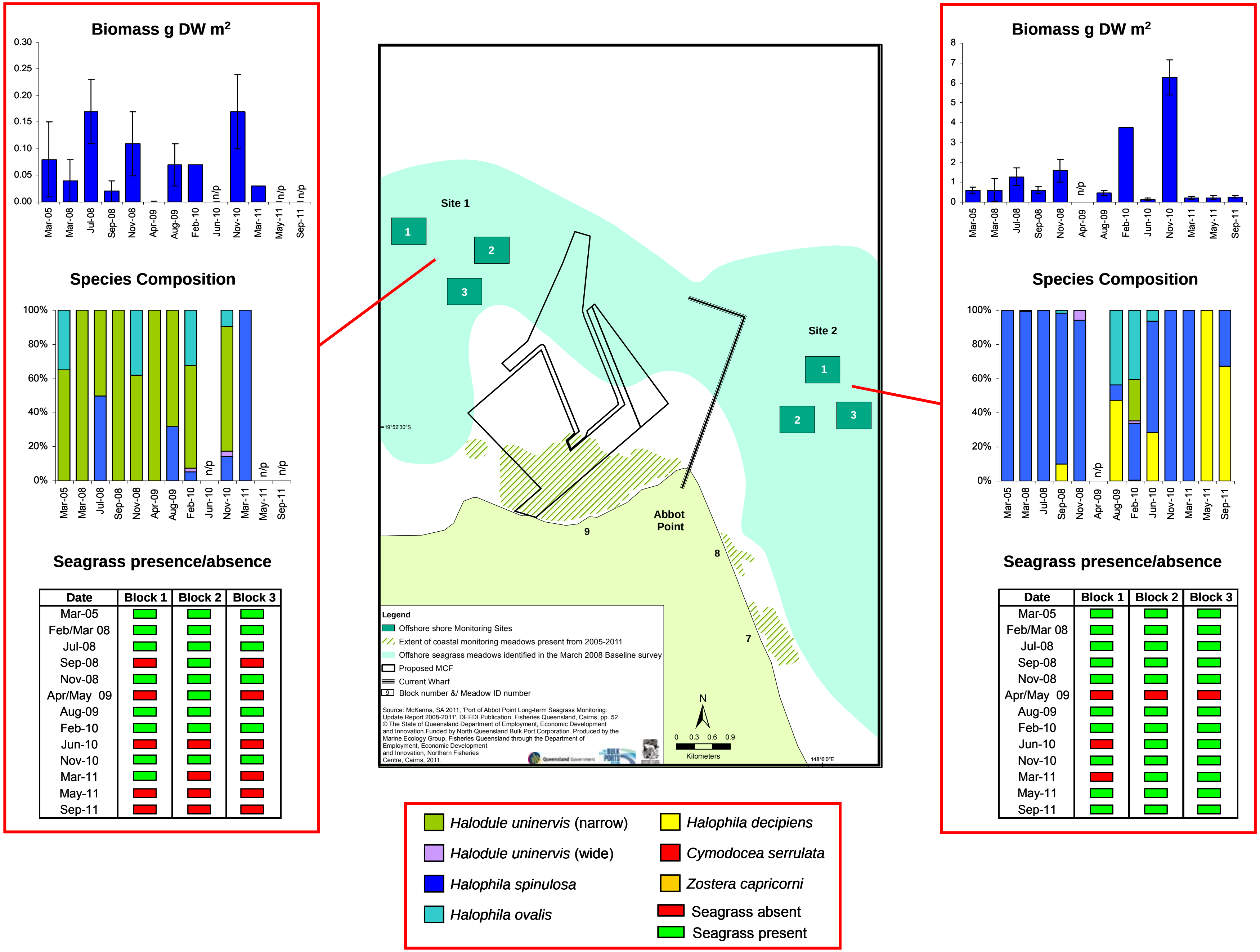


Figure 2a. Changes in meadow biomass, species composition and presence/absence of seagrass in monitoring blocks for the offshore monitoring sites from March 2005, March 2008 - September 2011. NP – seagrass not present.

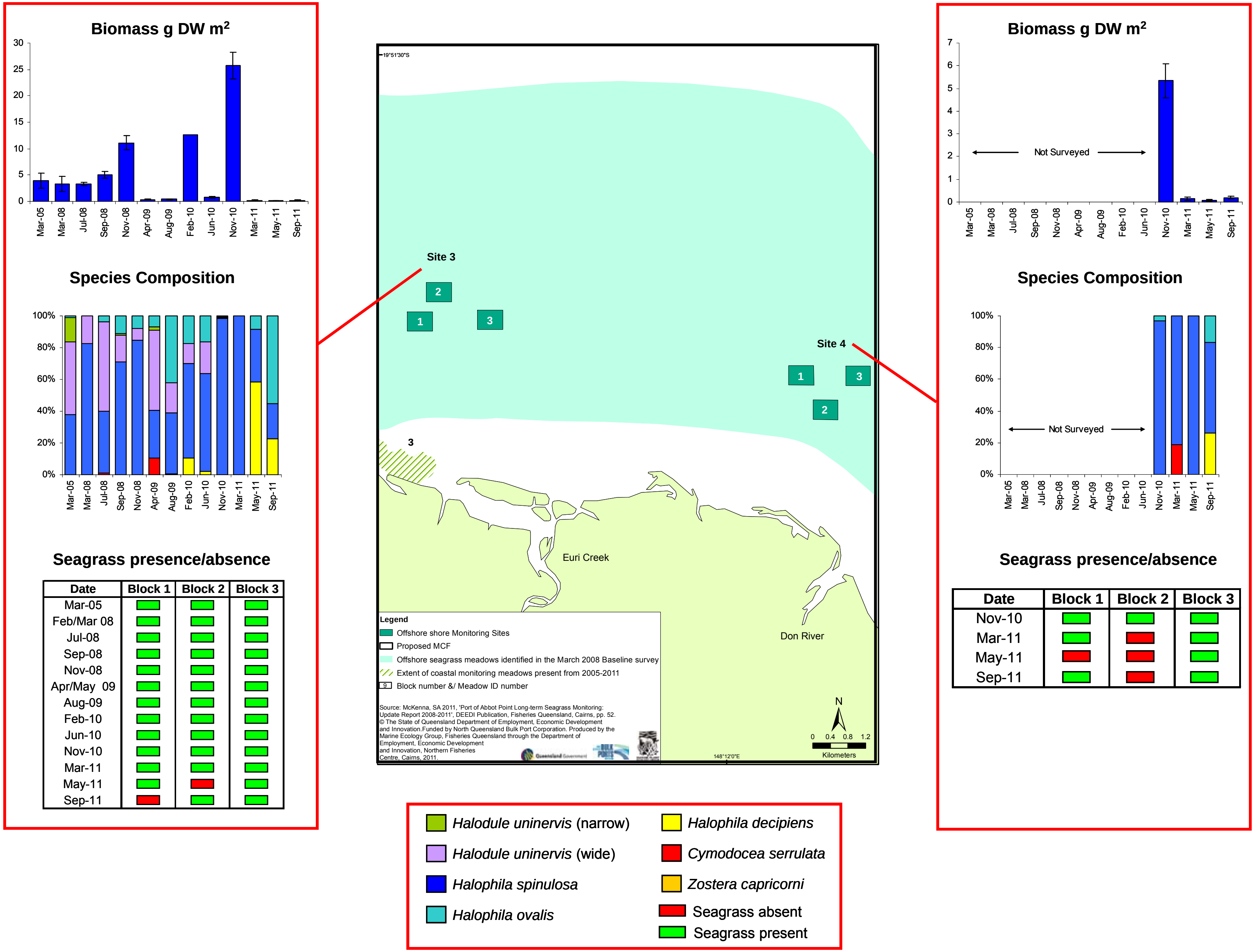


Figure 2a. Changes in meadow biomass, species composition and presence/absence of seagrass in monitoring blocks for the offshore monitoring sites from March 2005, March 2008 - September 2011. NP – seagrass not present.

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 2010 La Niña system which started in July 2010 and didn't ease until May/June 2011 (www.bom.gov.au). This La Niña event is one of the strongest on record and contributed to the extremely wet period experienced in Queensland from late November 2010 to mid January 2011 (www.bom.gov.au).

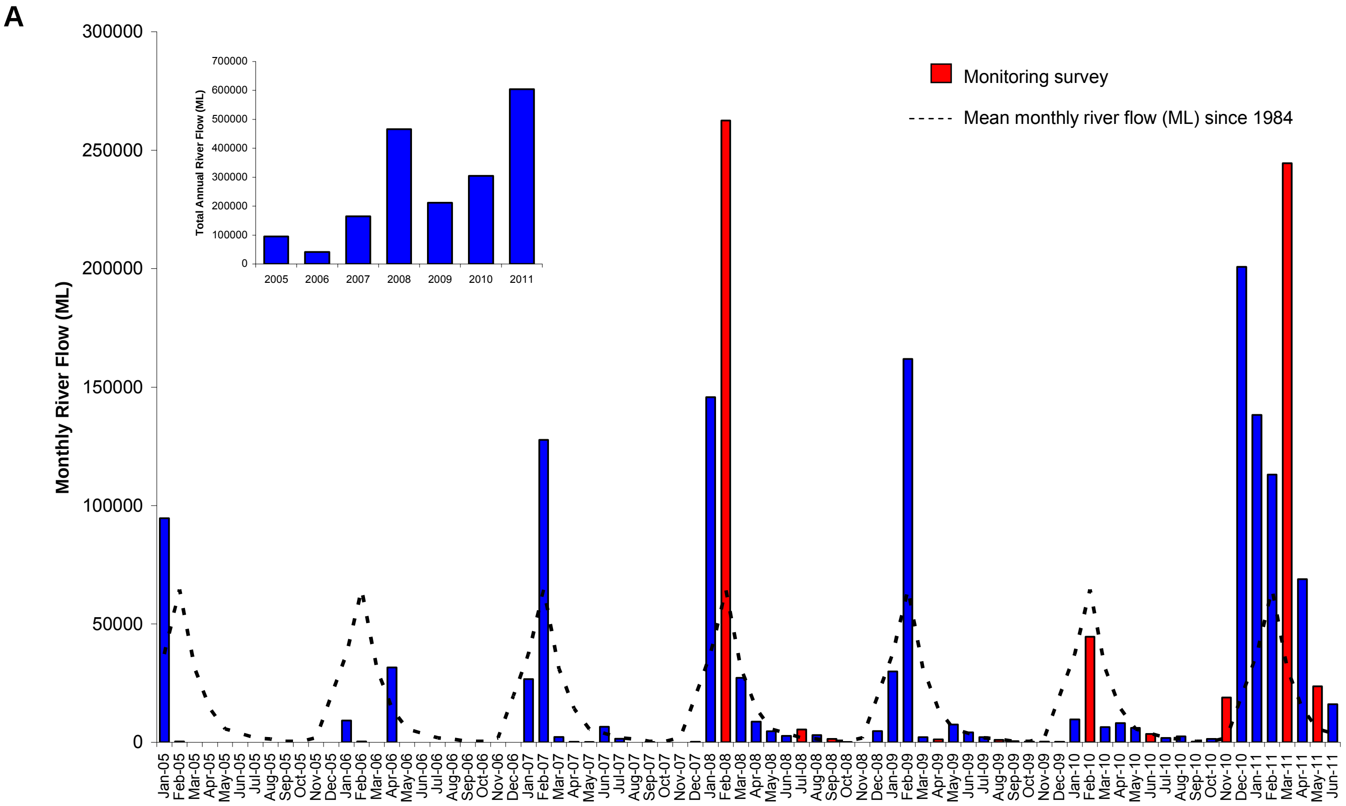
Significant climatic events that have directly affected Bowen/Abbot Point include:

- **March 2011:** Highest rainfall on record at Bowen with extensive and prolonged flooding of the Don River and major and minor creeks (Figure 3B),
- **January-February 2011**: Category 5 Tropical Cyclone Yasi crossed the coast at Mission Beach north of Bowen,
- **January 2011:** Category 2 Tropical Cyclone Anthony crossed the coast at Bowen,
- **December 2010:** Wettest December on record for the State of Queensland. Many significant weather systems affected the state causing widespread and significant flooding,
- **March 2010**: Category 3 Tropical Cyclone Ului crossed the coast at Airlie Beach south of Bowen,
- **February 2010**: Flooding of the Don River,
- **March 2009**: Category 5 Tropical Cyclone Hamish passed along the coast ~ 125km off the coast at Bowen,
- **January-February 2008**: Major monsoonal trough. Rainfall in February 2008 was almost three times the 20 year average for that month which coincided with high flows of the Don River (Figure 3a & b),
- **March 2006**: Category 5 Tropical Cyclone Larry crossed the coast at Innisfail north of Bowen.

Weather recorded at Bowen between 2005 and 2011 demonstrated large inter-annual variability (Figures 3a & b, 4a & b). 2005 and 2006 were characterised by higher temperatures and lower rainfall than the other years, while 2008 to 2011 had at least twice has much rainfall compared to 2005, with many records being broken during this time (Figure 3b). These major rainfall events coincided with high flows of the major catchment for the Abbot Point area, the Don River (Figure 3a). River flows at the Don River exceed monthly averages from November 2010 through to June 2011, with 2011 having the highest total annual river flow since 2005 (Figure 3b).

Total quantity of solar radiation was lowest in the winter months versus summer, and highest and consistently above average in 2009. 2010 had below average quantities of solar radiation (Figure 4b).

Validated river flow and temperature data was not available from the Department of Resource Management and Bureau Of Meteorology post June 2011.



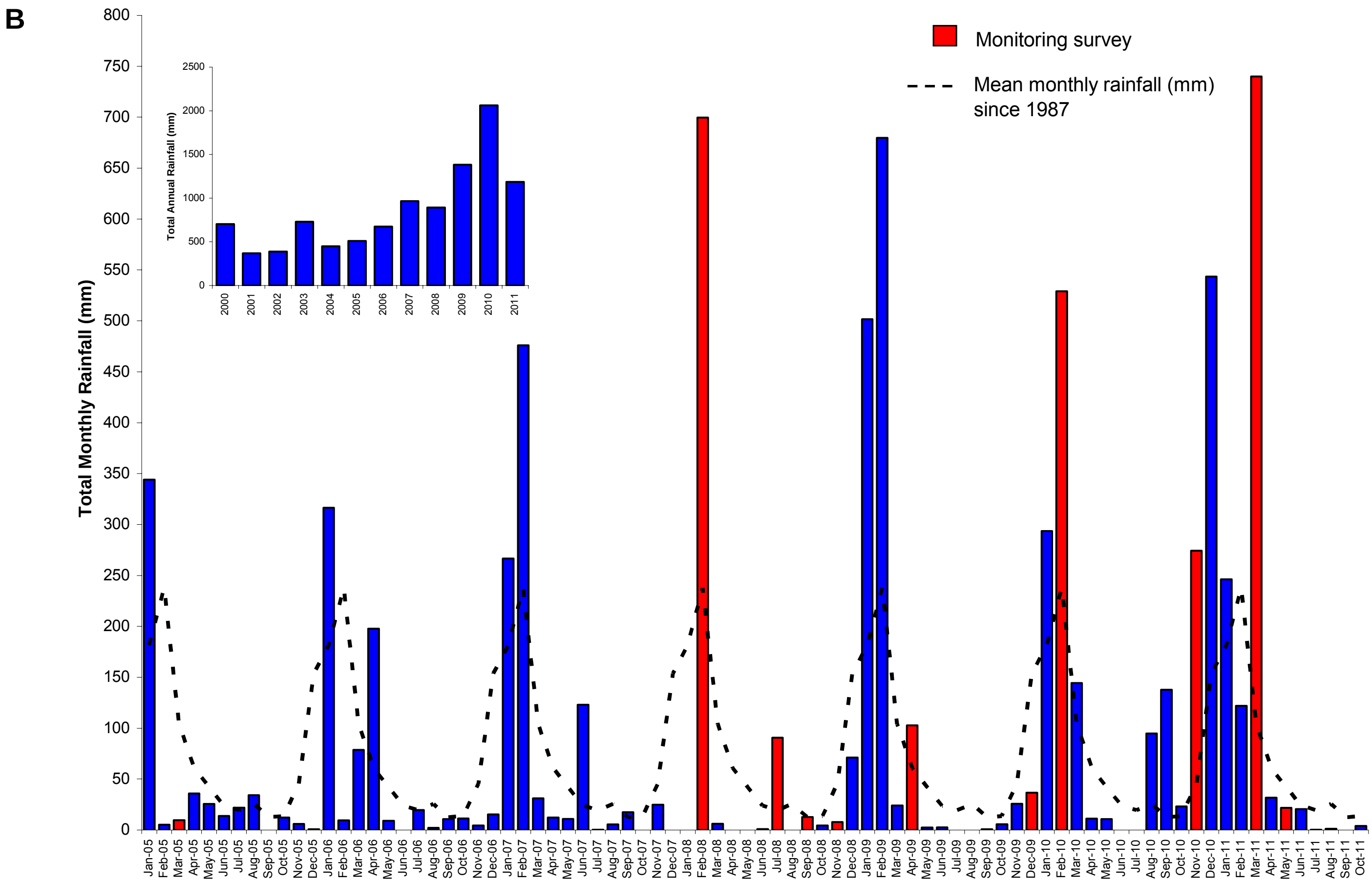


Figure 3. (**A**) Total monthly river flow for the Don River from 2005 - 2010 (www.derm.qld.gov.au); (**B**) Total monthly rainfall (mm) for the Bowen area from 2005 – 2011 (www.bom.gov.au).

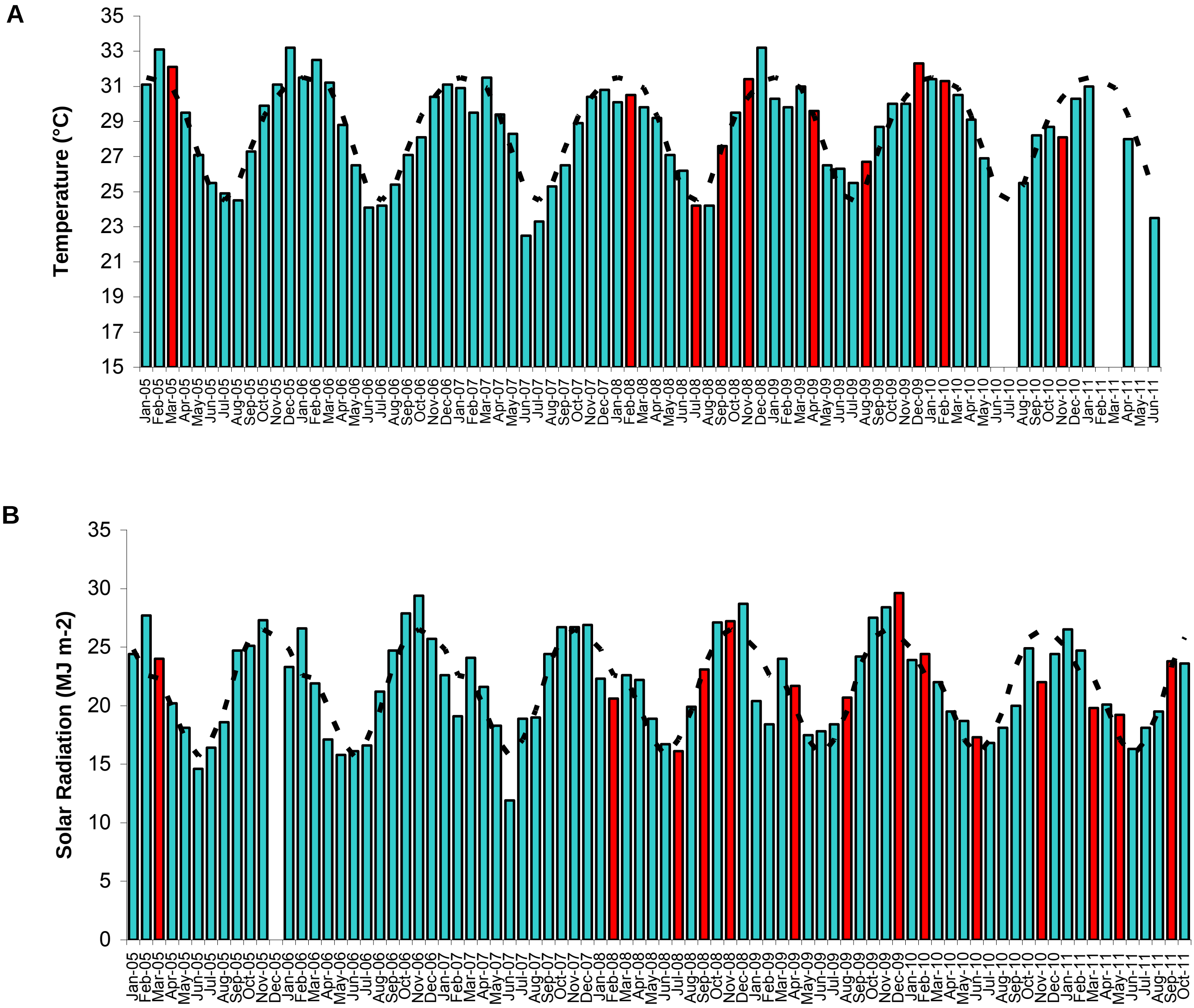


Figure 4. (**A**) Mean monthly temperature and (**B**) Monthly solar radiation (mega joules/m^2) for the Bowen area from 2005 – 2011 (www.bom.gov.au).

DISCUSSION

The results of the seagrass monitoring program have found that seagrass meadows at Abbot Point are highly dynamic responding to a range of environmental drivers such as coastal flooding and cyclones, as well as seasonal cycles that may impact upon sediment re-suspension, light availability and nutrient dynamics. There has been a broad seasonal pattern for seagrasses at Abbot Point with reduced distribution and biomass post-wet season with a subsequent recovery and peak in late spring/early summer. Such seasonality is similar to patterns observed elsewhere in Queensland and throughout the Indo-Pacific (Erfteheijer and Herman 1994; McKenzie 1994; Rasheed 2004; McKenna et al. 2008; Unsworth et al. 2010; Chartrand et al. 2011).

The La Niña event of 2010/11 combined with severe Tropical Cyclone Yasi is the most likely factor contributing to the significant loss of seagrass at Abbot Point since November 2010. This major weather event has reduced the resilience and capacity for recovery of Abbot Point seagrasses. Since the November 2010 survey seagrass has been absent at four of the five coastal monitoring meadows and one of the offshore sites. In areas that did have seagrass present between March 2011 and September 2011, seagrass biomass and distribution was very low. It is likely that the combined effects of elevated turbidity as a result of above average flooding, and wind and storm surges due to cyclones has resulted in greatly reduced light availability, contributing to the decline of coastal meadows and offshore seagrass at the end of each wet season, particularly in 2010/11. There is potential for a full recovery of seagrasses, however a second (2011/12) wet season of high rainfall and flooding could further affect the already vulnerable seagrasses at Abbot Point.

One of the major environmental determinants of seagrass distribution, abundance and productivity is light (Duarte et al. 1997; Vermaat et al. 1997). Coastal rainfall and river plumes are known to be one of the major drivers of seawater turbidity throughout the region which in turn affects the availability and quality of light that reaches seagrass. While seagrass minimum light requirements differ among species changes in the availability of light with increasing depth remains the primary factor affecting the overall distribution of seagrasses (Bjork et al. 1999; Hemminga and Duarte 2000; Erftemeijer and Lewis 2006; Ralph et al. 2007). Studies of seagrasses in tropical regions have indicated that genera such as *Zostera* and *Halodule* require significantly greater light requirements (Grice et al 1996; Bach et al 1998; Collier et al. 2009) than other genera such as *Halophila* spp. (Freeman et al. 2008). At Abbot Point it has been the higher light requiring species such as *Zostera capricorni* and *Halodule uninervis* that have been most effected with many areas previously dominated by these species being lost. *Halophila* species with a much lower light requirement have also been impacted at the deeper areas of their distribution where they are likely to be at their light limits. In addition these lower light adapted species have become more common in the shallow areas previously dominated by the higher light species. These species changes provide strong evidence that light limitation may be the primary cause of observed losses of seagrass.

While well adapted to lower light conditions and typically dominant in subtidal and highly turbid areas, *Halophila* will decline quickly with adverse conditions such as extreme low light (Kenworthy et al. 1989; Durako et al. 2003). The same genera however, are quick to respond positively when conditions such as light improve. *Halophila* species are fast growing and are early colonisers in suitable growing sediments when conditions are favourable (Hammerstrom et al. 2006). They are capable of producing relatively long lived seeds that can lay dormant in the sediment for at least two years (McMillan 1991, Hammerstrom and Kenworthy 2003, Hammerstrom et al. 2006). The recent addition of light (Photosynthetically Active Radiation (PAR)) loggers to the Abbot Point seagrass monitoring program will greatly assist in determining the drivers of seagrass change and the relationship between light and seagrass condition.

Similar large scale declines of seagrass occurred over the 2010/11 wet season in other north-eastern Queensland coastal locations where the team conducts similar monitoring programs. The majority of intertidal *Zostera* meadows in Mourilyan and Gladstone decreased in biomass in

November 2010 (Fairweather et al. 2011a; Chartrand et al. 2011), while monitoring in Cairns revealed that there were similar declines in intertidal and subtidal meadows (Fairweather et al 2011b). These declines corresponded with major rainfall events and severe episodic flooding that occurred across the state in 2010/11.

There is potential for a full recovery of seagrasses at Abbot Point, however, experimental studies between 2008 and 2010 found that there were strong differences between meadow types and species in their capacity for recovery and the mechanisms employed to recolonise areas at Abbot Point (see Unsworth et al. 2010). Coastal meadows dominated by *Halodule uninervis* were more likely to rely on asexual reproduction for recovery from losses while the deepwater sites dominated by *Halophila* were able to recover through a combination of sexual and asexual reproduction. These results indicate that the deepwater meadows have a greater capacity for meadow recovery from larger scale disturbances such as flooding and tidal surges compared to the coastal meadows. These coastal meadows would be reliant on an adult population from which to recover from and are therefore more vulnerable to longer term impacts should widespread loss occur (Unsworth et al. 2010).

Implications for Port Management

Results of the latest survey indicate that seagrasses at Abbot Point are in a vulnerable state. Consecutive above average wet seasons that likely led to the large declines in density and distribution have left seagrasses with reduced resilience to further stressors. The cumulative impacts of natural stressors, combined with potential increased impacts from future port activities and development, place these seagrasses at a heightened risk.

Seagrass meadows at Abbot Point are of high ecological and economic value. Abbot Point seagrass meadows have been found to be diverse and productive compared to similar ports (ie. Hay Point, Gladstone and Mackay), providing evidence that they make a major contribution to supporting fauna and providing critical functions to the coastal ecosystem such as nutrient and carbon cycling, water filtration and sediment stabilisation (Costanza et al. 1997; Hemminga & Duarte 2000; Mckenna et al. 2008; Unsworth et al. 2010). Seagrasses also provide important habitat and feeding resources for IUCN listed vulnerable species of dugong and green turtle (Hughes et al*.* 2009).

Port activities during the life of the monitoring program have not appeared to have had a significant impact on seagrasses in the local area. However, careful attention to developing effective light management triggers that are appropriate to the ecological requirements of local seagrass species will be important to ensure the continued recovery and long term viability of these seagrass meadows. This is particularly relevant given proposed developments at the Port of Abbot Point that include extensive dredging programs.. Studies at Abbot Point indicated that if large scale loss of seagrasses were to occur, some level of recovery would be possible in meadows dominated by *Halophila*, however, meadows dominated by *Halodule uninervis* that rely on asexual meadow recovery are unlikely to have the capacity to recover quickly from large losses if the adult population is lost. The available information indicates that it would be critical to manage any future developments that may potentially disturb the local water quality (particularly light availability) at Abbot Point in a way that ensures the longer term viability of adult populations of seagrass.

The current monitoring program at Abbot Point provides the basis for developing effective seagrass management strategies and also is at the scale and resolution to provide a Before After Control Impact (BACI) design for the area and enable natural environmental change to be separated from any potential anthropogenic impacts. The program can also be used as part of a reactive dredge management program, based on the use of water quality thresholds (Sofonia and Unsworth 2010; Chartrand et al. 2010). Understanding natural cycles of change in Abbot Point seagrasses is also important as monitoring has shown that climate events have the capacity to reduce the resilience of seagrasses in the region to current human activities. Applying the best available knowledge through ongoing research will dramatically improve the ability to manage and mitigate threats as they arise.

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APPENDIX

Appendix 1.

Results of Behrens-Fisher test statistic for above-ground biomass of coastal monitoring meadows in the Port of Abbot Point: March 2005 & March 2008 – September 2011. Only where significant differences were found between years are shown in the below table with associated test statistic (t') and degrees of freedom (v'). Significance was set at $p<0.01$.

Location	Year x Year	*t'* (Behrens Fisher)	*v'* (weighted df)
Coastal Meadow 3	None	–	–
Coastal Meadow 5	Mar 2005 x July 2008	17.89	2
	Mar 2008 x July 2008	18.52	2
	July 2008 x Dec 2009	19.59	2
Coastal Meadow 7	July 2008 x Apr 2009	3.60	10
	x Aug 2009	6.77	7
	x June 2010	5.67	8
	Sept 2008 x Dec 2009	4.85	13
	Nov 2010 x Apr 2009	4.52	7
	x Aug 2009	7.42	4
	x Dec 2009	4.68	12
	x June 2010	6.45	6
Coastal Meadow 8	None	–	–
Coastal Meadow 9	Apr 2009 x Nov 2010	3.18	16
	Nov 2010 x Dec 2009	3.28	16
	x June 2010	3.91	11
Deepwater Site 1	July 2008 x March 2008	3.02	13
	x Sept 2008	4.57	15
	x Apr 2009	7.97	8
	x Mar 2011	3.47	14
	Apr 2009 x Nov 2010	3.36	8
Deepwater Site 2	Nov 2010 x Jun 2010	3.50	8
	x Mar 2011	3.47	8
	x May 2011	3.46	8
	x Sept 2011	3.44	8
Deepwater Site 3	Jul 2008 x Apr 2009	5.74	8
	x Aug 2009	5.38	9

	x Jun 2010	4.70	10
	x Nov 2010	3.55	8
	x Mar 2011	6.04	8
	x May 2011	6.26	8
	x Sept 2011	6.31	8
	Sep 2008 x Apr 2009	4.36	8
	x Aug 2009	4.24	8
	x Jun 2010	3.93	8
	x Mar 2011	4.50	8
	x May 2011	4.60	8
	x Sept 2011	4.63	8
	Nov 2008 x Apr 2009	3.52	8
	x Aug 2009	3.48	8
	x Jun 2010	3.38	8
	x Mar 2011	3.57	8
	x May 2011	3.60	8
	x Sept 2011	3.61	8
	Nov 2010 x Mar 2005	3.24	10
	x Mar 2008	3.48	9
	x Jul 2008	3.55	8
	x Apr 2009	4.04	8
	x Aug 2009	4.02	8
	x Jun 2010	3.97	8
	x Mar 2011	4.06	10
	x May 2011	4.08	9
	x Sept 2011	4.09	8
Deepwater Site 4	Nov 2010 x Mar 2011	4.10	8
	x May 2011	4.17	8
	x Sept 2011	4.06	8

Appendix 2

A. Mean above-ground biomass (g DW m^{-2}) of coastal monitoring meadows within the Port of Abbot Point, March 2005, February 2008 – September 2011.

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

NP – Meadow not present

B. Area (ha) of monitoring meadows within the Port of Abbot Point, March 2005, February 2008 – September 2011.

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**
Sept 11	NP	NP	3.12 ± 2.66	NP	NP	**3.12 ± 2.66**

NP– Meadow not present

C. Mean above-ground biomass (g DW m-2) of offshorer monitoring sites in the Port of Abbot Point, March 2005, February 2008 – September 2011.

Sampling Date	Mean Biomass ± SE (g DW m^{-2}) (dominating seagrass species)			
	Site 1	**Site 2**	**Site 3**	
Mar 05*	0.08 ± 0.07 (*Halodule uninervis* (thin))	0.59 ± 0.15 (*Halophila spinulosa*)	3.98 ± 1.43 (*Halophila spinulosa*/*Halodule uninervis* (wide))	
Feb/Mar 08*	0.04 ± 0.04 (*Halodule uninervis* (thin))	0.60 ± 0.57 (*Halophila spinulosa*)	3.28 ± 1.38 (*Halophila spinulosa*)	
Jul 08	0.17 ± 0.06 (*Halodule uninervis* (thin) & *Halophila spinulosa*)	1.27 ± 0.44 (*Halophila spinulosa*)	3.31 ± 0.38 (*Halodule uninervis* (wide))	
Sept 08	0.02 ± 0.02 (*Halodule uninervis* (thin))	0.61 ± 0.17 (*Halophila spinulosa*)	5.10 ± 0.65 (*Halophila spinulosa*)	
Nov 08	0.11 ± 0.06 (*Halodule uninervis* (thin) & *Halophila ovalis*)	1.58 ± 0.55 (*Halophila spinulosa*)	11.07 ± 1.33 (*Halophila spinulosa*)	
Apr/May 09	0.0006 ± 0.0006 (*Halodule uninervis* (thin))	NP	0.34 ± 0.06 (*Halodule uninervis* (wide))	
Aug 09	0.07 ± 0.04 (*Halodule uninervis* (thin) & *Halophila ovalis*)	0.46 ± 0.11 (*Halophila spinulosa*)	0.45 ± 0.09 (*Halophila spinulosa*)	
Feb 10**	0.07 ± (*Halodule uninervis* (thin) & *Halophila ovalis*)	3.75 ± (*Halophila ovalis*/*Halophila spinulosa*)	12.69 ± (*Halophila spinulosa*/*Halophila ovalis*)	
June 10	NP	0.14 ± 0.05 (*Halophila spinulosa*)	0.77 ± 0.12 (*Halophila spinulosa*)	
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*)

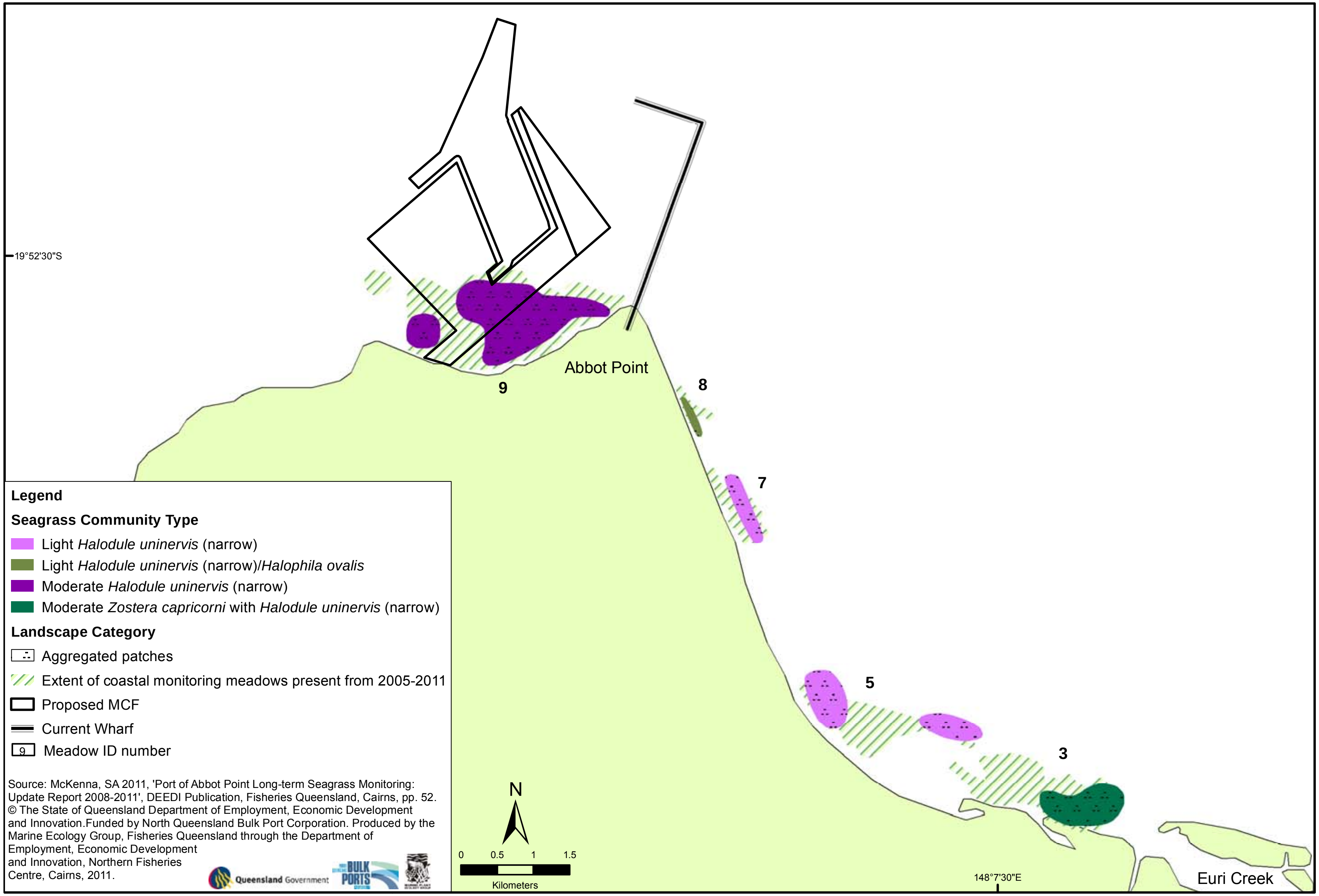
* - Mar 05 & Feb/Mar 08 surveys were Baseline surveys so the location of Monitoring Blocks were not established thus Biomass is derived from transects in the baseline survey that were located closest to monitoring blocks that were established in July 2008.

** - 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

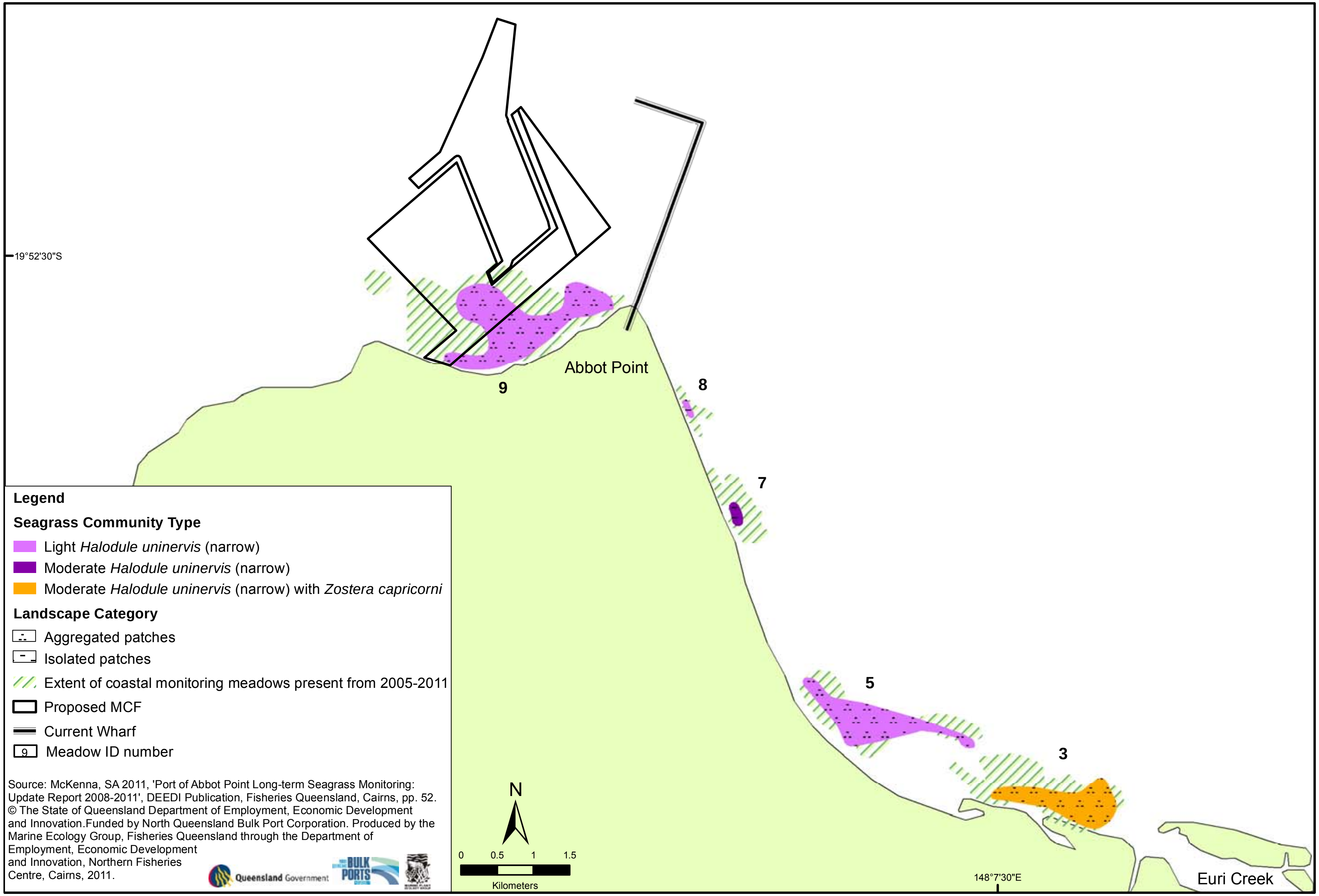
NP – No seagrass present in monitoring blocks

Appendix 3. Coastal monitoring meadow community type, landscape category and distribution within the Port of Abbot Point, March 2005, February 2008 – September 2011, Maps 4-16.

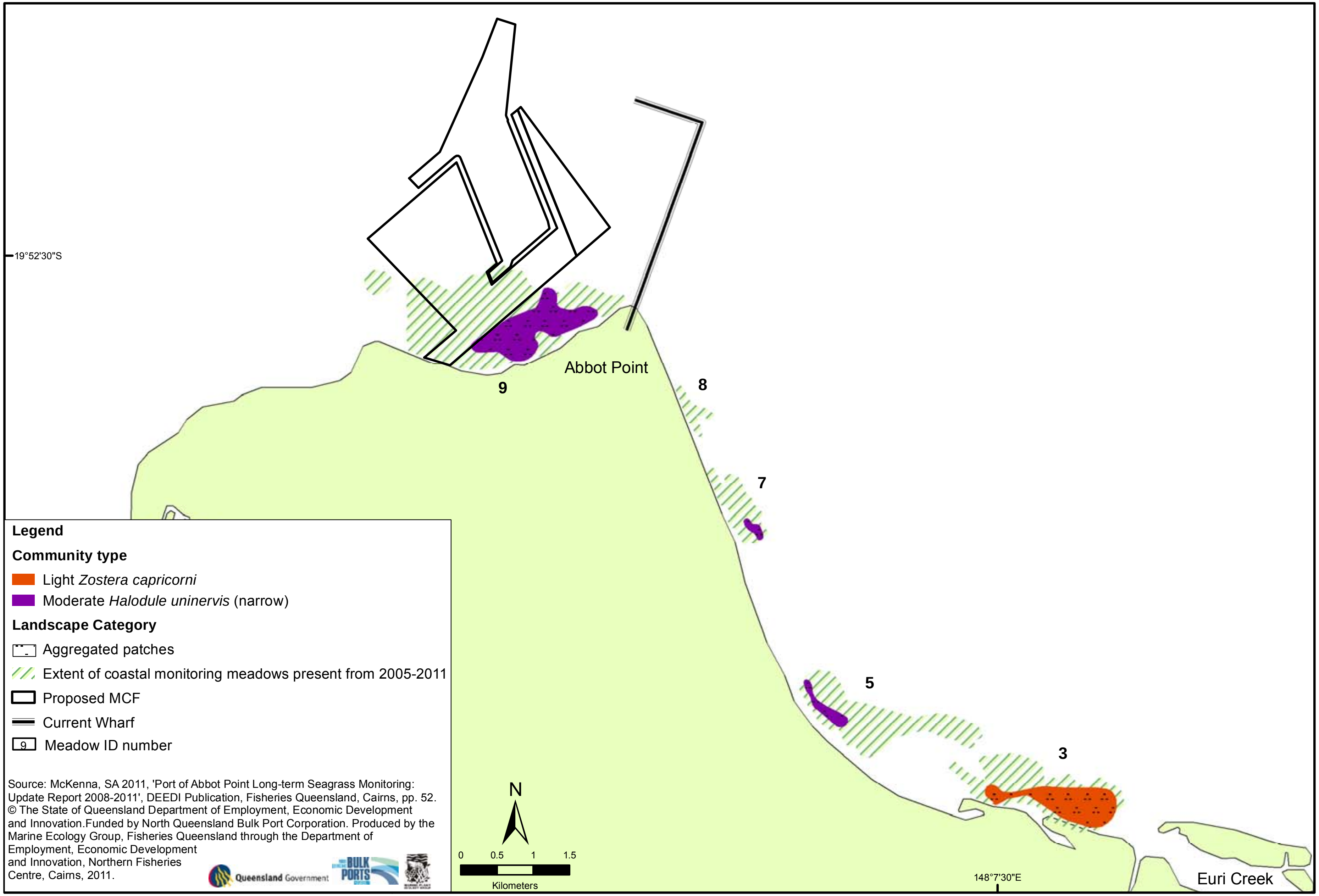
Map 4. Coastal monitoring meadows in the Port of Abbot Point March 2005



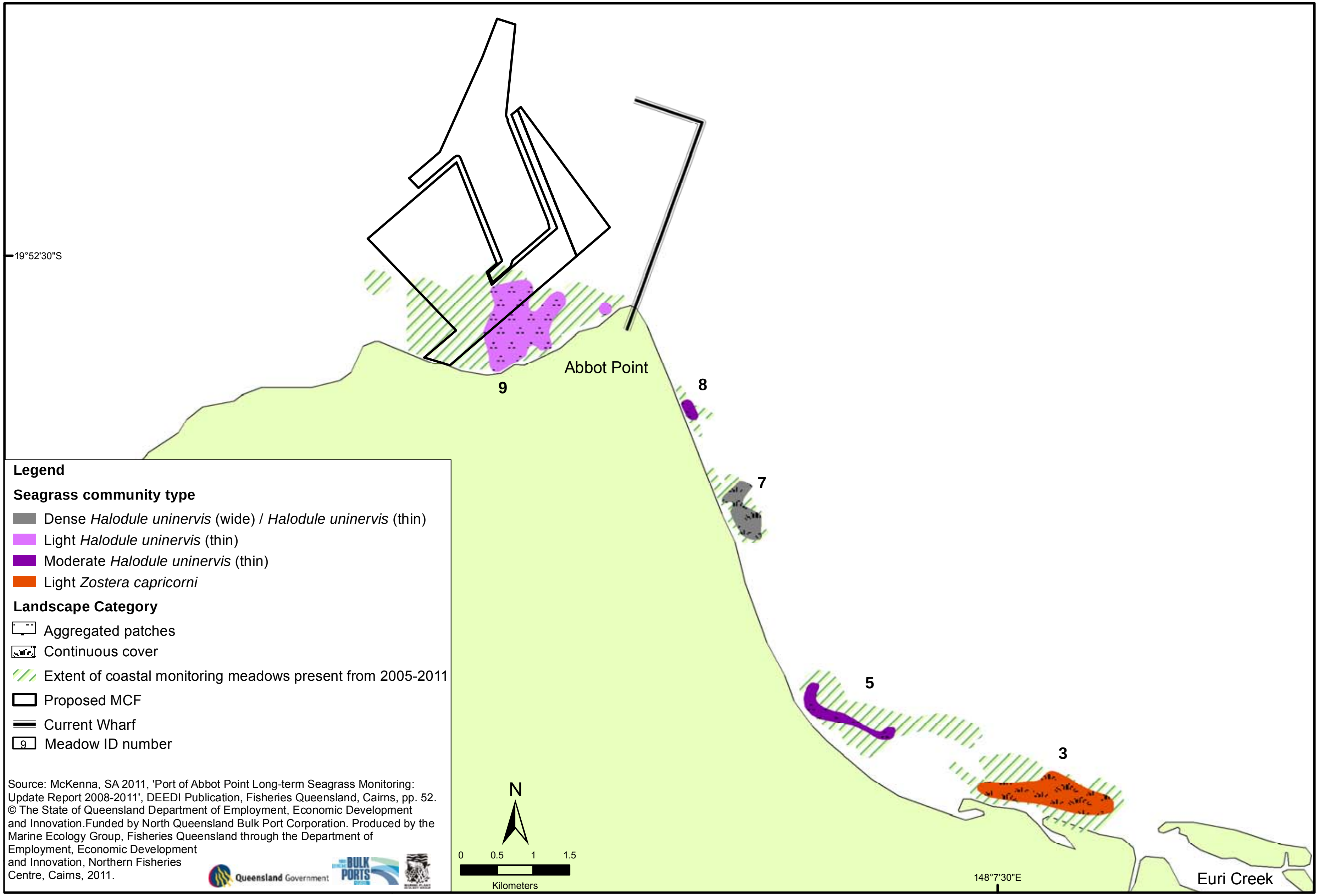
Map 5. Coastal monitoring meadows in the Port of Abbot Point March 2008



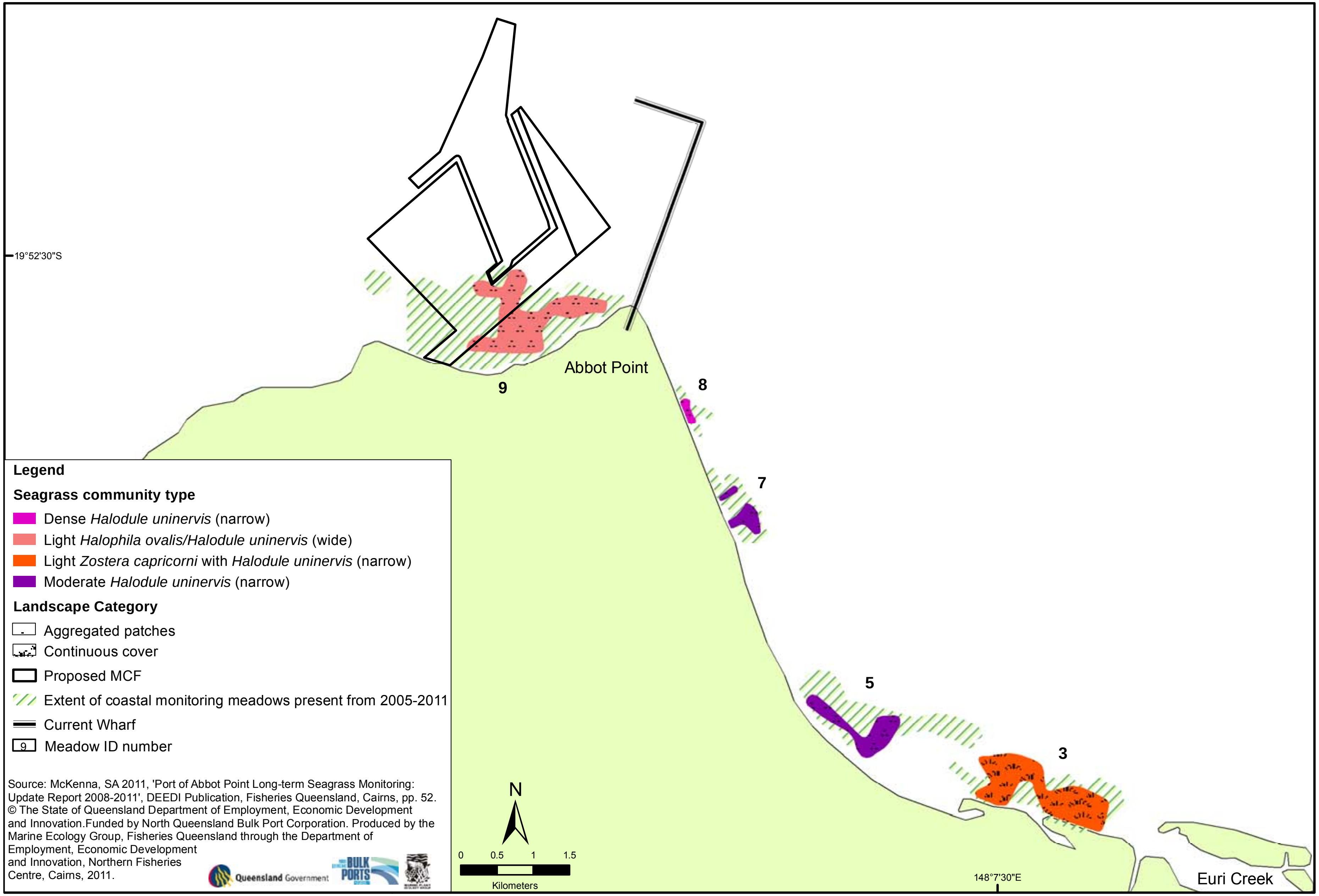
Map 6. Coastal monitoring meadows in the Port of Abbot Point July 2008



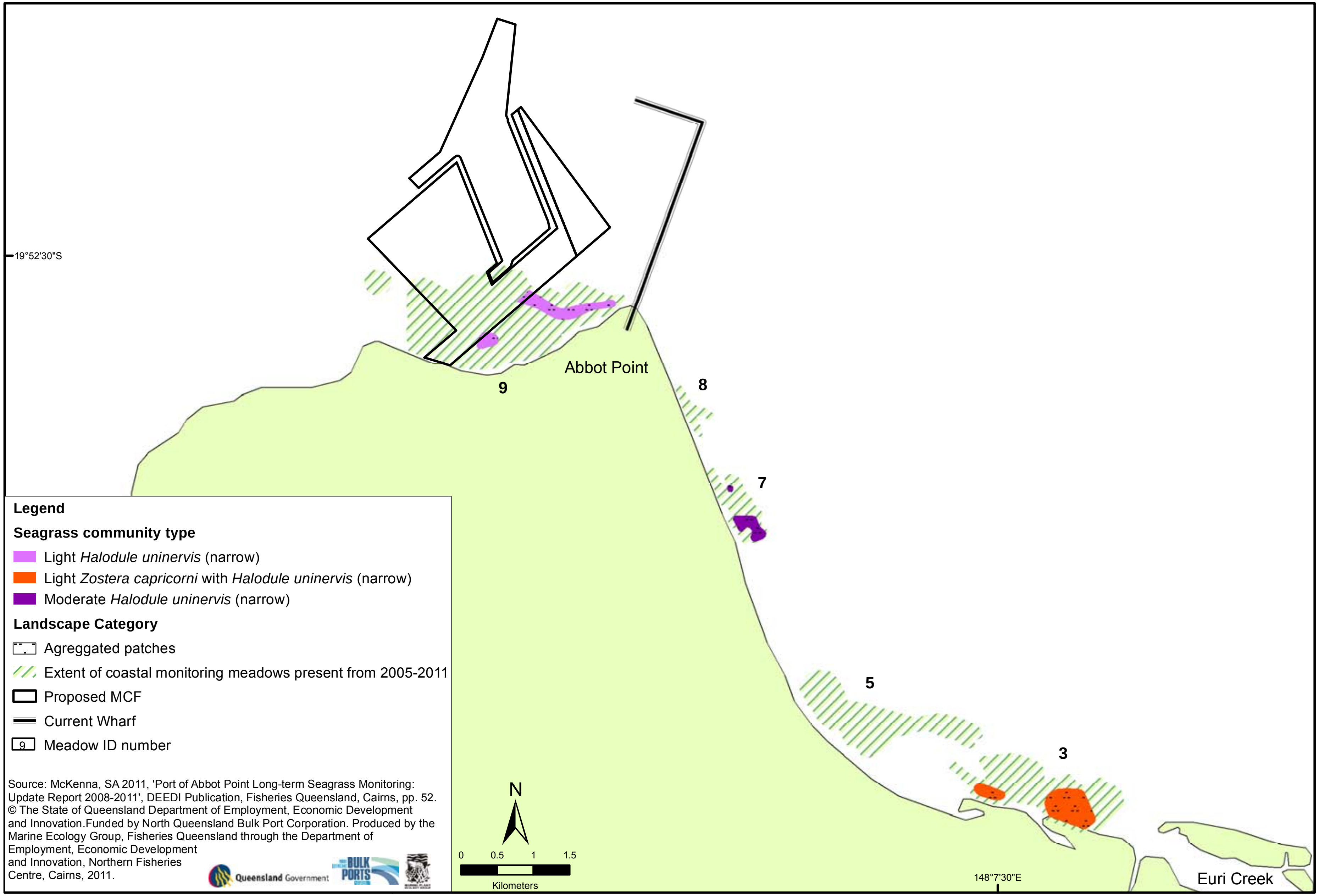
Map 7. Coastal monitoring meadows in the Port of Abbot Point September 2008



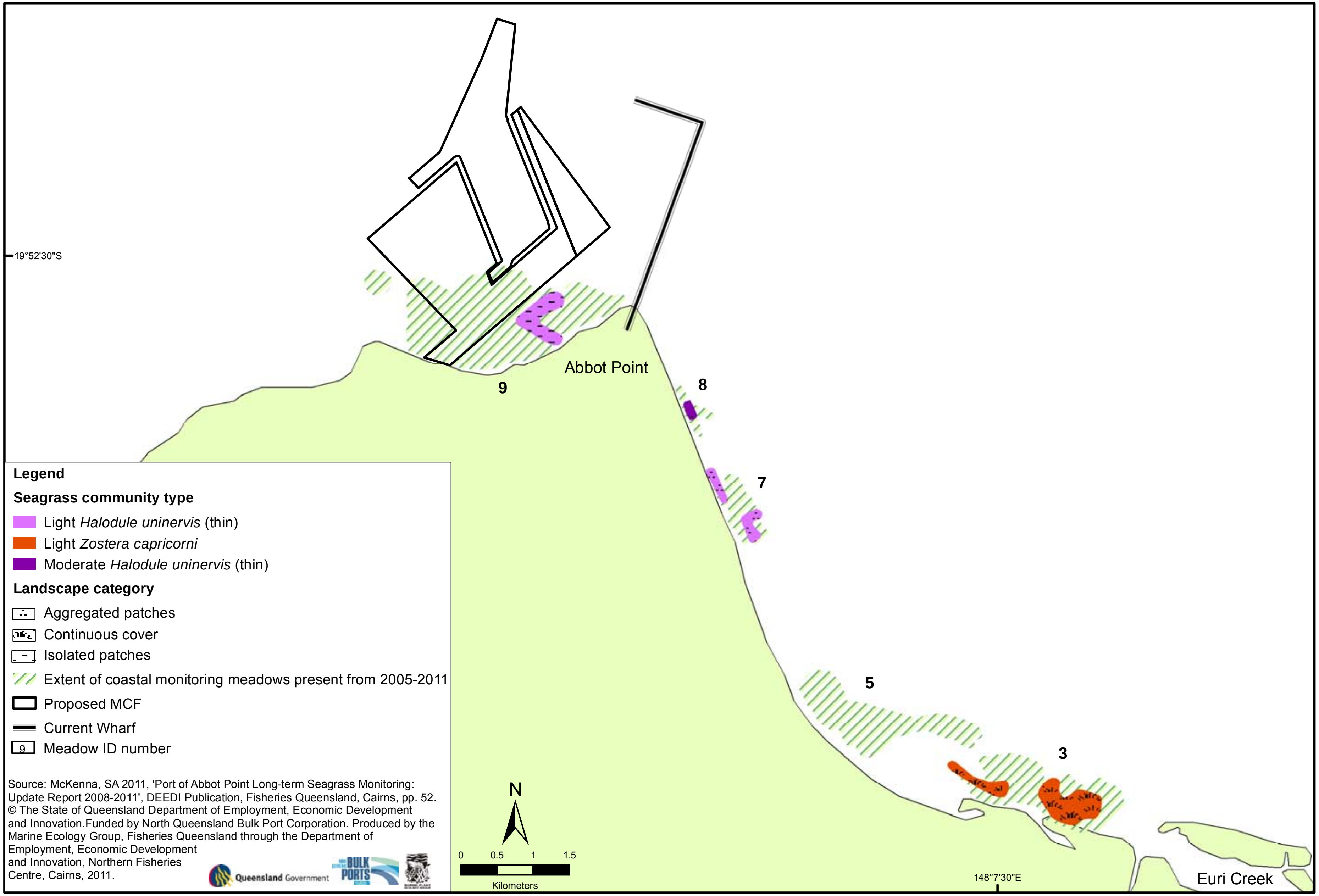
Map 8. Coastal monitoring meadows in the Port of Abbot Point November 2008



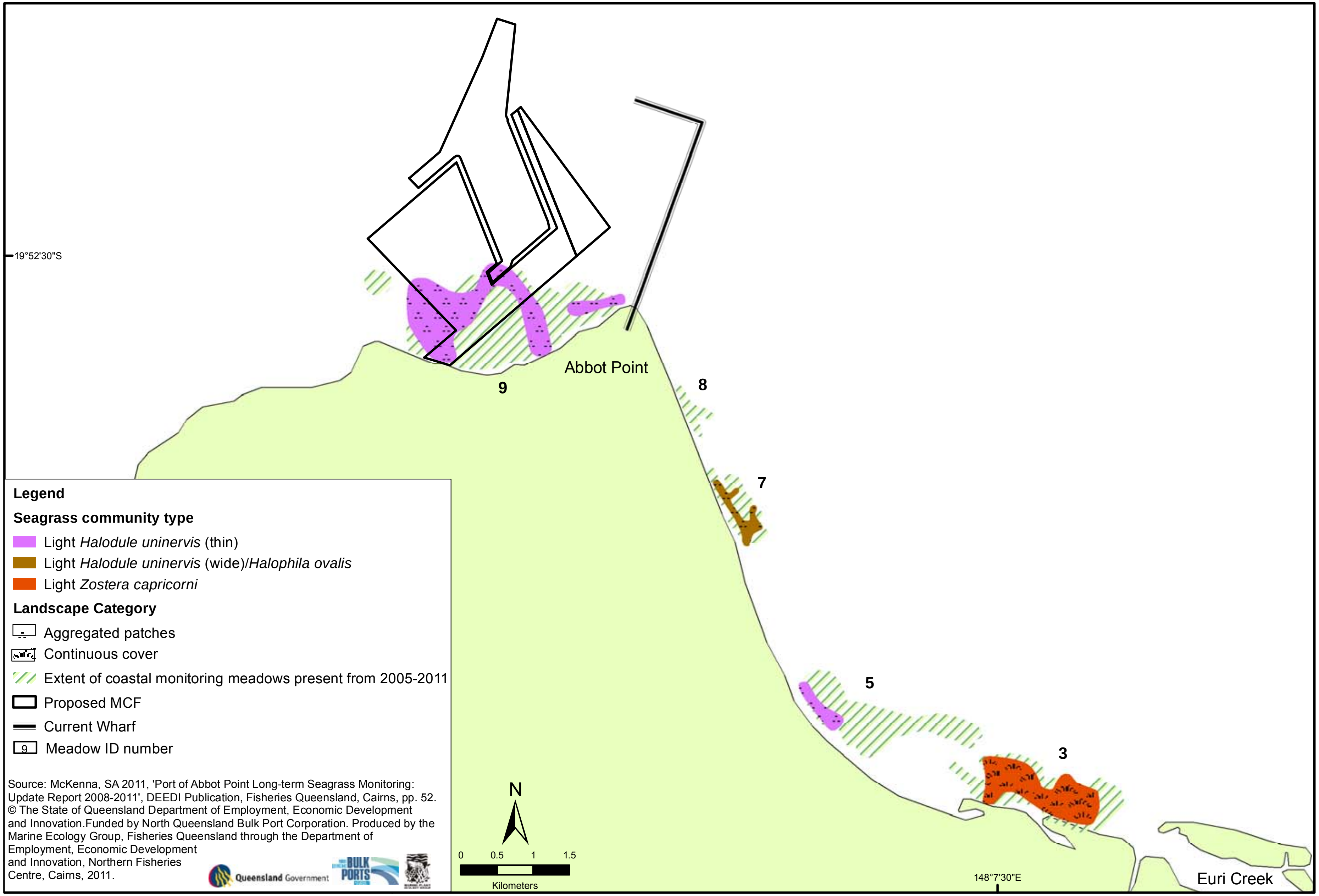
Map 9. Coastal monitoring meadows in the Port of Abbot Point April/May 2009



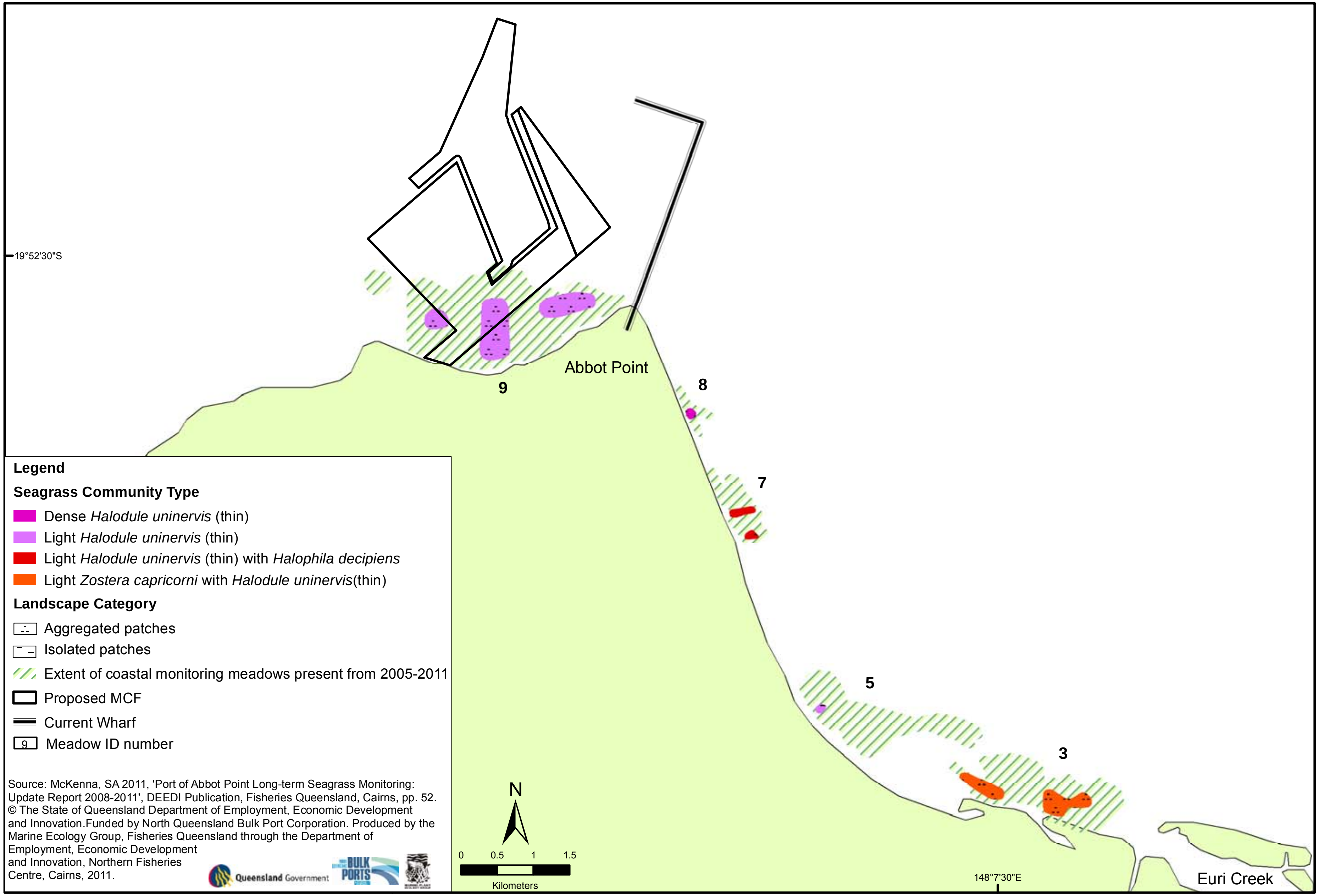
Map 10. Coastal monitoring meadows in the Port of Abbot Point August 2009



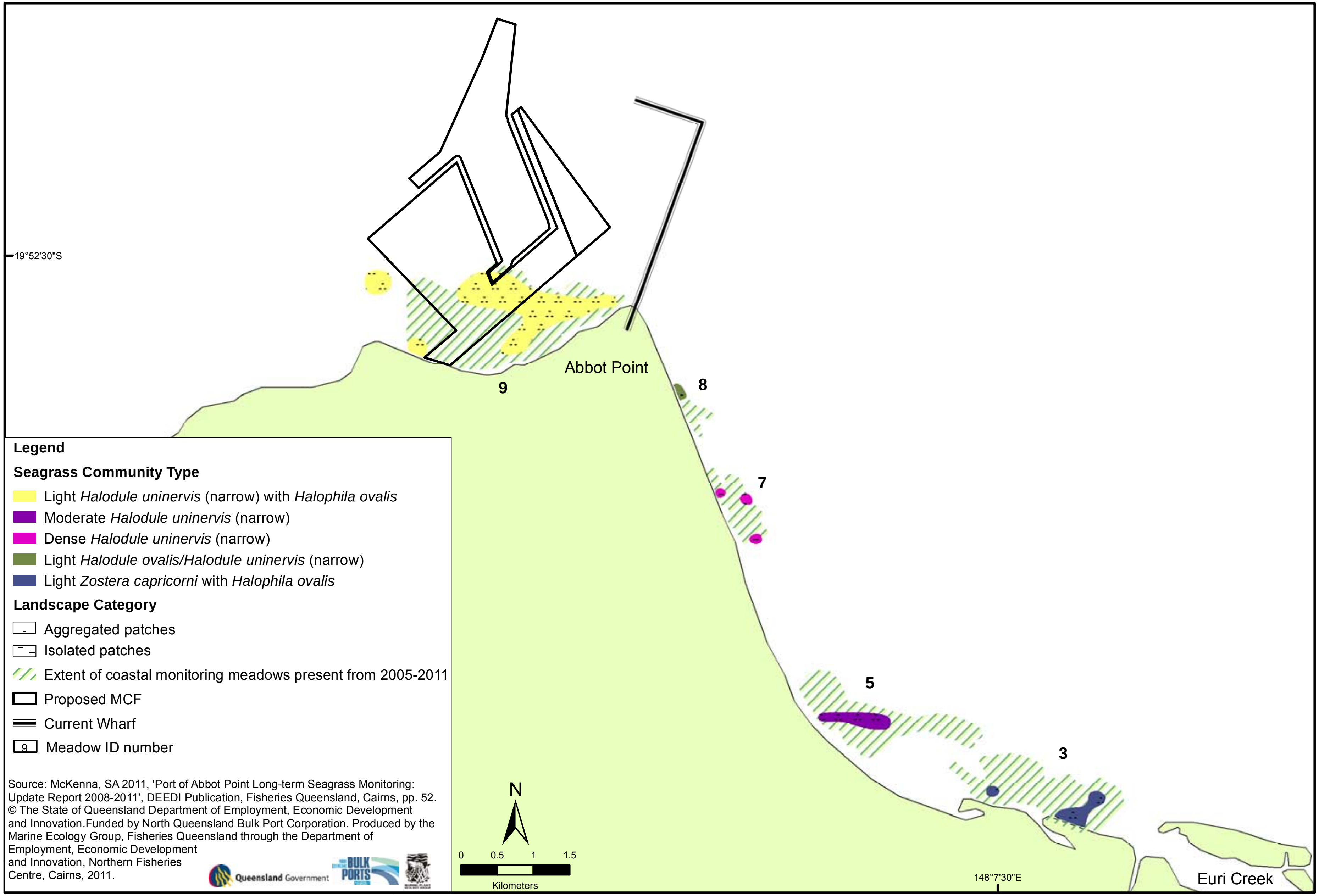
Map 11. Coastal monitoring meadows in the Port of Abbot Point December 2009/February 2010



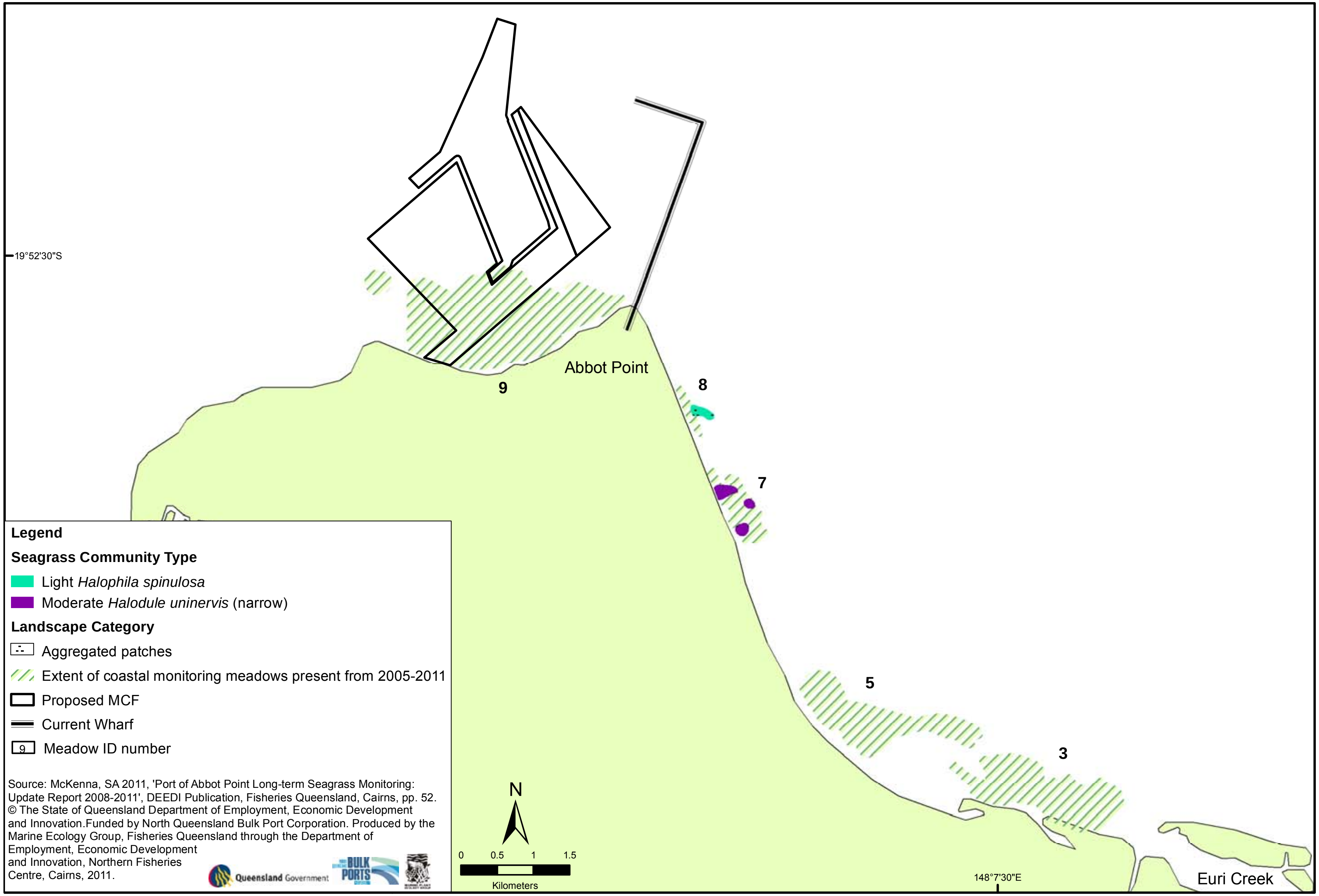
Map 12. Coastal monitoring meadows in the Port of Abbot Point June 2010



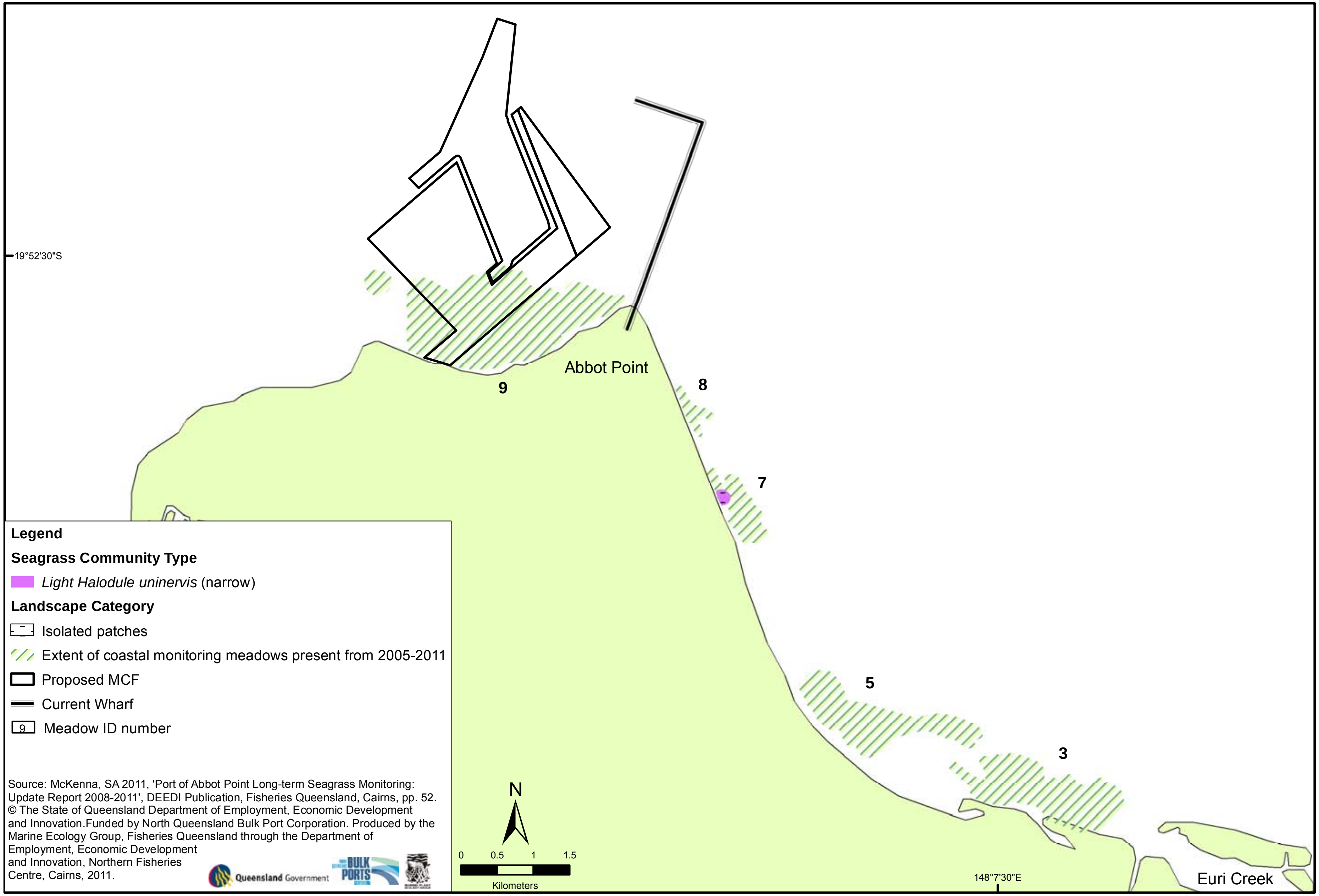
Map 13. Coastal monitoring meadows in the Port of Abbot Point November/December 2010



Map 14. Coastal monitoring meadows in the Port of Abbot Point March 2011



Map 15. Coastal monitoring meadows in the Port of Abbot Point May 2011



Map 16. Coastal monitoring meadows in the Port of Abbot Point September 2011