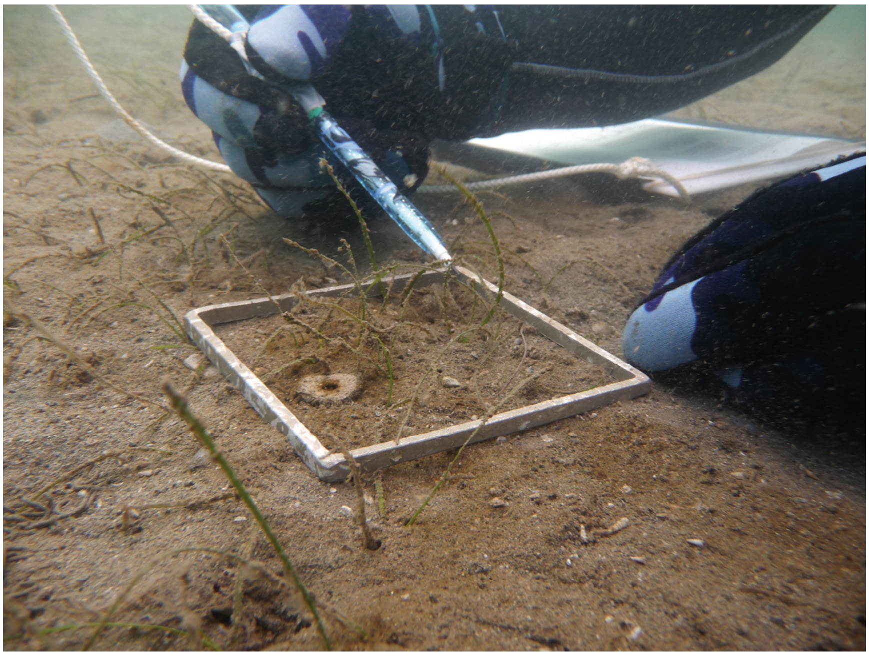
Department of Employment, Economic Development and Innovation

Seasonal dynamics, productivity and resilience of seagrass at the Port of Abbot Point: 2008 – 2010



Unsworth, R.K.F., McKenna, S.A. and Rasheed, M.A.

North Queensland Bulk Ports Corporation

Toward Q2 Tomorrow's Queensland

Queensland Government

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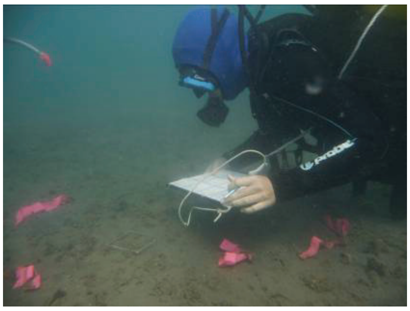


EXECUTIVE SUMMARY

This report details the results of seagrass baseline assessments, quarterly seagrass monitoring, and experimental research on seagrass resilience and productivity conducted between 2008 and 2010 at the Port of Abbot Point, North Queensland. This program of research and monitoring was commissioned by North Queensland Bulk Port (NQBP) Corporation in order to provide an understanding of the spatial and temporal change of seagrasses in the vicinity of the Port; their ecological and economic value, and their capacity to recover from future port related impacts.

Seagrass coverage was extensive, with meadows comprising 42% of the survey area. Seagrass meadows occurred from the shoreline to a distance of approximately 10km offshore and covered an area of up to 21,000ha. 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. Small meadows comprising the larger leaved species *Zostera capricorni* and *Cymodocea serrulata* were also recorded.

Seagrasses at Abbot Point were highly dynamic, changing as a function of season, but also influenced by extreme weather events during the life of the study. The productivity and resultant biomass of seagrasses at Abbot Point reached a maximum in the late dry season, a trend consistent with observations of seagrasses throughout Queensland.

Seagrass meadows at Abbot Point were highly productive, producing 237grams of carbon per m^2 per day. Although this is roughly half the productivity of seagrass meadows on reef platforms in the Torres Strait, this net productivity compares highly with many productive marine and terrestrial ecosystems worldwide. The productivity of these seagrasses supports an abundant and diverse 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 mega fauna such as Dugong, Turtle and Humpback whale observed in proximity to the port.

Seagrasses at Abbot Point were found to have some levels of resilience to stress, however this varied with species and community type and will be dependent in the future upon the continued availability of seed reserves. Species such as *Halophila spinulosa* were found to have a high capacity for recovery through the use of seed reserves in the sediment, however shallow near-shore species such as *Halodule uninervis* failed to recover quickly from simulated disturbance, relying on asexual propagation and were more vulnerable to longer term impacts should widespread loss occur.

Seagrass meadows at the Port of Abbot Point are highly productive and provide habitat and food for a range of important fauna. These seagrass meadows are dynamic, with some habitats having a higher capacity for recovery from loss than others. They are currently subject to a range of anthropogenic and natural threats potentially reducing their resilience to increased 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 program presented here can form the basis of a seagrass assessment and monitoring strategy to aid in the management of dredge related impacts.

INTRODUCTION

Background

The Port of Abbot Point is located 25 km north of Bowen in north Queensland (Map 1). At present the major activity within the port is the export of coal, with 14.4 million tonnes of total throughput of coal in 2008/09 (NQBP 2010). Existing port infrastructure includes a trestle jetty and conveyor connected to a berth and shiploader, located 2.75km offshore (managed by the port authority, North Queensland Bulk Port (NQBP) Corporation). The terminal at Abbot Point is currently undergoing numerous expansions with the addition of a second wharf and shiploader, and additional onshore stockyards and machines (NQBP 2010).

The Queensland Government is investigating the development of a new industrial precinct in the Abbot Point/Bowen area as part of its "Northern Economic Triangle State Development Area" program. Part of the requirement for the industrial precinct is the expansion of the Port of Abbot Point into a multi-purpose port facility to support the north's heavy industry sectors. These potentially include an alumina refinery, aluminium smelter, iron and steel making, nickel refinery, shale oil exports, liquefied natural gas exports, coke, chlor-alkali plant and a power station.

The construction period for the Multi-Cargo Facility (MCF) is expected to span a 3-4 year period beginning in 2010/11 and is expected to cost around $1.0 billion (NQBP 2010). Conceptual development options for a suitable wharf/berthing facility have been developed by NQBP (Map 1). This development will require a major capital dredging campaign and reclamation to establish a protected harbour for the expanded facilities.

NQBP is committed to the environmentally responsible management and maintenance of it's ports. They have previously recognised that seagrasses make up an ecologically important and environmentally sensitive habitat in the Port of Abbot Point (Rasheed *et al.* 2005). Previously mapped seagrass meadows are likely to play a significant role in fisheries productivity and the overall ecological productivity of the region. Future port activities and infrastructure developments such as the MCF could therefore potentially impact these seagrass communities through direct removal (dredging), burial (reclamation) and indirectly through turbid plumes created during dredging operations.

To assist in minimising marine impacts associated with port activities and infrastructure developments, NQBP commissioned further detailed studies of seagrass at the Port of Abbot Point. The Marine Ecology Group (MEG) through the Department of Employment, Economic Development and Innovation (DEEDI) was commissioned to undertake two baseline surveys and experimental research of the seagrass at the Port of Abbot Point, commencing in February 2008. These studies provided key information to aid in selecting the most sound port development options and also act as a foundation for the development of suitable guidelines, environmental trigger levels, and monitoring programs to protect seagrasses, should the development proceed.

This report describes the results from the two baseline surveys and quarterly monitoring assessments since 2008. The report also describes results that enable these meadows to be placed in the context of their ecosystem and fisheries value, and their resilience and capacity for recovery from dredge related impacts.

Study Site

The port of Abbot Point is located on the eastern coast of north Queensland, 25 kms north of Bowen (Map 1). The port limits extend from Abbot Bay (to the west) to Gloucester Head (to the southeast). The port area is entirely enclosed by the Great Barrier Reef World Heritage Area

(GBRWHA). In addition, two 'Dugong Protection Areas' have been established, one being outside the Port limits in Upstart Bay to the northwest of Abbot Point, and the other inside the Port limits encompassing most of Edgecumbe Bay (approximately 50km and 13km away from the port respectively). A declared Fish Habitat Area (FHA) also lies within the port limits approximately 36km away from the port (Map 1).

Abbot Point is located in the dry tropics with dry winters and wet humid summers. The wet season is commonly from December to March, with an average annual rainfall of 842.1mm (February being the wettest month at 242.9mm; (BOM 2010)). Mean daily temperatures range from a minimum in July of 13.5°C to a maximum of 31.5°C in January (BOM 2010).

The subtidal and intertidal area within the port limits has been described as typical of those found in other regions of north Queensland (PCQ 2005; Rasheed *et al.* 2005; McKenna *et al.* 2008). The area is dominated by open silty/sandy substrate with seagrass communities being the dominant benthic habitat feature. There are no significant areas of habitat forming benthic macro-invertebrates or large reef/coral areas, and only a very low percent cover of algae (Rasheed *et al.* 2005).

Port of Abbot Point Seagrasses

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

Seagrass was first mapped within the Abbot Point port limits during broad-scale surveys of the east coast of Queensland conducted by Fisheries Queensland in 1987 (Coles *et al.* 1992). In 2005, NQBP commissioned Fisheries Queensland to conduct a more detailed study of the seagrass, algae and benthic macro invertebrate communities in the vicinity of the existing port facilities (Map 2) (Rasheed *et al.* 2005). The 2005 survey concluded that seagrass meadows were the dominant benthic habitat (8779.5 ha), with no significant areas of habitat forming benthic macro-invertebrates and a very low coverage of algae in the region.

As part of the present studies, Fisheries Queensland conducted detailed seasonal baseline surveys in 2008 (McKenna *et al.* 2008). Results of those surveys also found extensive areas of coastal and offshore seagrass meadows (20,803 ha; 42% of the survey area) covering the region from Branch Creek to Bowen to a distance of approximately 10km offshore (see McKenna *et al.* 2008 for details). Seagrass species and meadow types ranged from low biomass coastal *Halodule uninervis* meadows to higher biomass deep water *Halophila spinulosa* meadows.

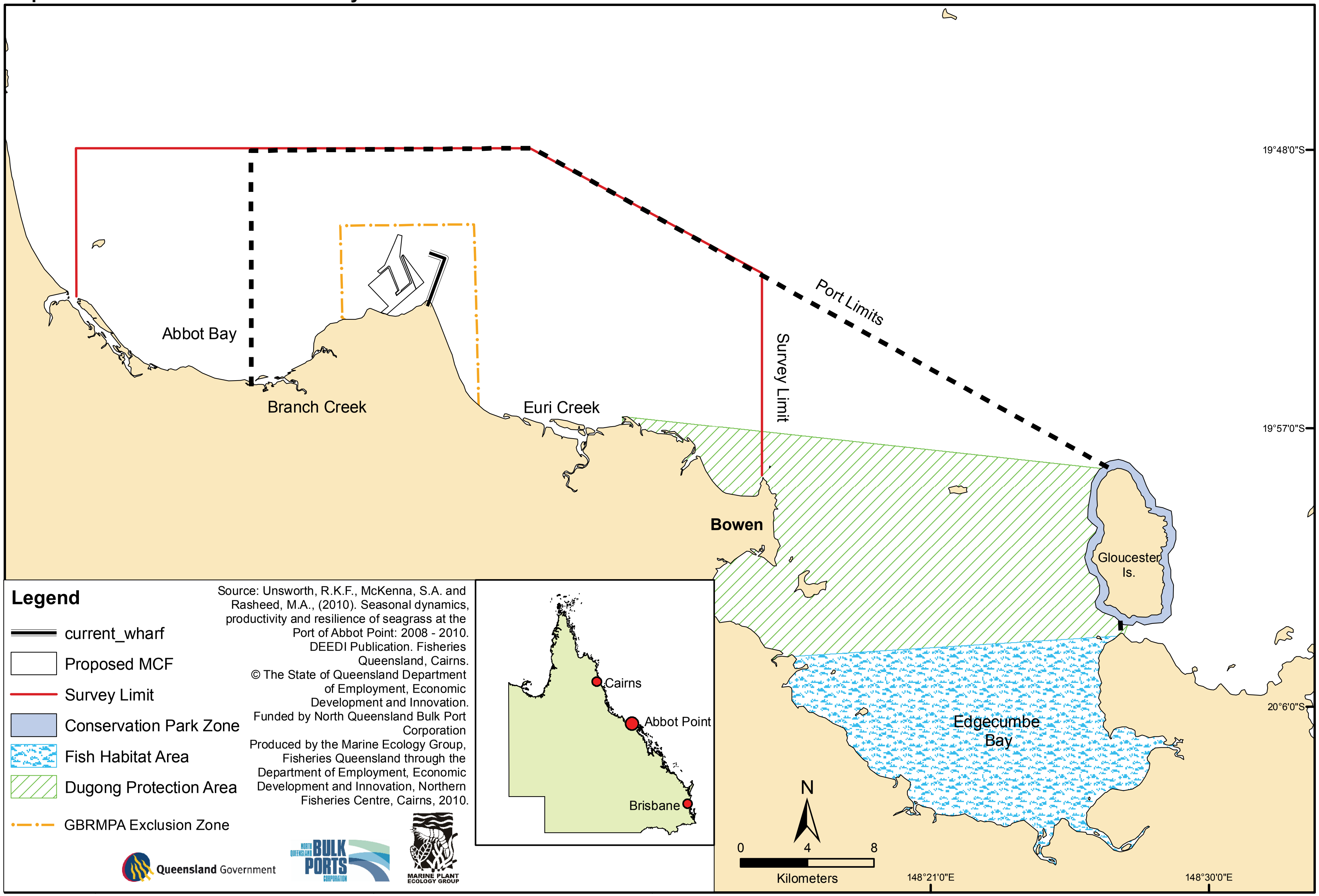
Eight species of seagrass have been identified within the port limits (Coles *et al.* 1992; Rasheed *et al.* 2005; McKenna *et al.* 2008). The majority of seagrass meadows are patchy, variable in density, and consisted principally of *H. spinulosa* in offshore meadows, while coastal meadows were dominated by *H. uninervis* (Coles *et al.* 1992; Rasheed *et al.* 2005; McKenna *et al.* 2008).

Seagrass abundance and distribution in North Queensland has been shown to vary seasonally, typically with a spring/summer maxima and a winter minima (McKenzie 1994; Rasheed *et al.* 2008b) as it relates to differences in wet and dry season conditions.

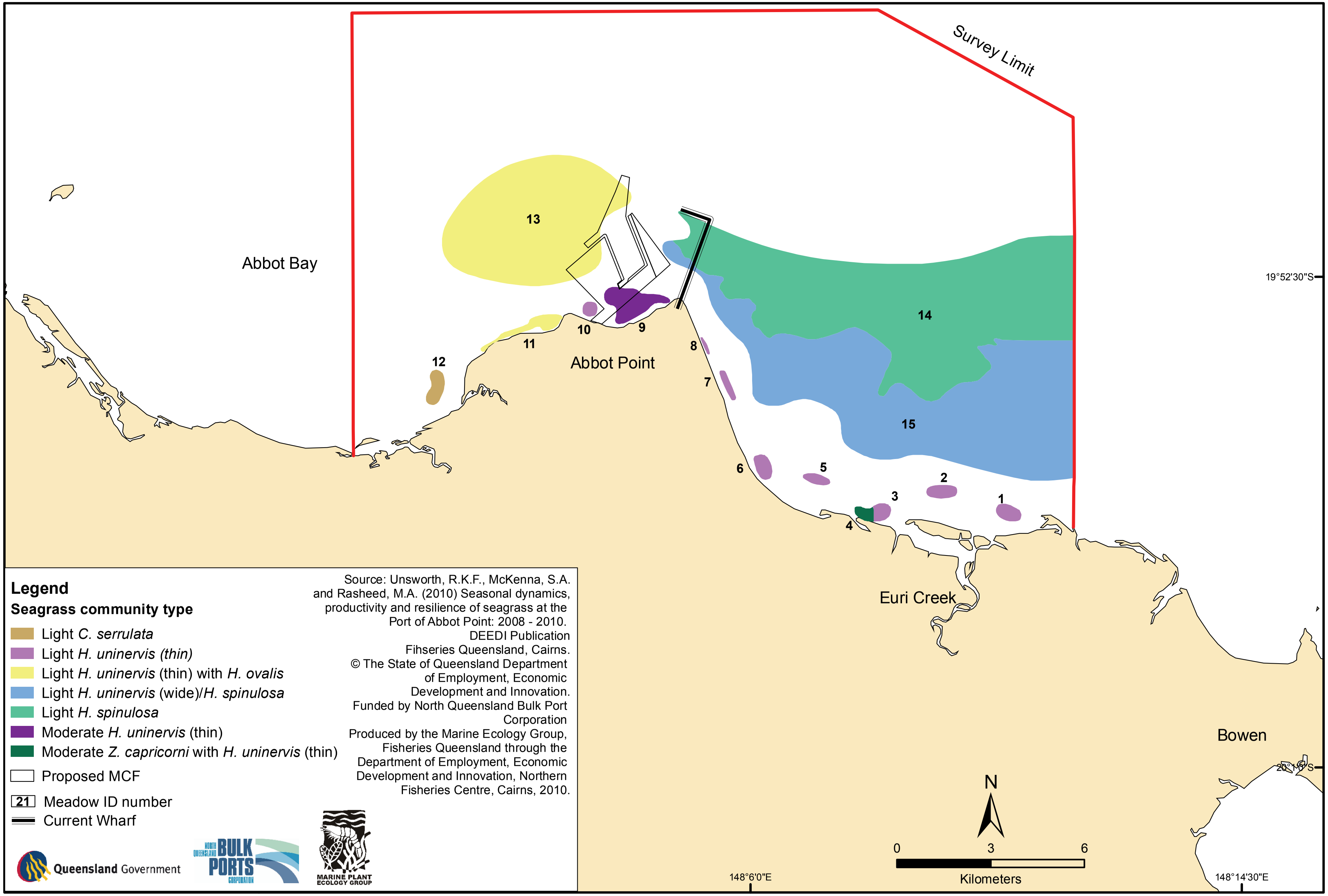
The large areas of seagrass meadows mapped in 2005 and 2008 were considered likely to play a role in fisheries productivity, and contribute significantly to the overall ecological productivity of the area. Many of the seagrass meadows were found to be of a type preferred as food for dugong and turtle. These meadows potentially provide a food source for dugong moving along the coast between the nearby Dugong Protection Areas (DPA's) to the northwest and southeast of the port (Coles *et al.* 2002) (Map 1). Studies of Abbot Bay have also recorded fish, prawn and crab species in seagrass beds (Coles *et al.* 1992; Rasheed *et al.* 2005). This is consistent with the role of other seagrass beds in Queensland of similar community type that have commonly been found to provide food and nursery grounds for juvenile fish and prawns (Watson *et al.* 1993).

Five species of marine turtles have been observed nesting, or foraging in seagrass beds within the Port limits at Abbot Point (Bell 2003; Agnew *et al.* 2004). Bell (2003) conducted a baseline turtle foraging and nesting study in 2003, which identified the port area as a nesting habitat for Flatback (*Natator depressus*) and Green (*Chelonia mydas*) turtles, as well as being a foraging habitat for adult Green and Loggerhead (*Caretta caretta*) turtles. Bell (2003) also found that the port area supported a notable number of foraging juvenile and sub-adult turtles. Furthermore, the presence of the endangered Hawksbill (*Eretmochelys impricata*) turtle has been noted in the port limits of Abbot Point (Agnew *et al.* 2004).

Map 1. Location of Abbot Point Survey area



Map 2. Seagrass community types in the port of Abbot Point March 2005



METHODS

Sampling Approach

The seagrass program at Abbot Point had two major components; Part A : Baseline Seagrass Assessments; and Part B : Monitoring and Experimental Investigations. The sampling approach was based on the need to provide NQBP with:

- An understanding of seagrasses within the port of Abbot Point to assist selecting a suitable development option with minimal marine impact.
- Information to assist in the development of suitable guidelines and environmental thresholds to protect seagrasses based on measurements of their resilience and capacity for recovery.
- A framework of long term monitoring sites to provide pre-dredge baseline information and form the basis of monitoring sites for seagrass health during and after dredging works.

1. **Part A** – Baseline Assessments (conducted February/March 2008 & September 2008; see McKenna *et al.* (2008) for full details;

   The **objectives** of the baseline assessments were to:

   - Establish seasonal baseline information on the seagrass communities in close proximity to proposed port development options.

   - Identify suitable seagrass areas for longer-term monitoring.

2. **Part B** – Monitoring and Experimental Investigations (results presented in this report)

   There are two major components to **Part B** of the project;

   1. Long-term monitoring of a subset of key seagrass meadows that are representative of the range of seagrass species and habitat types (intertidal and subtidal) present in the Port of Abbot Point;

   2. Manipulative experiments to determine resilience, productivity and recovery of the various seagrass species found in the area and determine their fisheries value.

   The **objectives** of the these studies reported here were to;

   - Conduct long-term monitoring of seagrasses potentially impacted by the proposed port developments identified in the baseline assessments.

   - Establish key characteristics of seagrass meadow resilience for the various seagrass meadow types likely to be affected by the proposed developments, including capacity for recovery and meadow productivity.

   - Provide information on the fisheries nursery habitat value of seagrass in the area.

   - Establish permanent monitoring locations suitable for assessment of dredge impacts and recovery.

This report contains maps and information pertaining to the results of nine seagrass monitoring events, and results of the experimental investigations conducted between February 2008 and June 2010 (Table 1).

Part B

1. Long term monitoring of key seagrass meadows

From the results of the first baseline survey, five coastal meadows and three offshore areas were identified as suitable for long-term seagrass monitoring (Map 3). These areas were selected because they represented the full range of seagrass species and habitat types (intertidal and subtidal) present in the Port of Abbot Point. Surveys of the selected meadows were to be carried out on a quarterly basis beginning July 2008. Due to weather constraints however, exact quarterly surveying was sometimes hard to achieve and the survey was carried out in the next available weather window (Table 1).

Quarterly assessments were used to better establish seasonal variation in the Abbot Point seagrass meadows. This information on the natural variability of seagrass meadows close to the port will be essential in interpreting potential impacts of capital dredging and port expansions. Should the port development program proceed, the subset of monitoring meadows would provide sites to establish a ‘Before/After/Control/Impact’ (BACI) type design (Underwood 1981) to detect potential impacts of the development on seagrass meadows.

Part B

2. Seagrass Resilience, Productivity & Capacity for Recovery

Key aspects of seagrass recovery, productivity and fisheries values were examined at representative seagrass meadow types in Abbot Point (Map 3). Data gathered in these studies provides information on how meadows will likely respond to capital works-related disturbance by quantifying aspects of their ecological and fisheries values. There were three major components outlined in this part of the investigation:

1. **Capacity for recovery**
2. **Productivity**
3. **Fisheries value**

Table 1. Time line of sampling events

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	✓			✓							
Monitoring subset of meadows			✓	✓	✓	✓		✓	✓ 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

Sampling Design

There were three major surveying components; offshore (deepwater) seagrass monitoring surveys, coastal intertidal to shallow subtidal seagrass monitoring surveys, and manipulative experiments.

1. Offshore Monitoring

Deepwater seagrass was monitored at 3 sites in the offshore seagrass meadows identified in the 2008 Baseline surveys (Map 3). Within each site, 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 a research vessel. 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 (Plate 1). 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.* 2003; Rasheed *et al.* 2005; Chartrand *et al.* 2008), 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 can 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 (see 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 is made by an observer viewing the screen. All observers were calibrated to a standard set of video images that have been harvested and measured.

3. ***Algae*** – Presence/absence, algae type and percent cover (identified according to (Cribb 1996). Percent cover was estimated from the video grab. Algae collected in the sled net and grab will provide a taxa list.

    - ***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 one-litre 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

Plate 1. Offshore video sampling sled, and sorting benthic samples from the sled net

2. Coastal Monitoring

Methodology and sample design for the coastal survey sites were similar to that developed by the MEG for seagrass/marine habitat surveys and monitoring programs previously used at Abbot Point (Rasheed *et al.* 2005; McKenna *et al.* 2008) and established in other north Queensland locations, such as in Cairns, Mourilyan Harbour, Upstart Bay, Mackay, Weipa, Karumba and Thursday Island (Taylor *et al.* 2006; Rasheed *et al.* 2008a; Chartrand and Rasheed 2009; Unsworth and Rasheed 2010).

Sampling sites for each monitoring survey were located along transects that ran perpendicular to the shoreline, extending approximately 1km offshore or past the offshore boundary of the monitoring meadow. Additional random sites were sampled between transects to check for habitat continuity. Sampling intensity of sites was approximately 50-200m intervals along each transect or where major changes in bottom topography occurred. Transects continued to at least the seaward edge of any seagrass meadows encountered. At each survey site, seagrass habitat characteristics, including seagrass species composition, above-ground biomass, percent algal cover and sediment type were determined. The percent cover of other major benthos, time, depth below mean sea level (MSL) and position (GPS) was also recorded at each site.

Seagrass biomass (above-ground biomass) at each site was determined using a modified "visual estimates of biomass" technique described by (Mellors 1991). This technique involved a free-diver ranking seagrass biomass in the field in three random placements of a $0.25m^2$ quadrat at each site (Plate 2). Ranks were 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 meter (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 were 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.

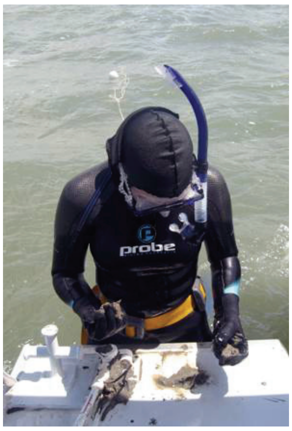
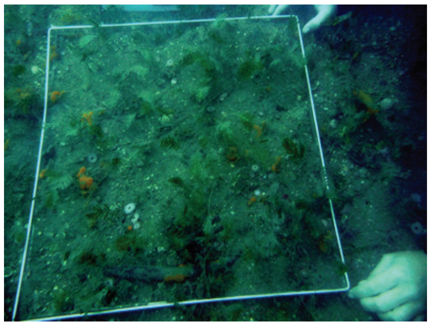




Plate 2. Sampling sites recorded by GPS were assessed by free divers to measure seagrass biomass and species composition to characterise the coastal habitat.

Habitat Mapping and Geographic Information System

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

- ***Habitat characterisation sites*** – 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 :

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

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

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

Table 2. Nomenclature for community types in the Port of Abbot Point 2008-2010

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

Table 3. Density categories and mean above-ground biomass ranges for each species use in determining seagrass community density in the Port of Abbot Point 2008-2010

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

Each seagrass meadow was assigned a mapping precision estimate (±m) based on the mapping methodology utilised for that meadow (Table 4). Mapping precision estimates ranged from 10m for isolated seagrass meadows, to 500m for larger subtidal meadows. The mapping precision estimate was used to calculate a range of meadow area for each meadow and was expressed as a meadow reliability estimate (R) in hectares. Additional sources of mapping error associated with digitising aerial photographs onto basemaps and with GPS fixes for survey sites were embedded within the meadow reliability estimates.

Table 4. Mapping precision and methodology for seagrass meadows in the Port Abbot Point 2008-2010

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

3. Manipulative Experiments

Seagrass Resilience, Productivity & Capacity for Recovery

Three seagrass meadows representative of the range of community types found within the port of Abbot Point were selected for detailed experimentation (Map 3). These experimental sites were established to determine key characteristics of seagrass meadow resilience for the various seagrass meadow types likely to be affected by the proposed developments, including capacity for recovery, productivity and fisheries values.

Experimental studies began in May 2008 (Table 1). At this time recovery experiments commenced at Sites 1 and 2, while Site 3 was established in July 2008. Productivity measures were first conducted during March 2008 and fisheries sampling (ie. beam trawling) began in August/September 2008 (Table 1). Exact quarterly surveying was hard to achieve due to weather and the survey was carried out in the next available weather window.

1. Capacity for recovery

The rate of seagrass recovery, the role of sexual and asexual reproduction, and the species involved in re-colonisation following loss/removal, was investigated at three sub-tidal meadows within the Port limits (Map 3). These investigations followed the methodology developed by (Rasheed 1999; Rasheed 2004) for investigating seagrass recovery after loss/removal. Each of the three experimental sites was subject to a randomised block design of 12 (0.25 m^{-2}) treatment plots of seagrass. The blocks were located randomly within the meadows. The 12 plots were subject to 3 replicates of 4 different treatments and were blocked together in order to maximise the number of replicate treatments that could be sampled in the narrow windows of time (use of SCUBA) available for sampling (Table 5).

At each site, 6 of the 0.25 m^{-2} plots of seagrass had seagrass material including roots and rhizomes removed. To determine how recolonisation is influenced by asexual reproduction (seagrass runners), half (3) of the cleared plots in each block had an aluminium border sunk 250mm into the sediment. The border isolates treatments from asexual colonisation by stopping rhizome extension from seagrass surrounding the plots. To investigate how recolonisation is influenced by the availability of sexual propagules (seeds), recovery of seagrass was compared among plots that have all material removed but the seed bank left intact. Recolonisation of all the cleared plots were compared to control plots in each block that were left undisturbed. Seagrass recovery and re-growth from each individual 0.25 m^{-2} plot was measured using leaf shoot density and visual estimates of above ground biomass (Rasheed 1999; Rasheed 2004). These are two non-destructive methods of measuring regrowth. The number of flowering and fruiting bodies of each seagrass species present in the plots was also counted by observers.

Measurements of the seed bank and the occurrence of flowers and fruits was also recorded by taking seed bank cores (Plate 3) (Table 1). On each sampling occasion, 12 cylindrical cores (15cm diameter x 25cm depth) were taken randomly around the study site. The density of seeds in the meadows (seeds m^{-2}) was determined from the average number of seeds per core. The number of shoots, flowering shoots seedlings, and attached fruits of each species was also recorded for seagrass from each core. Sediment cores were sieved through a stack of test sieves (4mm, 2mm and 1mm) to separate out seagrass seeds and fruits from the sediment. Material from these sieves was then placed in a shallow tray of water and any seeds present were removed, identified and recorded. Apart from *H. ovalis*, fruits and seeds of the species occurring at Abbot Point were sufficiently large to be retained in the 1mm sieve (den Hartog 1970). Fruits of *H. ovalis* were large enough to be isolated, but seeds may have been small enough to escape detection.

Plate 3. Diver taking seed bank cores at experimental sites

Table 5. Description of treatments for recovery experiments.

Treatment	Cleared	Not Cleared	Bordered	Not Bordered	Replicates
C1		✓	✓		3
C2		✓		✓	3
E1	✓		✓		3
E2	✓			✓	3

2. Productivity

The primary productivity of the selected seagrass meadows (including meadows in the footprint of proposed developments) was measured using techniques recently applied by the MEG to determine productivity of seagrass meadows in the Torres Strait (Rasheed *et al.* 2008b). This followed methods outlined in (Short and Duarte 2001), and were used to determine the total above ground production, carbon produced and meadow turnover time for Abbot Point seagrass meadows. To assess these parameters the information collected in the monitoring surveys was combined with measurements of shoot density and productivity for individual species and literature derived values of percent carbon for new growth. This information was used to estimate above ground production and meadow turnover for all monitoring events (Figure 1).

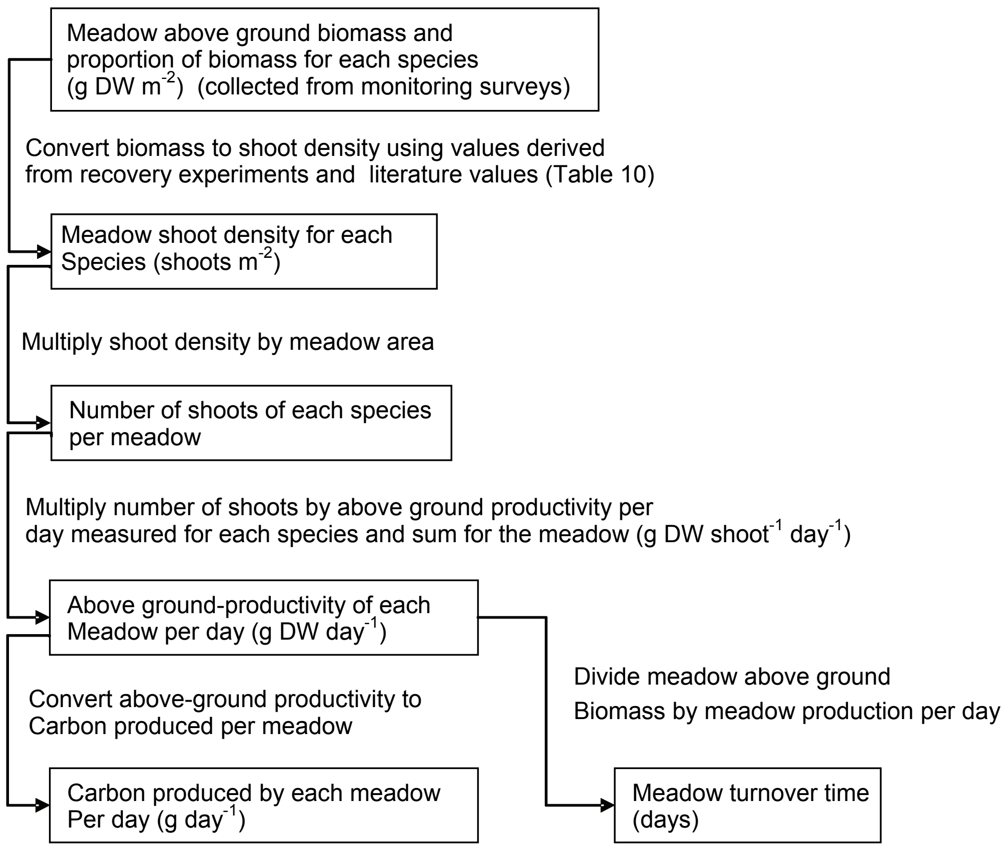


Figure 1. Flow chart detailing methodology for calculating above ground primary productivity, carbon produced and turnover time for seagrass meadows at Abbot Point (from (Rasheed *et al.* 2008b).

A) Conversion of meadow above ground biomass to shoot density

The above ground biomass for each monitoring meadow was converted to meadow shoot densities for each species. This was achieved by using relationships derived from the recovery experiments in this study and other studies (for *Zostera capricorni* and *Cymodocea serrulata*) where biomass and shoot density were simultaneously recorded (Table 10). The relationship between above ground biomass and shoot density for each of the species was determined and applied to the conversion (Appendix 3).

The calculated mean shoot densities for each species in each meadow (shoots m^{-2}) was converted to number of shoots of each species per meadow by multiplying the shoot density by the meadow area (for coastal monitoring meadows) which was determined from the monitoring surveys.

As the offshore monitoring sites did not provide an estimate of area and were based upon a stratified design, meadow productivity at a per m^2 basis was calculated from the offshore monitoring sites and the values extrapolated to a spatial basis by using the total area (ha) of the deepwater seagrass meadows identified in the March 2008 Baseline survey.

B) Above ground production of species

Above ground productivity information for each species found within the three experimental sites was collected. Logistical issues prevented the collection of *in situ* productivity measurements for two of the species found at Abbot Point, *Zostera capricorni* and *Cymodocea serrulata*. For these two species, values collected from previous studies in tropical locations were used (Pollard and Greenway 1993; Rasheed *et al.* 2008b). Three methods were used according to the growth habits of the species found in the meadows:

1) ***Leaf marking*** - For leaf replacing seagrass species (*Halodule uninervis*), the leaf growth rate was determined using the *in situ* leaf marking method. A hole was punched through all the leaves of an individual shoot using a syringe (Plate 4). This was just below the top of the basal meristem (sheath) of each shoot. As a leaf grows, the hole moves upwards from the basal meristem. The new leaf growth was any growth that occurs between the hole in the sheath and the scar on the leaf. A minimum of 30 shoots were marked for each species. Plants were harvested approximately 14 days after marking and brought back to the laboratory for separation into old and new growth (Plate 5). The dry weight biomass of each leaf section was then calculated by multiplying the measured surface area of each leaf section by the weight per unit area.
2) ***Rhizome tagging*** – Rhizome tagging was used to determine the leaf growth rate for non-leaf replacing species such as *Halophila ovalis* and *Halophila spinulosa* and the below ground production of all species. Rhizomes were tagged at the basal meristem with a coloured wire loop (Plate 7). Subsequent growth of the tagged seagrass produced a new shoot and roots that trap the wire loop in the newly formed node. A minimum of 10 rhizomes were tagged for each species. Tagged seagrasses were harvested 3 to 8 days after tagging and biomass of new leaf material measured in the laboratory.
3) ***Leaf clipping*** - For the di-meristematic non-leaf replacing species, *Halophila spinulosa*, a leaf clipping method was used in addition to rhizome tagging (Plate 6). This species has a meristem at the tip of the leaf cluster where new leaves are produced on existing shoots, as well as the new leaf shoots produced at the basal meristem on the rhizome. The youngest leaf on the tip of individual shoots was clipped in the field at a “radical” angle that can be recognised when the plants are harvested 3-8 days after clipping. A minimum of 20 leaf tips was clipped in the field. New growth added was determined by removing drying and weighing any leaves that were produced above the “clipped” leaf on the shoot.

Plate 4. Diver punching holes to mark “new” versus “old” growth

Plate 5. “New” and “old” biomass samples ready to be measured and dried

Plate 6. Diver clipping *H. spinulosa* leaf clusters

Plate 7. Diver tagging rhizomes at the basal meristem

C) Above ground productivity of meadows

To calculate the total above ground productivity of meadows, the number of shoots (leaf replacing species) or basal meristems (non-leaf replacing) of each species in the meadow (section **A**) was multiplied by the biomass added for each shoot or basal meristem per day calculated in section ‘**B’** above. Meadow above ground productivity was expressed as dry weight added for each meadow per day (g DW day^{-1}) and was calculated for all monitoring events (Table 10).

D) Meadow turnover

The turnover time of each meadow was measured by dividing the meadow biomass (g DW m^{-2}) by the meadow productivity (section **C**) (g DW m^{-2} day^{-1}). The resulting figure represents the number of days required for a meadow to completely turnover its current standing above ground biomass.

E) Above ground carbon production

For this study, a value of 34.34% of the total above ground dry weight produced by seagrasses as being comprised of carbon was used. This value was used by (Rasheed *et al.* 2008b) and was based on a range of literature values (Atkinson 1983; Koike *et al.* 1987; Erftemeijer 1994) that were geographically and environmentally applicable.

3. Fisheries value

Three sites (one inshore and two offshore) were identified to conduct beam trawling to examine the fisheries nursery value of the seagrass meadows and their utilisation by invertebrate and fish communities (Map 3). Sampling at these sites was conducted according to Table 1 and was aimed to pick up any seasonal variations in the recruitment of invertebrates and fish.

Sampling was conducted at the time of high water at night, with a beam trawl (1.5m wide, 0.5m high with a 2.0mm mesh) (Plate 8) towed along a 100m transect (a total of 150m^2 sampled). Three replicate trawls were conducted at each of the beam trawl sites, as previous studies in North Queensland have shown that this is sufficient to adequately sample the representative fauna (Coles *et al.* 1993; Chartrand *et al.* 2008).

Plate 8. Beam trawling was conducted at night to assess prawn stocks and other commercially valuable stocks around the Port of Abbott Point

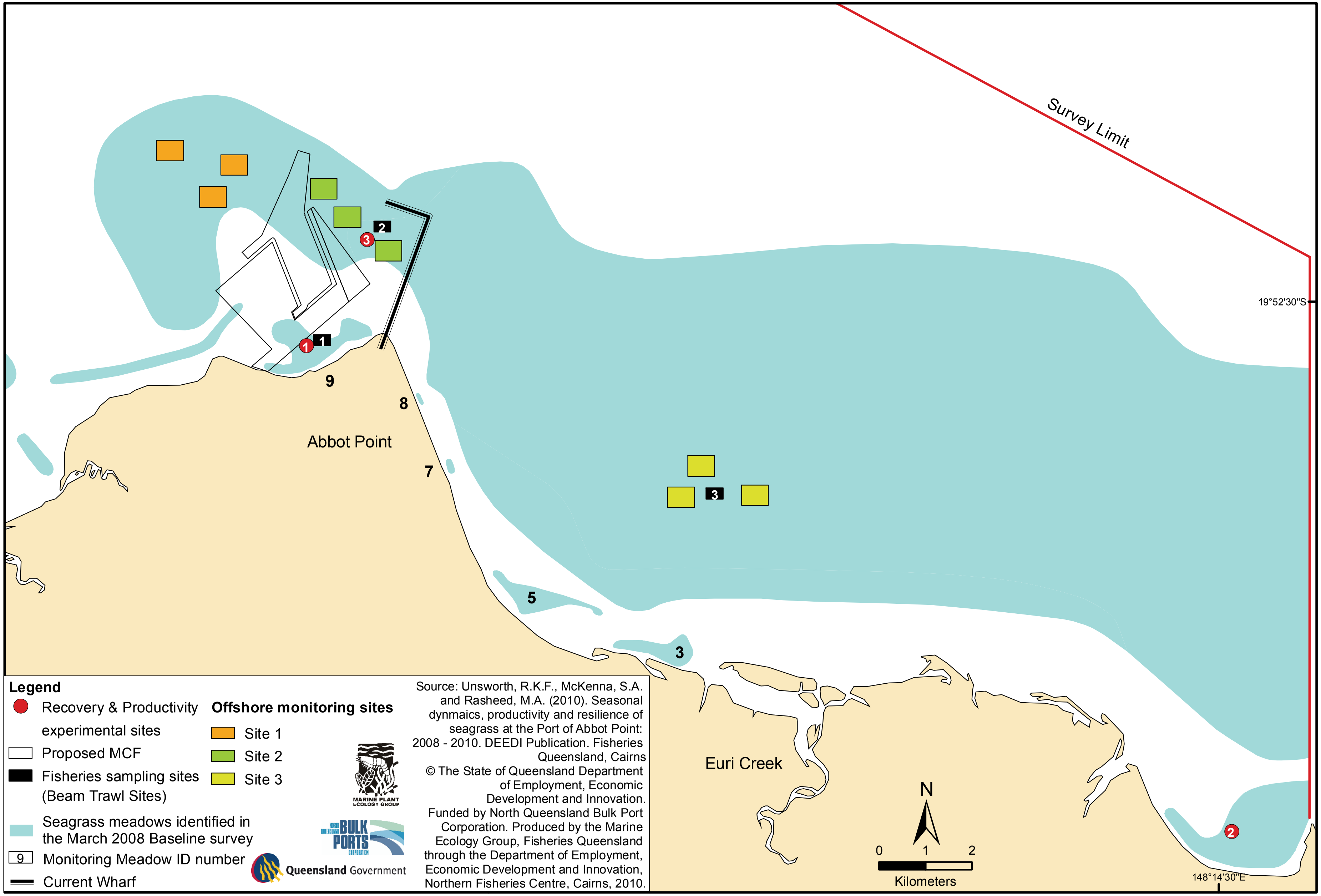
All Penaeidae (prawns) were identified to the lowest taxonomic unit possible (species, genus or family) according to (Dall 1957) and (Grey et al. 1983) and carapace length measured to the nearest millimetre. All fish were identified as far as possible and standard length (tip of snout to last vertebra) measured. Numbers of Brachyura (crabs), sepiolids (cuttlefish), squid and miscellaneous crustaceans (carids, isopods, amphipods and stomatopods) were recorded for each trawl. Biomass (grams dry weight) of fish, penaeids (all species pooled), crustaceans and miscellaneous from each trawl was also determined by drying (60°C, 48 hours) and weighing samples.

4. Statistical analysis

All data presented in the results is shown as means (± standard error), except where otherwise stated. Statistical analysis was conducted on data from the quarterly monitoring program and from the recovery experiments. The quarterly monitoring analysis used one-way ANOVA. Where data did not conform to the assumptions of ANOVA, data were transformed. Where data continued to differ from the assumptions of ANOVA it was still conducted, but in order to minimise the possibility of recording a Type 1 error, an α level of 0.01 was used instead of $\alpha = 0.05$ (Underwood 1997).

One-way ANOVA was also used to examine shoot density data within the recovery experiments. This was conducted to test the effects of different experimental treatments at each individual discrete sampling time and utilised tukeys pairwise comparisons. Where data did not conform to the assumptions of ANOVA, Kruskal-Wallis one-way ANOVA on ranks was conducted utilising Holm-Sidak pairwise comparison. In order to compare each recovery experiment with respect to time, one-way repeated measures ANOVA was also conducted on each individual treatment, and where data did not conform to the assumptions of ANOVA Friedman, repeat measures ANOVA on ranks was used.

Map 3. Seagrass Monitoring and Experimental sites in the Port of Abbot Point



RESULTS

1. Quarterly Monitoring of representative seagrass meadows

Seagrass species, distribution, abundance and changes

Following the February/March 2008 baseline survey, there were a total of 7 monitoring surveys conducted at the Port of Abbot Point between July 2008 and June 2010. Seven seagrass species (from 3 families) were identified in the survey area with *Halophila spinulosa* dominating the deeper sub-tidal areas, and *Halodule uninervis* (wide & thin varieties) dominating the inshore areas (Table 6). The 7 monitoring surveys showed that meadow biomass and distribution was highly variable through time, with some meadows (5 & 8; offshore Site 1) becoming absent for periods (Table 7 & 8; Figure 2). Seagrass was consistently present throughout the potential port facility expansion area, through all seasons.

A broad seasonal pattern of higher seagrass biomass in coastal and deepwater meadows in the latter half of the year was apparent, with highest biomass generally recorded in the late dry season (Sept to Dec). LSD comparison of means following one-way ANOVAs generally grouped monitoring events in the late dry seasons together, and those in the wet seasons together (see Appendix 1).

Coastal Monitoring Meadows

The coastal monitoring meadows were variable in distribution and biomass between monitoring surveys with the majority of the meadows across all monitoring surveys consisting of isolated and aggregated patches of seagrass (Map 4). These meadows were dominated primarily by *Halodule uninervis* in all surveys with one *Zostera capricorni* meadow (3) located west of Euri Creek (Map 4).

Mean above-ground biomass was consistently highest in meadow 3 which was the only meadow with a constant substantial coverage of *Zostera capricorni*. Seagrass biomass changed significantly between monitoring surveys at meadows 3, 5 and 7, but no significant change through time was detected in meadow 9 (Appendix 1). Within the coastal meadows there was a general pattern for seagrass to increase in above-ground biomass from March 2008 to September and November 2008 and then consistently decline to June 2010.

Meadows 5 & 8 were often sparse isolated patches of *Halodule uninervis* and were sometimes absent altogether in 2009 (Table 7).

The highest total area of coastal monitoring meadows was recorded in February/March 2008 (250.5 ± 108.6 ha), while the lowest was recorded in April/May 2009 (79.8 ± 54.2 ha). The distribution of these coastal monitoring meadows varied between surveys but did not seem to follow any discernable seasonal pattern.

The species composition of the coastal monitoring meadows was mostly stable throughout the monitoring program (Figure 2). Meadow 3 was the only meadow to undergo a distinct species shift. This was from being dominated by *Halodule uninervis* in the March 2005 and March 2008 monitoring surveys, to *Zostera capricorni* in the July 2008 survey and all other monitoring surveys after that. Meadows 7, 8 and 9 had periods of elevated proportions of *Halophila ovalis* (Figure 2).

Offshore Monitoring Sites

Similar to the coastal meadows, the above-ground biomass of the deepwater monitoring sites generally reached a maximum in the latter months of 2008 and 2009, and showed declines in biomass in the first half of both 2008 & 2009, coinciding with the end of the wet season. Seagrass biomass changed significantly between monitoring surveys at Sites 1 and 3 (Appendix 1). The December 2009 survey was not included in the analysis as there was no visibility at any of the sites and therefore no biomass measurements were able to be obtained. The biomass values presented in Table 9, for the December survey, were derived from the calculation of shoot counts (which were collected in the field at each site) converted to biomass, based on the biomass and shoot counts that were already determined at the same sites from other monitoring surveys.

The deepwater meadows were more species rich and more variable in species composition with respect to season compared to the coastal meadows (Figure 3). Site 1 had the largest fluctuations in seagrass presence in the monitoring blocks of all offshore sites (Map 4). Seagrass was present in only two blocks in September 2008 and April/May 2009 and no seagrass was present at all at site 1 in the June 2010 survey. This absence of seagrass was reflected in the overall above-ground biomass for the site (Figure 3). The dominant species at Site 1 was *Halodule uninervis. Halophila spinulosa* contributed larger proportions during the winter/dry season months (July 08 & Aug 09), while *Halophila ovalis* was more evident in the wet season (Mar 05, Nov 08 & Dec 09). These changes however were not reflected in overall biomass (Figure 3).

Seagrass at the offshore monitoring Site 2 was absent in the April/May 2009 survey and not present at one monitoring block in the June 2010 survey (Map 4). The absence of seagrass in April/May 2009 was reflected in the species composition change observed in the following three surveys. Prior to April/May 2009 *Halophila spinulosa* dominated the site. Post April/May 2009 *Halophila ovalis* and *Halophila decipiens* contributed larger proportions to the site. By June 2010 *Halophila spinulosa* was becoming dominant again.

The highest biomass site, Site 3 (*Halophila spinulosa* dominated) was the most species rich, with 6 species being identified at the site (Figure 3). Seagrass was always present at this site throughout the monitoring program (Map 4). Changes in relative species composition at Site 3 did not correspond to seasonality or changes in seagrass community biomass.

Table 6. Seagrass species found within the Port of Abbot Point, March 2005 & February 2008-June 2010.

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

Table 7. Mean above-ground biomass (g DW m^{-2}) of monitoring meadows within the Port of Abbot Point, March 2005 & February 2008 – June 2010.

		Mean biomass ± SE (g DW m^{-2}) (no. sites within meadow)								
Meadow ID	**Dominating seagrass species**	**Mar 05**	**Feb/Mar 08**	**Jul 08**	**Sept 08**	**Nov 08**	**Apr/May 09**	**Aug 09**	**Dec 09**	**Jun 10**
3*	*Z. capricorni*	0.09 ± 0.03 (6)	3.71 ± 1.72 (8)	4.55 ± 1.68 (15)	8.91 ± 4.17 (11)	6.98 ± 2.95 (14)	3.34 ± 0.95 (9)	2.76 ± 0.99 (14)	1.59 ± 0.55 (31)	0.84 ± 0.4 (13)
5*	*H. uninervis* (thin)	0.03 ± 0.03 (1)	0.05 ± 0.02 (9)	1.57 ± 0.08 (3)	1.54 ± 0.57 (6)	1.30 ± 0.71 (6))	NP	NP	0.005 ± 0.003 (5)	0.06 ± 0 (1)
7*	*H. uninervis* (wide) and (thin)	0.06 ± 0.06 (1)	2.84 ± 0 (1)	3.72 ± 0.33 (4)	6.7 ± 2.21 (12)	2.87 ± 0.74 (9)	1.68 ± 0.46 (8)	0.43 ± 0.18 (7)	1.0 ± 0.62 (13)	0.76 ± 0.4 (6)
8	*H. uninervis* (thin)	0.03 ± 0.03 (1)	0.52 ± 0.52 (2)	NP	1.65 ± 0.33 (2)	5.01 ± 1.72 (3)	NP	1.57 ± 1.18 (2)	NP	5.04 ± 0 (1)
9	*H. uninervis* (thin)	1.63 ± 0.54 (16)	0.86 ± 0.47 (17)	1.1 ± 0.53 (12)	0.4 ± 0.15 (17)	1.02 ± 0.51 (20)	0.17 ± 0.08 (10)	0.63 ± 0.3 (3)	0.15 ± 0.08 (15)	0.11 ± 0.02 (6)

NP – Meadow not present
*Indicates that a significant difference ($P<0.05$) between monitoring events detected (see Appendix 1)

Table 8. Area (ha) of monitoring meadows within the Port of Abbot Point, March 2005 & February 2008 – June 2010.

		Area (Ha)								
Meadow ID	**Dominating seagrass species**	**Mar 05**	**Feb/Mar 08**	**Jul 08**	**Sept 08**	**Nov 08**	**Apr/May 09**	**Aug 09**	**Dec 09**	**Jun 10**
3	*Z. capricorni*	25.6 ± 6	55.5 ± 8	53.1 ± 8.3	56.95 ± 8.06	83.6 ± 10.5	32.4 ± 19.9	44.2 ± 9.3	75.4 ± 9.3	24.6 ± 6.8
5	*H. uninervis* (thin)	21.5 ± 6.1	67.9 ± 27.6	9.7 ± 1.9	19.83 ± 17.1	30.9 ± 18.6	NP	NP	13.3 ± 10.1	1.4 ± 1
7	*H. uninervis* (wide) and (thin)	19.5 ± 7.1	4.2 ± 0.9	3.6 ± 0.9	21.47 ± 2.38	12 ± 2.1	9.2 ± 5.6	13.2 ± 2.6	15.7 ± 6.2	5.1 ± 3
8	*H. uninervis* (thin)	5.6 ± 2.7	2.1 ± 0.7	NP	4 ± 0.81	3.7 ± 1	NP	3 ± 0.7	NP	1.6 ± 1
9	*H. uninervis* (thin)	125.8 ± 41	120.8 ± 71.4	67.0 ± 9	83.96 ± 10.26	83.1 ± 13.1	38.20 ± 28.7	22.9 ± 5.1	127.5 ± 17.8	56.3 ± 33.3
Total		**198 ± 62.9**	**250.5 ± 108.6**	**133.4 ± 20.1**	**213.3 ± 38.61**	**213.3 ± 45.3**	**79.8 ± 54.2**	**83.3 ± 17.7**	**231.9 ± 43.4**	**89 ± 45.1**

NP – Meadow not present

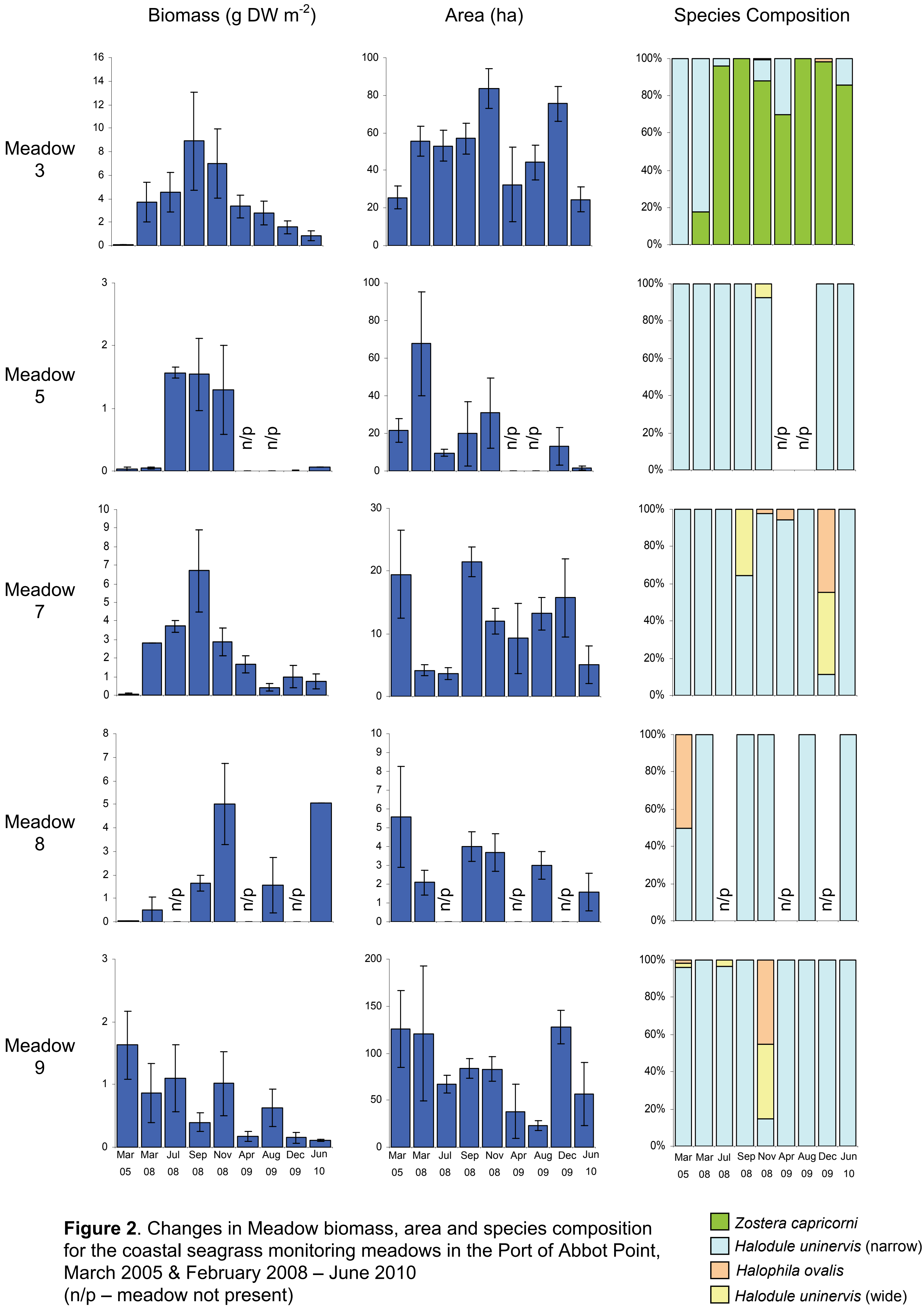


Figure 2. Changes in Meadow biomass, area and species composition for the coastal seagrass monitoring meadows in the Port of Abbot Point, March 2005 & February 2008 – June 2010
(n/p – meadow not present)

Table 9. Mean above-ground biomass (g DW m-2) of Deepwater monitoring sites in the Port of Abbot Point, March 2005 & February 2008 – June 2010.

Sampling Date	Presence of Seagrass	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*)

* - 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

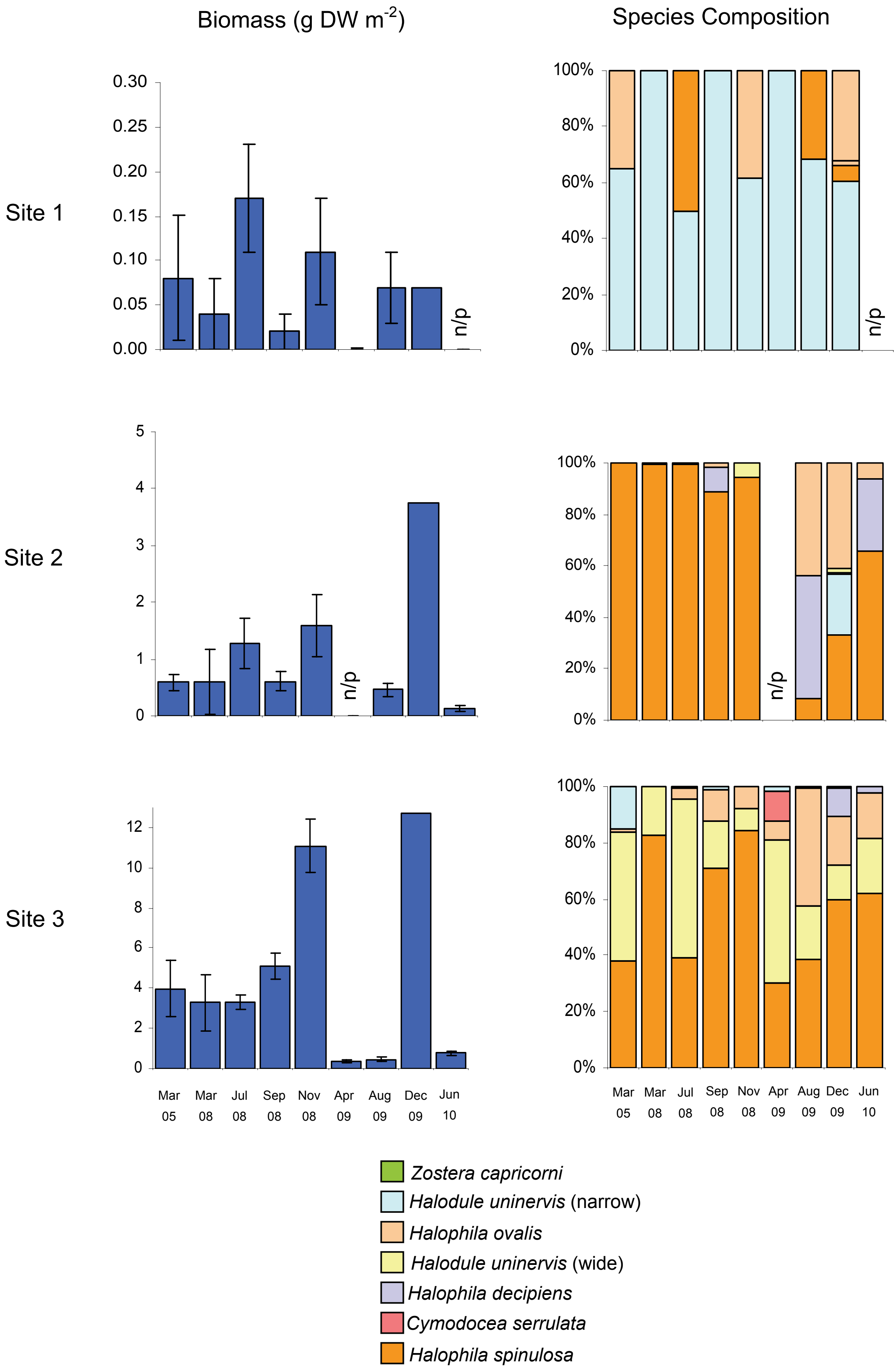
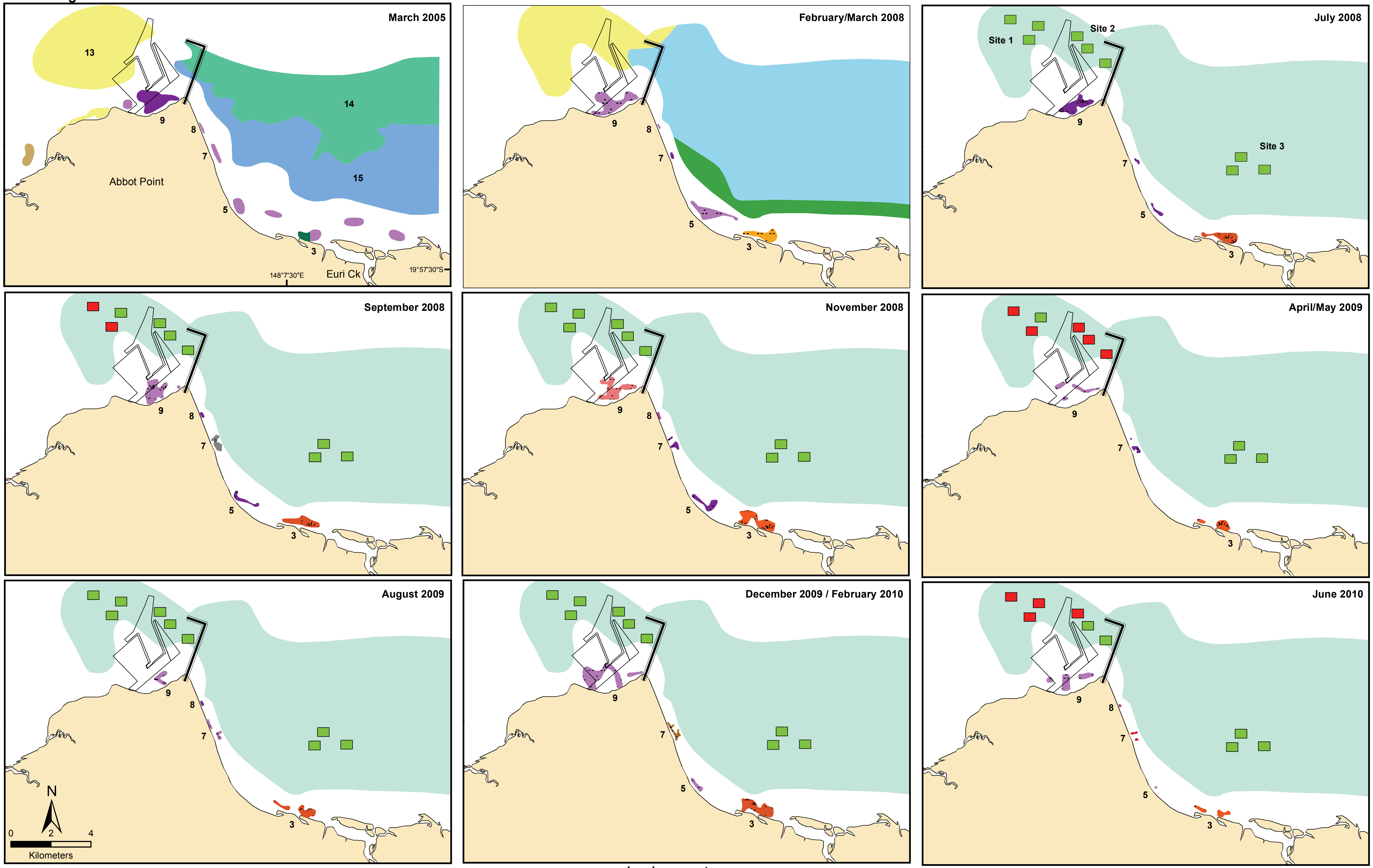


Figure 3. Changes in Meadow biomass, area and species composition for the deepwater seagrass monitoring sites in the Port of Abbot Point, March 2005 & February/March 2008 – June 2010

Monitoring meadows in the Port of Abbot Point - March 2005 & March 2008 - June 2010



Legend

Seagrass Community Type

- Light *Halodule uninervis* (thin)
- Light *Halodule uninervis* (thin) with *Halophila ovalis*
- Light *Halodule uninervis* (wide) with mixed species
- Light *Halodule uninervis* (wide) / *Halophila ovalis*
- Light *Halophila spinulosa* with mixed species
- Light *Zostera capricorni*
- Light *Zostera capricorni* with *Halodule uninervis* (thin)
- Light *Halophila ovalis* / *Halodule uninervis* (wide)
- Moderate *Halodule uninervis* (thin)
- Moderate *Halodule uninervis* (thin) with *Zostera capricorni*
- Dense *Halodule uninervis* (thin)

Landscape category

- Aggregated patches
- Continuous cover
- Isolated patches
- Draft development option
- Current Wharf

Offshore monitoring sites

- Seagrass Present
- Seagrass not present
- 9 Meadow ID number

NORTH QUEENSLAND BULK PORTS CORPORATION

MARINE PLANT ECOLOGY GROUP

Queensland Government

Source: Unsworth, R.K.F., McKenna, S.A. and Rasheed, M.A. (2010). Seasonal Dynamics, Productivity and Resilience ofSeagrasses at the Port of Abbot: 2008 - 2010. DEEDI Publication (DEEDI, Cairns)

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2. Capacity for Recovery

Three experimental seagrass recovery sites were studied at Abbot Point (Map 3). Site 1 was located in coastal monitoring meadow 9 (approx 2m dbMSL) and comprised entirely of *Halodule uninervis* in both narrow and wide forms. The second site (Site 2) was located in sheltered Queens Bay at Bowen and was a mixed species seagrass meadow. This meadow consisted of *Halodule uninervis* (narrow and wide), *Halophila spinulosa*, and *Halophila ovalis* and was approximately 6m dbMSL. Site 3 was located parallel to the current wharf at Abbot Point and was comprised exclusively of *Halophila spinulosa*. This was the deepest experimental site at approximately 13.4m dbMSL.

The role of sexual and asexual reproduction (seeds vs runners) in the recovery of the cleared experimental plots varied depending on site. In general, preventing asexual colonisation (bordering) had a significant impact on the rate at which cleared plots recovered in relation to control plots at Sites 1 and 2. In contrast, the prevention of asexual colonisation (bordering) had no significant impact on the recovery of cleared plots at Site 3.

Recovery of seagrass at sites 1 and 2 (where recovery was observed in plots) occurred approximately four months after the plots had been cleared. The recovery at site 1 was driven by *Halodule uninervis* (wide), while at site 2 it was driven by *Halodule uninervis* (narrow). In contrast cleared plots at site 3 recovered within two months of the original clearing with *Halophila spinulosa* the dominant species in recovering plots.

By May 2009, all seagrass was absent in the experimental plots and surrounding meadow at sites 1 & 3, while at site 2, no seagrass was found in the cleared & border and control & border treatments. The absence / low abundance of seagrass noted in these experimental sites was also observed throughout the coastal monitoring meadows and was probably due to storm events. In January/February there was wide spread flooding, heavy rainfall and storm surges throughout the survey area (Figure 13). It was due to this weather event that the scheduled assessments in February 2009 were not possible.

Recovery at Site 1 - Halodule uninervis (narrow and wide) assemblage

Halodule uninervis in both wide and narrow forms were the only species found at recovery Site 1. Seagrass at this site was significantly affected by time ($F_{4,59}$=18.3 , $p<0.001$) and treatment ($F_{4,59}$=9.1 , $p<0.01$), and these factors significantly interacted (Appendix 2A).

Having cleared the plots in May 2008, by July 2008 some recolonisation was observed in the cleared plots where asexual and sexual (i.e. recovery from seed banks) colonisation could occur (bordered and non-bordered). The shoot density of these plots however was still significantly different to those of the uncleared controls (Figure 4A, Appendix 2A). Four months after clearing (September 2008), seagrass from cleared plots (bordered and no-border) showed no significant difference to the shoot densities in the control plots, however, cleared bordered plots (colonisation from seeds only) remained very low in shoot density compared to other treatments (Figure 4A; Appendix 2A). This lack of a statistical difference probably relates to high variability rather than recovery within all cleared plots. The increased shoot abundance observed in the cleared no-border plots in September 2008 was mainly from the wide form of *Halodule uninervis* rather than the narrow form that had initially dominated the meadow in May and July 2008 (Figure 4B & C). By November 2008, the narrow form of *Halodule uninervis* was recovering within cleared no-border plots and the control plots (Figure 4B). The low shoot density in the cleared & border treatment indicates that recovery rate when only seed recruitment (sexual) is available is likely to be slower than when colonising from rhizome runners (asexual) is also available.

In May 2009 seagrass had completely disappeared in all quadrats probably as a result of the weather events that occurred in January/February 2009 as mentioned above (Figure 13).

Recovery at Site 2 - Mixed species assemblage

Recovery Site 2 had a mixed assemblage of species prior to clearing, which included *Halodule uninervis* (narrow & wide forms), *Halophila spinulosa* and *Halophila ovalis*. Shoot density at this site significantly varied through time ($F_{3,47}$=153 , p<0.001) and treatment ($F_{3,47}$=17 , p<0.01), and both these factors significantly interacted (Appendix 2B). Shoot density was highest for three of the four treatments in November (Figure 5A).

Prevention of asexual colonisation (bordering) had a significant impact on the rate of recovery of cleared plots in relation to plots open to both sexual and asexual recruitment (Figure 5A; Appendix 2B). At Site 2, there was virtually no recovery recorded where asexual colonisation was prevented (Figure 5A). Shoot density for this treatment reached its maximum extent of 8 shoots m^{-2} in July and September 2008 before widespread storm related losses that occurred in May 2009.

In contrast, where asexual colonisation could occur in cleared plots (no borders), seagrass recovered in total shoot density four months after clearing (September 2008) compared to controls reaching 733 ± 46 shoots m^{-2} (Figure 5A; Appendix 2B) (Plate 9). *Halodule uninervis* (wide) was mostly responsible for this initial recovery (Figure 5C). Recovery in these plots continued to November 2008, with the two *Halophila* species driving this increase, after which a decline in abundance occurred within all plots. Only the two treatments without a border (control and cleared) contained any biomass in May 2009 following storm disturbances, with *Halodule uninervis* (narrow and wide) the only remaining species.

Assessments in July 2008 were not possible at this site due to bad weather conditions arising towards the end of the field trip when Site 2 was being assessed.

Recovery at Site 3 – Halophila spinulosa assemblage

The experimental quadrats at Site 3 (Figure 6) only contained *Halophila spinulosa* prior to clearing and throughout the life of the experimental program. Seagrass at this site was found to be significantly affected by both time ($F_{3,59}$=4.9 , p<0.001) and treatment ($F_{3,59}$=74.7 , p<0.05), but an interaction between these factors was not recorded.

Shoot density of *Halophila spinulosa* in both the cleared treatments that were bordered and those that were un-bordered had completely recovered to levels observed in the control quadrats two months after clearing (September 2008) (Figure 6). This indicated that the prevention of asexual colonisation (bordering) did not have a significant impact on the rate at which cleared plots were able to recover from seeds alone in relation to the uncleared control plots (Appendix 2C).

Shoot density of *Halophila spinulosa* in the cleared quadrats continued to significantly increase to November 2008 and were not significantly different to the shoot densities of the control plots (Figure 6; Appendix 2C). By May 2009, seagrass was absent from the site associated with the storm and flood events (Figure 13).

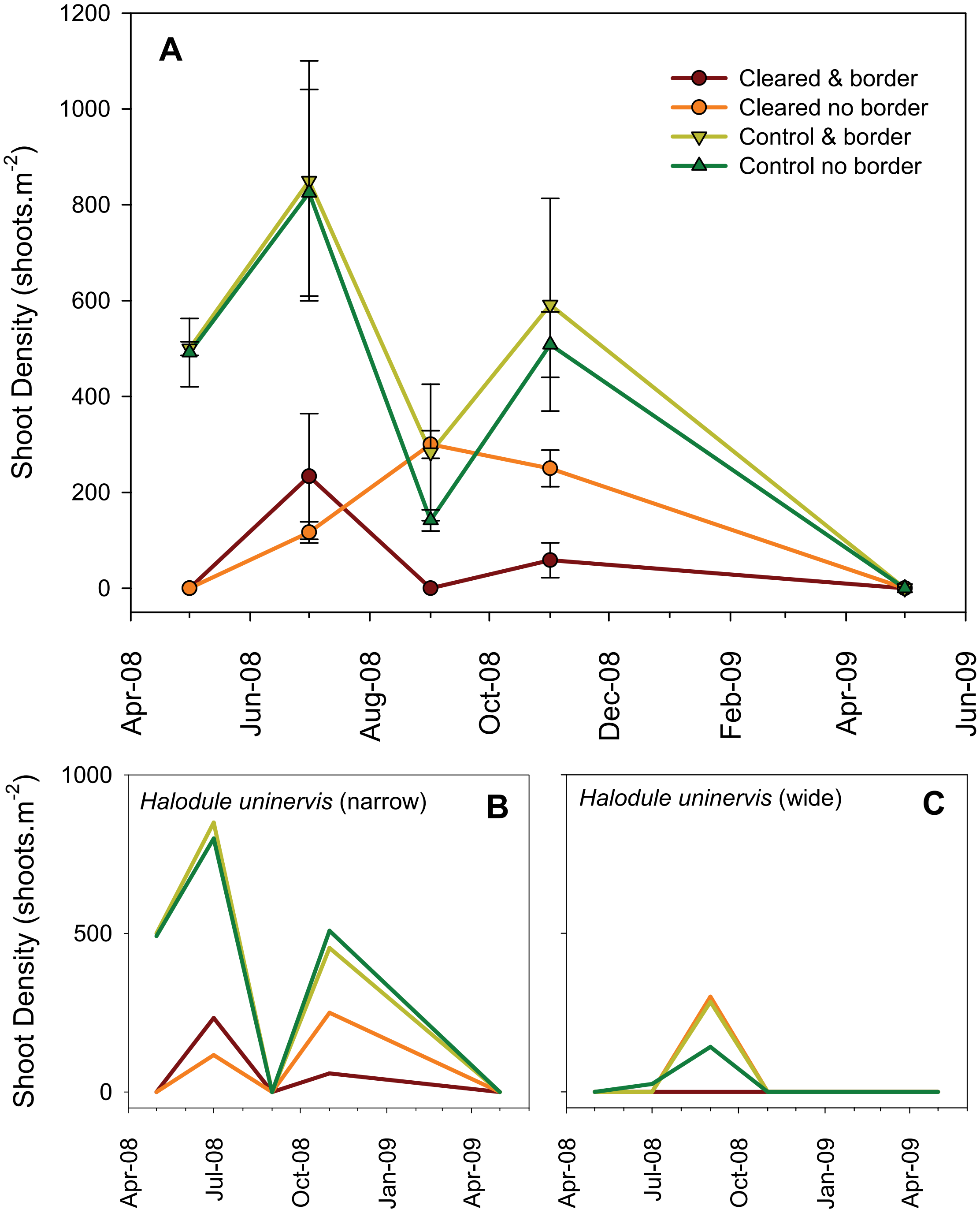


Figure 4. Mean leaf shoot density in treatments at experimental Site 1 for A) all species pooled; B) *Halodule uninervis* (narrow) and C) *Halodule uninervis* (wide)

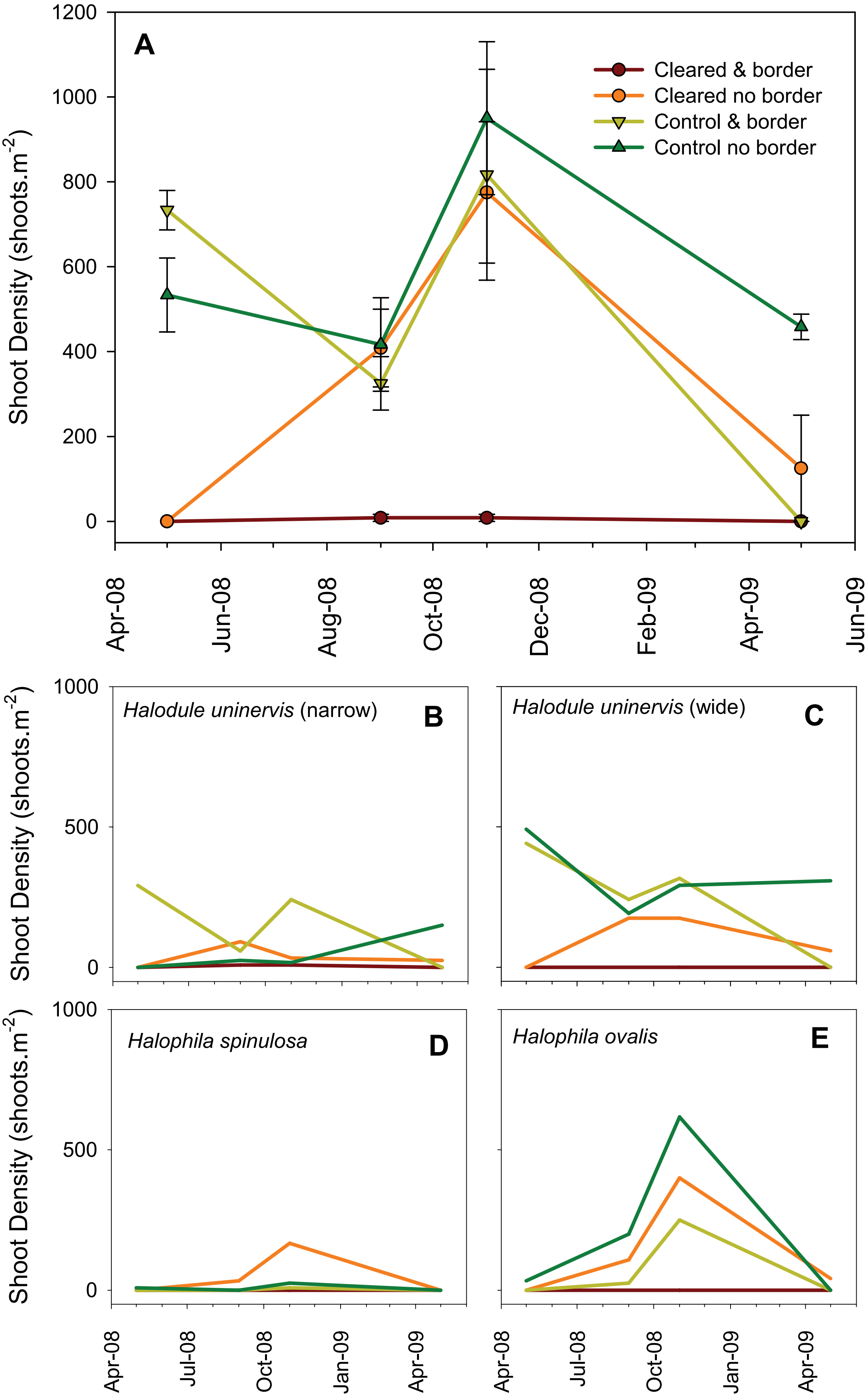


Figure 5. Mean leaf shoot density in treatments at experimental Site 2 for A) all species pooled; B) *Halodule uninervis* (narrow); C) *Halodule uninervis* (wide); D) *Halophila spinulosa*; E) *Halophila ovalis*

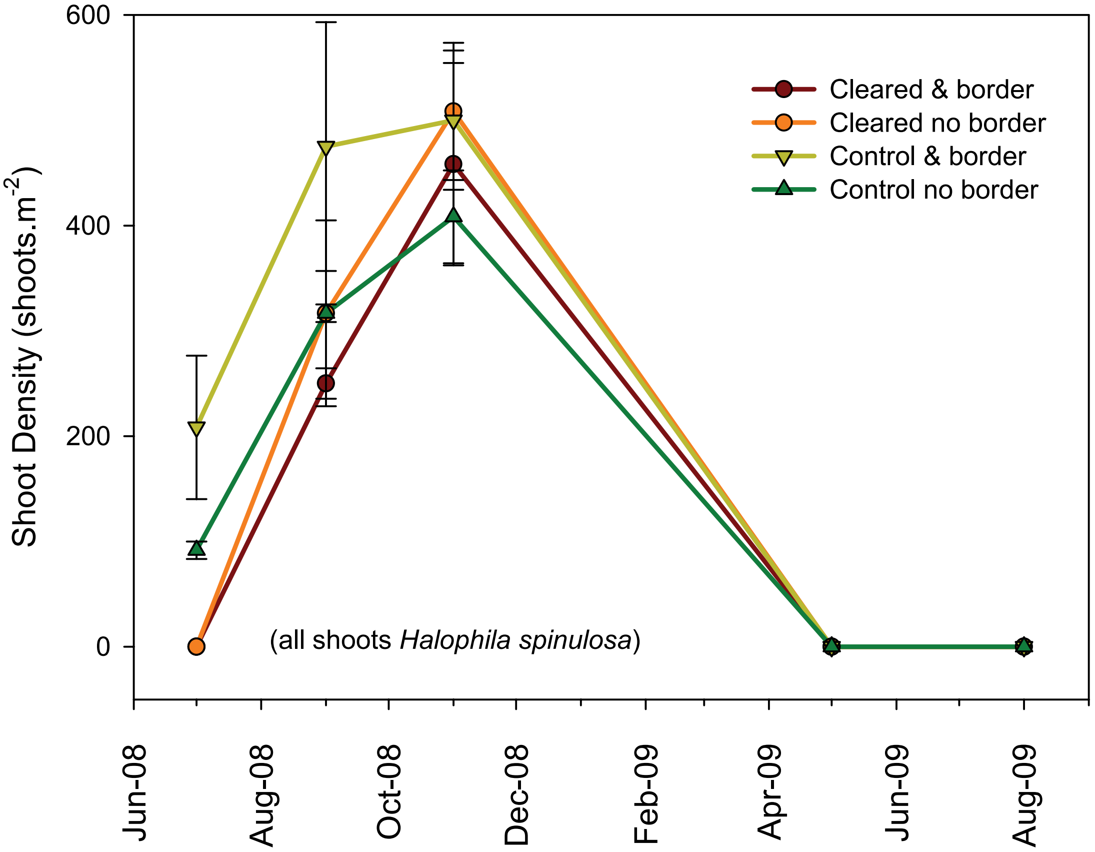
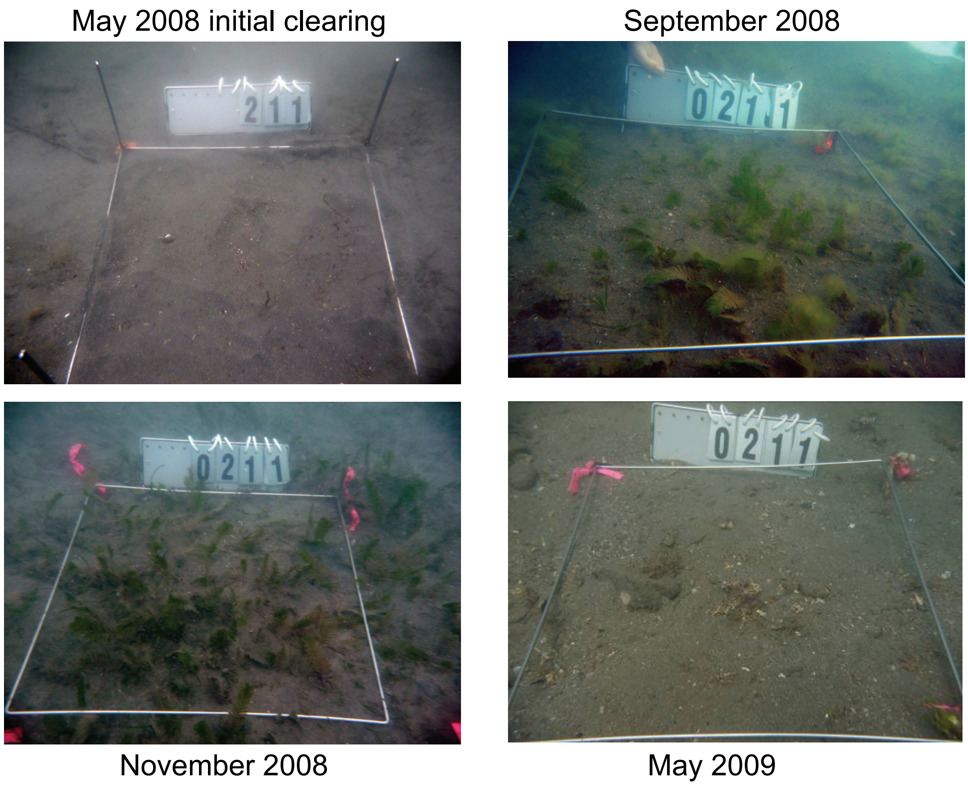


Figure 6. Mean leaf shoot density in treatments at experimental Site 3 for *Halophila spinulosa*



Seed sampling and Sexual propagules

Seagrass species did not appear to form significant seed banks despite some species being capable of producing long-lived seeds. The density of seeds found in the sediments at Abbot Point was extremely low. Seeds were only found on one occasion; August 2009 at Site 2 where 16 *Halodule uninervis* (1.33 ± 0.43 seeds m^{-2}) seeds were found in the samples. *Halophila* species may have produced seed banks but seeds of these species were too small to detect using the sieving methods for this study. *Halophila ovalis* flowering was recorded at recovery Site 3 in July 2008 and fruits attached to seagrass shoots were also recorded for *Halophila spinulosa* at Recovery Site 3 in September 2008.

3. Above Ground Productivity of Abbot Point Seagrasses

Above ground production of seagrass species

Seagrass net above ground productivity varied markedly between species (Table 10). Differences generally varied according to shoot size differences between species with the largest species adding the greatest biomass per shoot per day. The two largest species, *Zostera capricorni* and *Cymodocea serrulata* added the greatest dry weight per shoot per day, but this data was taken from other studies in similar environments (Table 10). Where it was possible to observe seasonal differences in growth in this study, *Halophila spinulosa* and *Halophila ovalis* added the greatest amount of new growth in the wet season months and the lowest amount of growth in the winter/dry season. In contrast, *Halodule uninervis* was most productive in the winter/dry season and least productive in the wet season (Table 10).

Table 10. Rate of new growth per shoot (mg.day^{-1}) used to determine productivity and turnover time of seagrass meadows at Abbot Point.

		New growth g DW shoot day $^{-1}$				
Species	**Marking Technique**	**Feb**	**May**	**Aug/Sept**	**Nov**	**Source**
Halophila ovalis	Rhizome tagging	1.66	1.66	1.47	1.29	This study
Halophila spinulosa	Leaf clipping	0.58	0.58	0.39	0.77	This study
Halodule uninervis	Leaf marking	0.13	0.13	0.27	0.20	This study
Zostera capricorni	Leaf marking	0.80	0.80	0.80	0.80	Rasheed *et al.* 2008
Cymodocea serrulata	Leaf marking	1.60	1.60	1.60	1.60	(Pollard and Greenway 1993)

Above Ground Productivity of Meadows

Productivity of meadows within the entire port limits.

Seagrass meadows identified in The Port of Abbot Point 2008 Baseline surveys (see McKenna *et al* 2008 for details) incorporated a higher amount of carbon per day into their above ground biomass in the dry season (1347 ± 149 kg C day^{-1}) compared to the wet season (1816 ± 207 kg C day^{-1}) (Table 11). By calculating a mean figure across these two seasons, an annual productivity figure for seagrasses in Abbot Point was determined as 577 ± 65 metric tonnes of Carbon per year. The productivity of the 23 meadows identified in the baseline surveys varied considerably from <0.1 kg C.day^{-1} in the smallest meadows (< 2 ha; meadows, 5, 8, 27) to over 1200 kg C.day^{-1} in the largest meadow (2700 ha; meadow 14) (Table 11).

Productivity of monitoring meadows through time

Mean productivity per unit area varied between the five monitoring meadows, with the *Zostera capricorni* meadow (meadow 3) having at least double the productivity of the other meadows at 47 ± 19 mg C.m^{-2}.day^{-1}. The least productive meadow was meadow 3, producing 3.0 ± 1.1 mg C.m^{-2}.day^{-1}.

Productivity varied seasonally within all meadows (Tables 12 and 13), with productivity reaching its maximum in September 2008 within meadows 3, 5 and 7, and in November 2008 within meadows 8 and 9. Pooling the data (Figure 7) provides a seasonal pattern of increased productivity during September and the lowest productivity observed in March. Integration of a polynomial function applied to the data in Figure 7 provides an annual productivity of 237g C m^{-2}.

Meadow turnover

The time required for meadows to turn over their above ground biomass ranged between 13 and 96 days. The turnover time for meadows reflected their species composition, with meadows dominated by species with long turnover time taking longer to turn over their above ground biomass than those dominated by species with short turnover time (Figure 8).

At Abbot Point, *Halophila spinulosa* was the fastest species to turnover above ground biomass, while *Halodule uninervis* was the slowest species taking almost 100 days to turnover their standing crop (Figure 8).

The *Zostera capricorni* monitoring meadow (3) had the fastest average turnover rate of the shallow sub-tidal meadows at 32 days. Turn over time for this meadow was generally fastest in the winter/dry season months and slowest in the wet season (Table 14).The deepwater monitoring meadows also turned over their above ground biomass at a fast rate, averaging 31 days. The turnover time of the deepwater sites did not follow any particular seasonal pattern.

Monitoring meadow 9 which was dominated by *Halodule uninervis* was the slowest to turn over its above ground biomass (average 71 days). The fastest turnover time for this meadow occurred in November 2008.

Table 11. Daily (± SE) seasonal (and total annual) estimated above ground seagrass carbon production (kg C meadow day^{-1}) of seagrass meadows Identified in the 2008 Wet Season and Dry Season Baseline surveys.

	Daily above ground carbon production (kg C day^{-1})	
Meadow ID	**Wet Season ± SE**	**Dry Season± SE**
3	12.5 ± 0.8	90.4 ± 6.0
5	0.1 ± 0.1	2.7 ± 0.8
7	0.4	12.1 ± 0.4
8	0.1 ± 0.1	0.6 ± 0.1
9	3.7 ± 1.2	2.9 ± 0.1
11		1.9 ± 0.5
12	0.9 ± 0.2	0.5
13	50.1	616
14	1202 ± 129	751 ± 144
15		133.8 ± 16.3
16	0.4 ± 0.1	
17	13.1 ± 2.8	17.8 ± 4.1
18	0.5 ± 0.1	
19	0.1	1.7 ± 0.3
20	19.6 ± 4.5	55.1 ± 5.4
21		15.5 ± 1.2
22	21.2 ± 4.9	27.9 ± 5.3
23	21.2 ± 4.9	72.3 ± 19.5
24		2.9
25		1.2
26		0.7
27		0.1
28		7.6 ± 2.3
TOTAL	**1347± 149**	**1816 ± 207**
Total annual Abbot Pont Above Ground Carbon Production (Metric tonnes)		**577.2 ± 65**

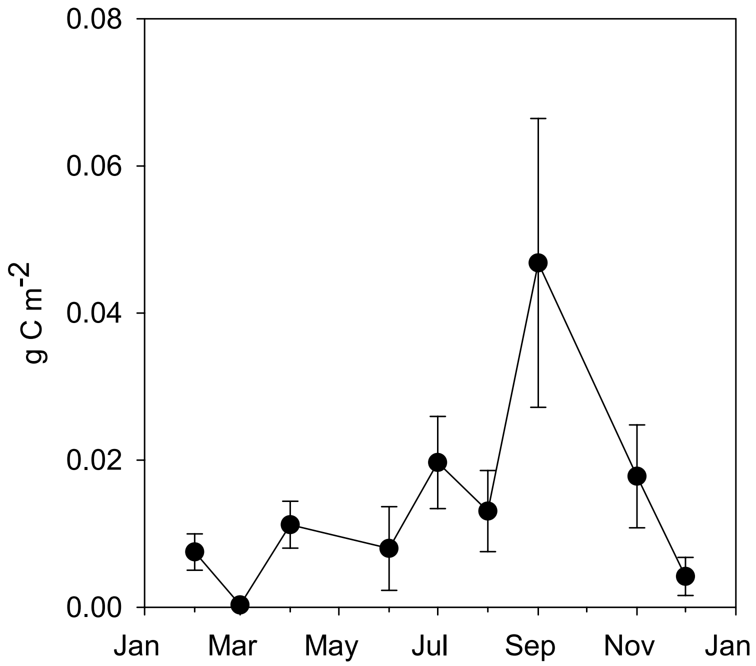


Figure 7. Mean (± SE) monthly above ground seagrass carbon productivity at Abbot Point (data points are individual sample trips conducted between 2005 and 2010). Integration of a quadratic polynomial function fitted to this data provides an annual value of 237g C m^{-2}.

Table 12. Above ground seagrass production of the monitoring meadows at Port of Abbot Point, March 2005 & March 2008 - June 2010.

	Meadow ID #	Dominant species	Meadow above ground production: Mean m^2 (<u>mg</u> DW m^{-2} day^{-1}) & Total (<u>kg</u> DW day^{-1})																	
			Mar 05		**Mar 08**		**Jul 08**		**Sept 08**		**Nov 08**		**Apr 09**		**Aug 09**		**Dec 09**		**Jun 10**	
			m^2	**Total**	**m^2**	**Total**	**m^2**	**Total**	**m^2**	**Total**	**m^2**	**Total**	**m^2**	**Total**	**m^2**	**Total**	**m^2**	**Total**	**m^2**	**Total**
Coastal	**3**	*Z. capricorni*	0.9	0.2	66.3	36.8	222.9	118.4	466.9	265.9	49.4	41.3	133.2	43.2	144.6	63.9	85.2	64.3	31.9	7.9
	5	*H. uninervis* (thin)	0.3	0.1	0.5	0.4	16.4	1.6	33.0	6.6	20.7	6.4	0.0	0.0	0.0	0.0	0.1	0.01	0.6	0.01
	7	*H. uninervis* (wide & thin)	0.6	0.1	29.5	1.2	38.6	1.4	144.6	30.4	51.4	6.2	30.2	2.8	9.3	1.2	59.2	9.3	31.5	0.3
	8	*H. uninervis* (thin)	2.3	0.1	5.4	0.1	0.0	0.0	35.3	1.4	79.7	2.9	0.0	0.0	25.0	0.7	0.0	0.0	52.3	0.8
	9	*H. uninervis* (thin)	0.4	0.0	8.9	10.8	11.4	7.7	8.6	7.2	60.7	50.4	1.7	0.7	13.5	3.1	2.5	3.1	1.2	0.7
Offshore 13,14,15		Mixed species	12.6	3685.2	30.6	4772.1	46.1	7187.8	83.5	13022	10.0	1556.6	33.7	5255.8	185.4	28931	185.4	28931	12.6	3685.2
Total			**20.5**	**3734**	**53.3**	**4901**	**122.4**	**7499**	**57.5**	**13129**	**29.2**	**1603**	**37.7**	**5325**	**55.4**	**29008**	**50.5**	**28941**	**20.5**	**3734**

Table 13. Above ground seagrass carbon production of the monitoring meadows at Port of Abbot Point, March 2005 & March 2008 - June 2010

	Meadow ID #	Dominant species	Meadow above ground production: Mean m^2 (mg DW m^{-2} day^{-1}) & Total (kg DW day^{-1})																	
			Mar 05		Mar 08		Jul 08		Sept 08		Nov 08		Apr 09		Aug 09		Dec 09		Jun 10	
			m^2	Total	m^2	Total	m^2	Total	m^2	Total	m^2	Total	m^2	Total	m^2	Total	m^2	Total	m^2	Total
Coastal	3	*Z. capricorni*	0.3	0.1	22.5	12.5	75.8	40.2	158.7	90.4	16.8	14.0	45.3	14.7	49.2	21.7	29.0	21.8	10.9	2.7
	5	*H. uninervis* (thin)	0.1	0.0	0.2	0.1	5.6	0.5	11.2	2.3	7.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
	7	*H. uninervis* (wide & thin)	0.2	0.0	10.	0.4	13.1	0.5	49.2	10.3	17.5	2.1	10.3	0.9	3.2	0.4	20.1	3.2	10.7	0.2
	8	*H. uninervis* (thin)	0.8	0.0	1.8	0.0	0.0	0.0	12.0	0.5	27.1	1.0	0.0	0.0	8.5	0.3	0.0	0.0	17.8	0.8
	9	*H. uninervis* (thin)	0.1	0.0	3.0	3.7	3.9	2.6	2.9	2.1	20.6	17.1	0.6	0.2	4.6	1.0	0.8	1.1	0.4	0.1
Offshore 13,14,15		Mixed species	15.6	1497	4.3	1253	10.4	1623	15.7	2444	28.4	4427	3.4	529	11.5	1787	63.0	9837	63.0	9837
Total			**2.9**	**1497**	**7.0**	**1270**	**18.1**	**1666**	**41.6**	**2550**	**19.6**	**4464**	**9.9**	**545**	**12.8**	**1810**	**18.8**	**9863**	**17.2**	**9840**

Table 14. Time (days) required for Abbot Point seagrass meadows to turn over their above ground biomass across time

	Meadow ID #	Dominant species	Turnover (days)								
			Mar-05	Mar-08	Jul-08	Sep-08	Nov-08	Apr-09	Aug-09	Dec-09	Jun-10
Coastal	3	*Z. capricorni*	96	56	16	16	26	21	16	15	22
	5	*H. uninervis* (thin)	96	96	96	47	63	0	0	63	96
	7	*H. uninervis* (wide &	96	96	96	46	56	56	47	17	24
	8	*H. uninervis* (thin)	13	96	0	47	63	0	63	0	96
	9	*H. uninervis* (thin)	77	96	96	47	17	96	47	63	96
Offshore (13,14 & 15)		Mixed species	46	21	52	42	51	12	10	28	19

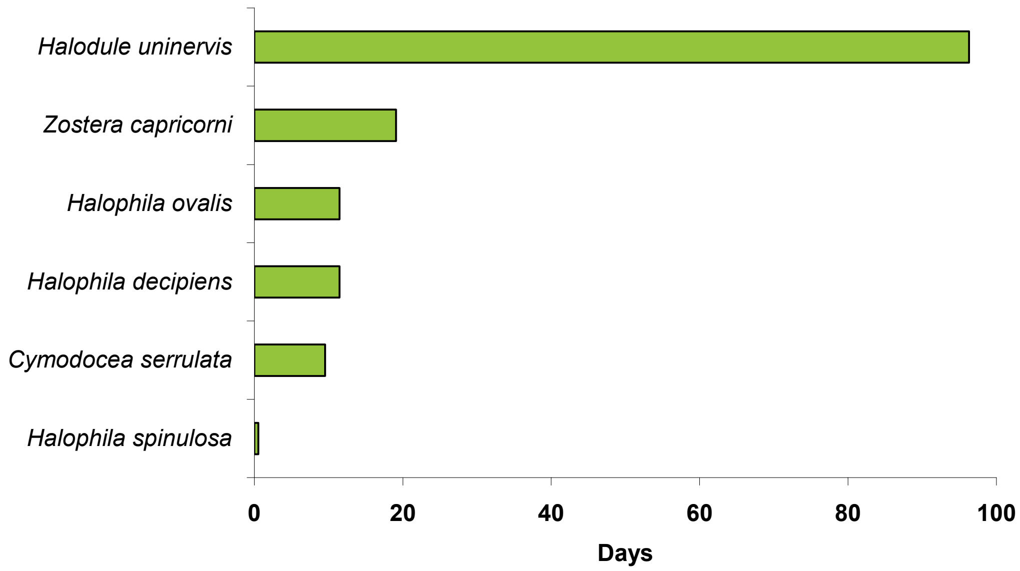


Figure 8. Above ground turnover time for Abbot Point Seagrass species

4. Fisheries Value

A total of 45 beam trawls were conducted at Abbot Point between August 2008 and August 2009. Three replicate trawls were conducted at three sites (1: Inshore, 2: Offshore, 3: Control) over five seasonal sampling trips. The most abundant faunal group caught were Caridean shrimps, followed by the commercially and recreationally important groups, the penaeids (prawns) and fish. A range of other fauna that included economically important species was also caught, but this was in low abundances. This included a range of species of gastropods, echinoderms, cephalopods, and other crustacean species including Mantis Shrimp, Swimming crabs, and Isopods (data for these species is not reported).

Penaeids (prawns)

A total of 8 species of penaeids from 4 genera were collected during the course of the surveys (Appendix 4). The majority of these species were however, commercially unimportant to prawn fisheries (Appendix 4). The most frequently caught species were from the genera *Metapenaeopsis* which occurred most frequently in April (Appendix 4).

The abundance of penaeids varied seasonally, with highest abundance recorded in April 2009 at the end of the wet season (Figure 9A; Appendix 5). Total penaeid biomass did not vary seasonally, indicating that smaller individuals dominated the high abundance in April 2009 (Figure 9B).

Site 3 had the largest abundances of penaeids, but Site 1 consistently contained penaeids that were longer in length throughout the program (Appendix 5). Penaeids were generally small, with mean average carapace lengths ranging from 4mm to 51.66 for *Penaeus esculentus*, a commercially important species (Appendix 4).

Caridean shrimp

Caridean shrimp were highly abundant at Abbot Point, with mean abundances of 125 ± 29 individuals per trawl. The abundance of this faunal group varied between season and site. Highest abundance was reached at site 1 in August 2009, while at the deeper sites 2 & 3, highest abundances were reached in November 2009.

Fish

Fish assemblages at Abbot Point contained species from 22 fish families, the most abundant of which were the *Apogonidae* (Cardinal fish), *Bothidae* (Flounder), *Pinguididae* (Sandperch), and the *Platycephalidae* (Flatheads) (Figure 11B). These family groups tended to be more abundant in November 2008 (Figure 11A).

58 species groups were identified, but due to sample degradation and taxonomic difficulties (individuals lumped into family categories) total fish species count is probably higher than 58 (Appendix 6). The most abundant individual species was *Apogon septemstriatus* (the seven banded cardinal fish) which was recorded at all sites (Appendix 6).

Abundance and biomass of fish assemblages at all three sites (inshore, offshore and control) varied seasonally. Mean abundance of total fish catch was highest in November 2008, while abundance and mean dry weight of fish caught was lowest in September 2008 (Figure 12A & B).

Inter-site variability was observed, with highest abundances always recorded at the southern offshore site (Site 3) and lowest abundance mostly at the inshore site (Site 1). The mean dry weight of fish caught at Site 1 was less than both Sites 2 and 3 across all surveys (Figure 12B).

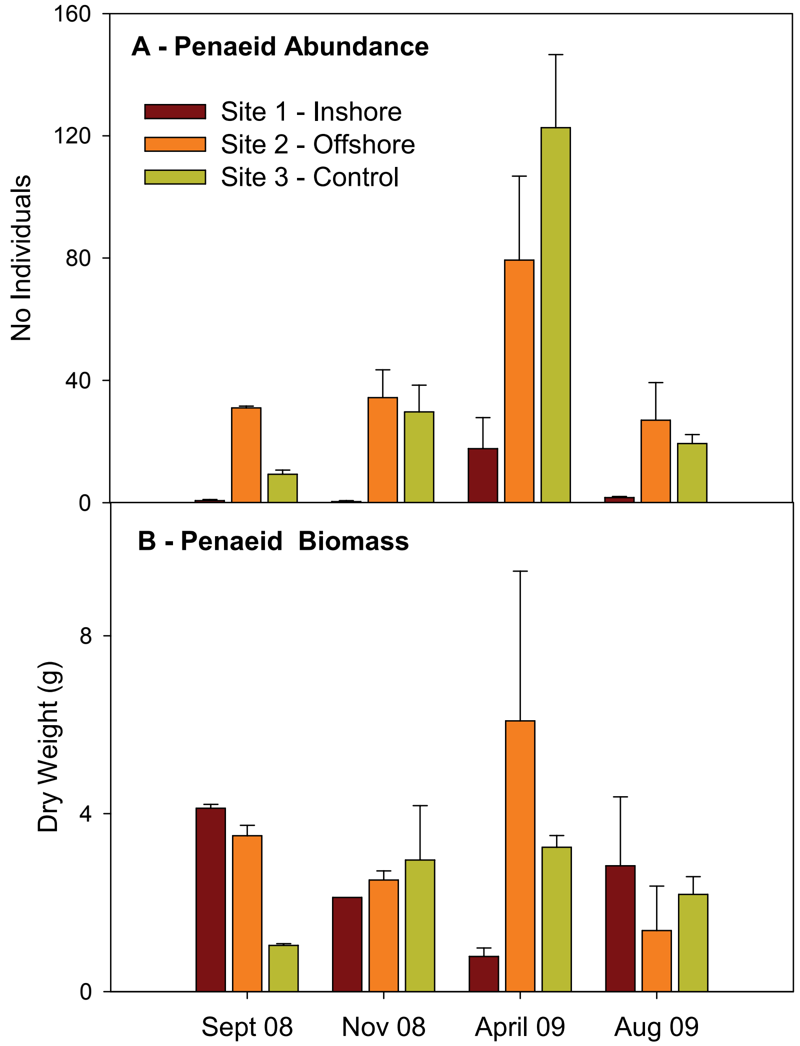


Figure 9. **A)** Mean number of penaeids ± SE and **B)** Mean dry weight biomass of penaeids at the three beam trawl survey sites (Inshore, Offshore & Control) surveyed between September 2008 and August 2009.

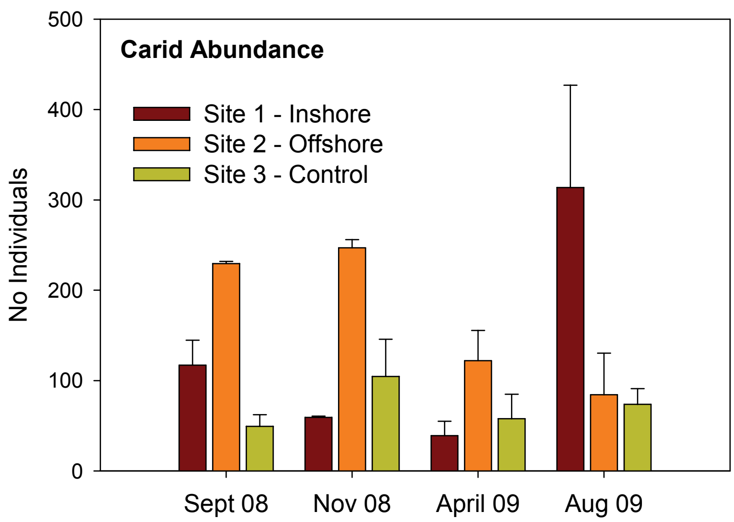


Figure 10. Mean number of caridean shrimp ± SE at the three beam trawl survey sites (Inshore, Offshore & Control) surveyed between September 2008 and August 2009.

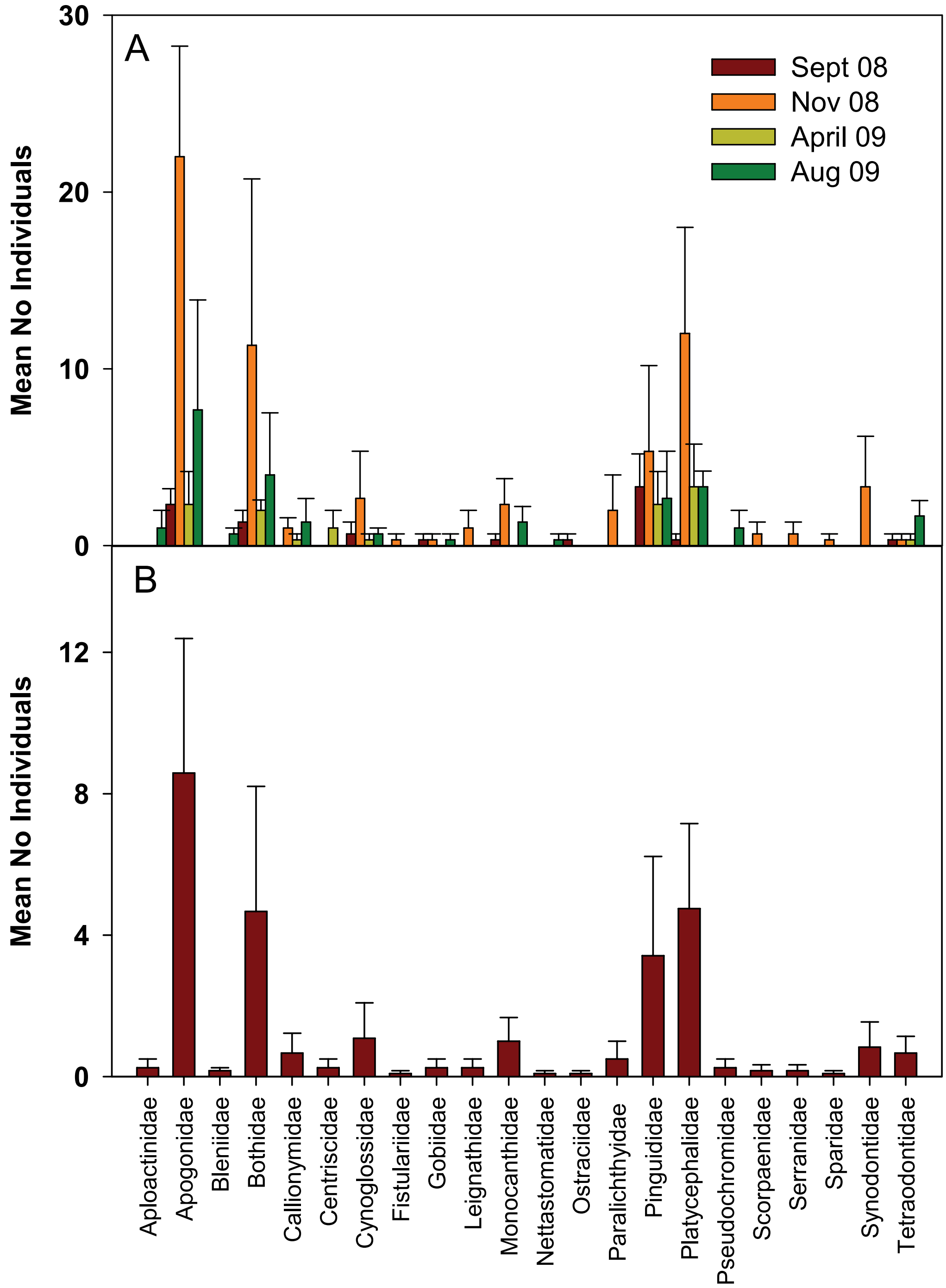


Figure 11. **A)** Mean number of individuals ± SE of each family during each sampling event **B)** Mean no of individuals of each family pooled across all sampling events (September 2008 - August 2009).

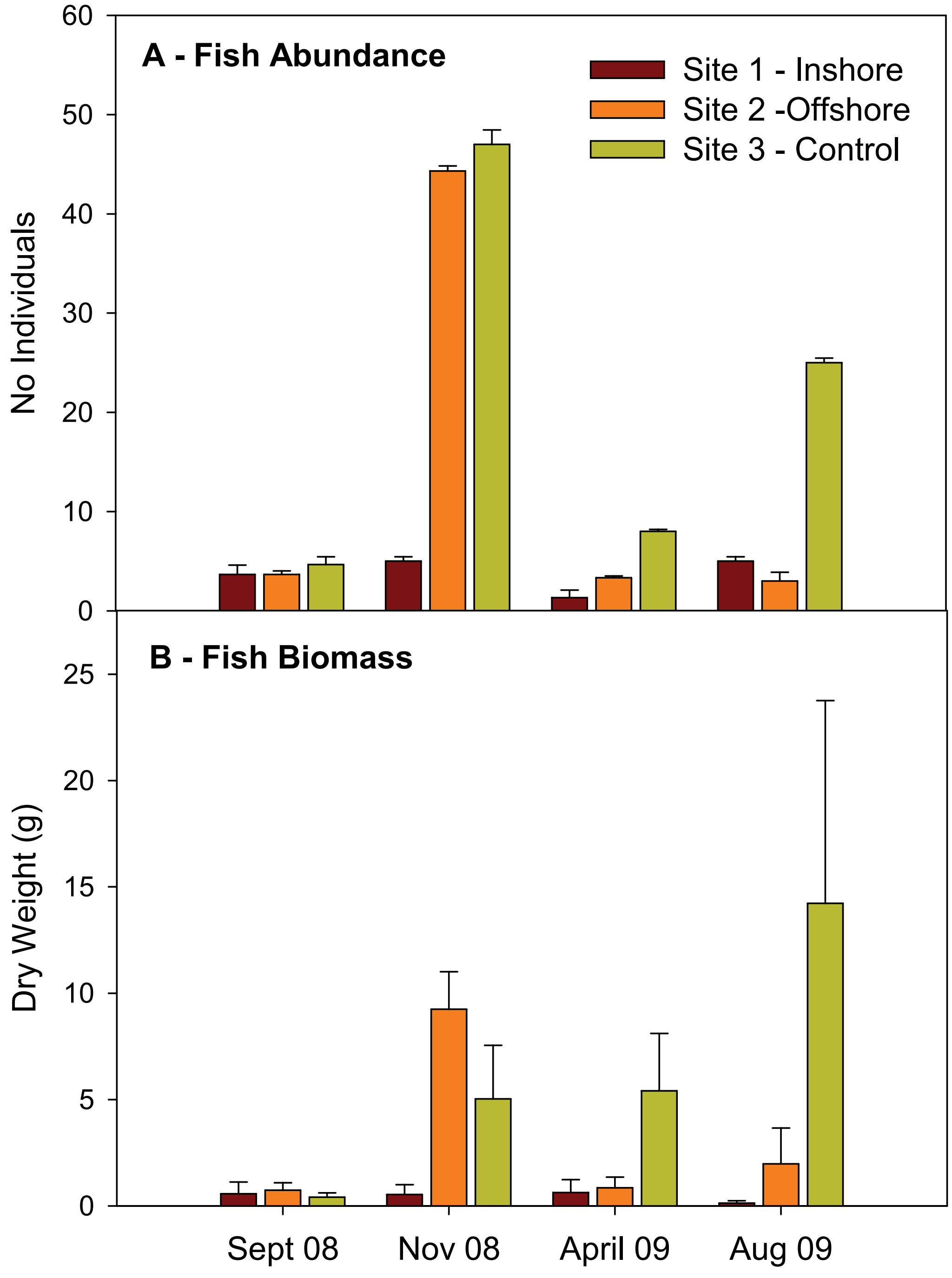


Figure 12. **A)** Mean number of fish ± SE and **B)** Mean dry weight biomass of fish at the three beam trawl survey sites (Inshore, Offshore & Control) surveyed between September 2008 and August 2009.

5. Abbot Point Climate Patterns during monitoring

During the seagrass assessments at Abbot Point, there were three major climatic events that affected the area. Prior to the first Baseline survey in February/March 2008 there was a major monsoonal trough that affected the Bowen/Abbot Point Area. Rainfall in February 2008 was found to be almost three times the 20 year average for that month which coincided with high flows of the major catchment for the Abbot Point area, the Don River (Figure 13 & 14). In March 2009 severe Tropical Cyclone Hamish passed the coastline of Abbot Point bringing large local flooding, rain and high winds to the area. There was also a flood warning released for the Don River near Abbot Point in February 2010.

Weather recorded at Abbot Point between 2005 and 2010 recorded large inter-annual variability. 2005 and 2006 were characterised by lower rainfall than the other years, with 2008 and 2009 having at least twice has much rainfall compared to 2005 (Figure 14). Air temperatures were highest in 2005 (29.1°C) and solar radiation highest in 2009 (Figure 15A & C). Average wind speed also varied annually, with the highest levels recorded in 2005 (24.5 $km.hr^{-1}$), and wind in 2007 and 2008 was in general much lower (14.1 and 18.1 $km.hr^{-1}$) (Figure 15B).

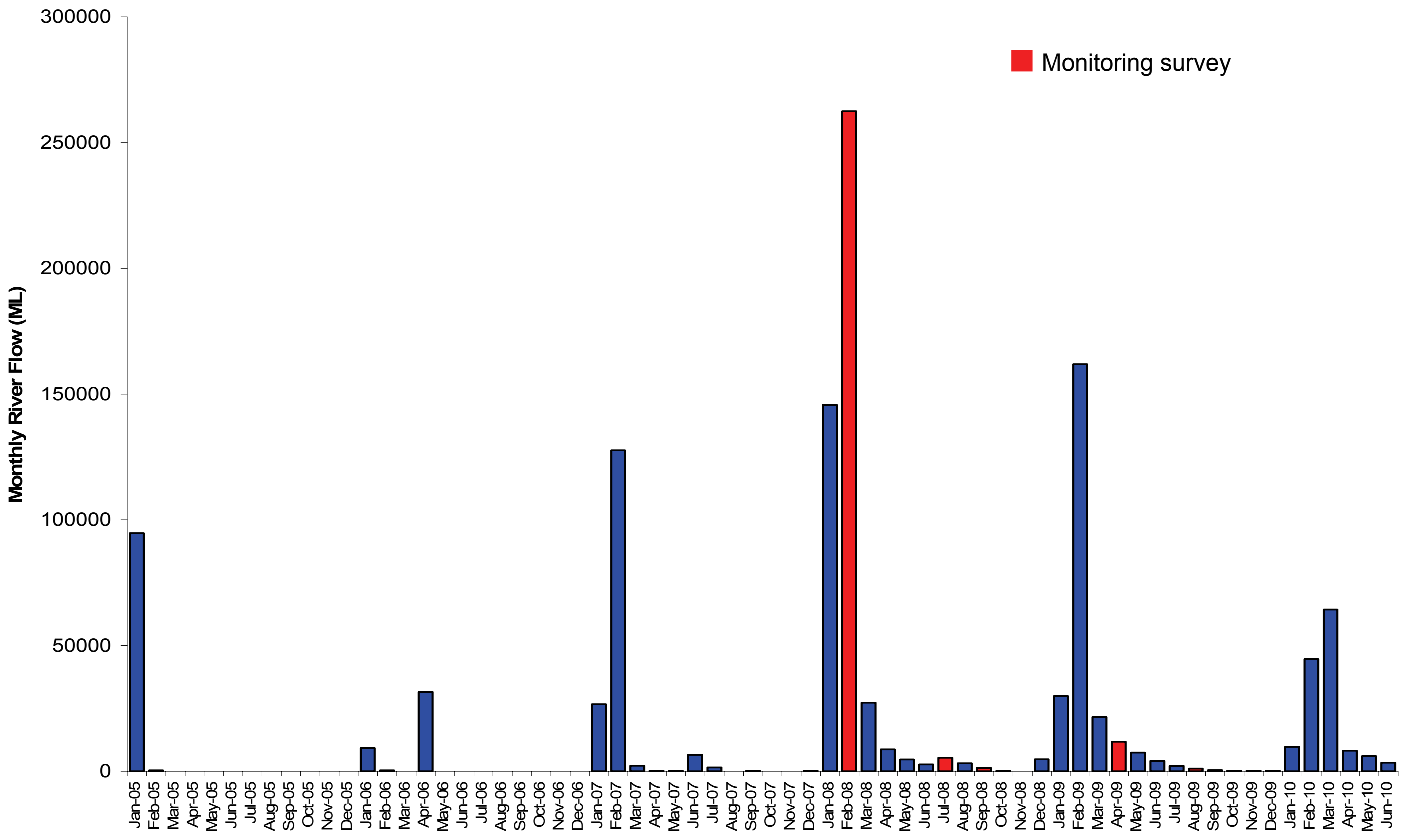


Figure 13. Total monthly river flow for the Don River between 2005 & 2010 (Marine Safety Queensland, 2010)

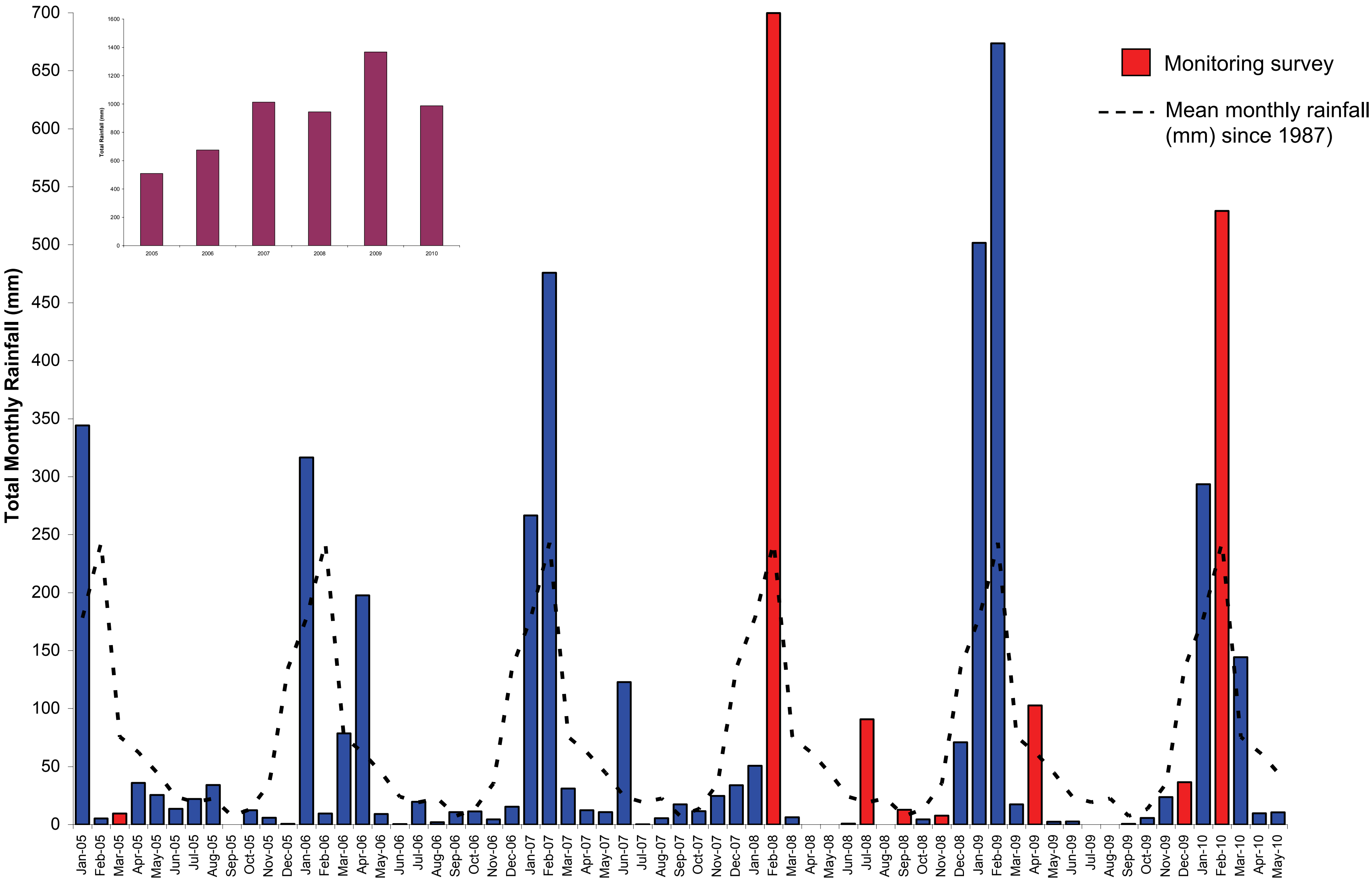


Figure 14. Total monthly rainfall (mm) for the Bowen area from 2005 – May 2010 and (Inset) Total annual rainfall from 2005 – May 2010 (Bureau of Meteorology).

Figure 15. A) Mean monthly temperature, B) Mean monthly wind speed and C) Monthly Solar radiation (mega joules/m^2) for the Bowen area from January 2005 to May 2010

DISCUSSION

Seagrass meadows in Abbot Point are highly dynamic, responding to a range of environmental stressors such as coastal flooding and cyclones, as well as seasonal cycles that impact upon water temperature, light availability and nutrient dynamics (see Figure 16). These seagrass meadows are of high ecological and economic value due to their role in providing important habitat and feeding resources for IUCN listed vulnerable species of dugong and green turtle (Hughes *et al.* 2009) and support economically important fisheries species (Watson *et al.* 1993; Unsworth and Cullen 2010). Seagrass meadows also play an important role in nutrient and carbon cycling within the coastal environment (Costanza *et al.* 1997; Hemminga and Duarte 2000).

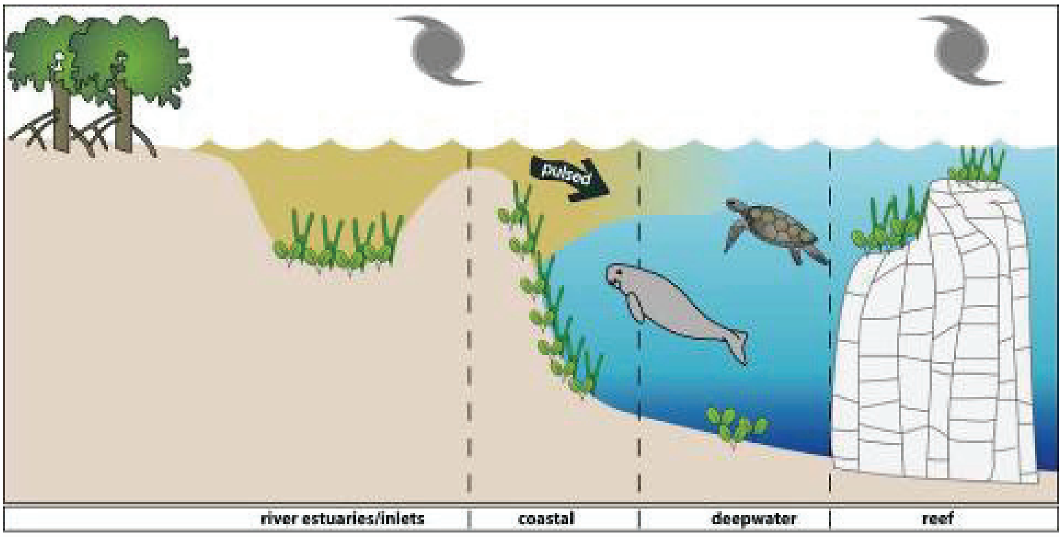


Figure 16 General conceptual model of seagrass habitats occurring within the Port of Abbot Point (from (Carruthers *et al.* 2002).

Although seagrass meadows at Abbot Point were generally sparse due to their subtidal low light environment, and not as productive as pristine reef top seagrass meadows (Rasheed *et al.* 2008b), their productivity compares highly with other globally important ecosystems (Table 15). This provides evidence that they make a major contribution to coastal productivity. Seagrasses at Abbot Point therefore are likely to play a major role in supporting fauna and providing critical functions to the coastal ecosystem such as nutrient cycling, water filtration, and sediment stabilisation.

Table 15. Net annual primary production of a range of different plant communities g C m^{-2}

Ecosystem	Location	Authors	Production (gCm^{-2} per annum)
Grasslands	Global	(Duarte and Chiscano 1999)	182
Tropical Mangrove	Global	(Lugo 1988)	335
Temperate Forest	Europe	(Luyssaert *et al.*)	447
Tropical Rainforest	Amazon	(Malhi *et al.* 2009)	1150
Tropical Reef Seagrass	Torres Strait	(Rasheed *et al.* 2008b)	434
Seagrass Average	Global	(Duarte and Chiscano 1999)	344
Tropical Coastal Seagrass	**Abbot Point**	**Present study**	**237**

Seagrass seasonality and productivity

Seagrass meadows observed at Abbot Point were typical of coastal and deepwater seagrass meadows along the north Queensland coast, containing seven species (Coles *et al.* 2003; Coles *et al.* 2009). This diversity was high compared with surveys of similar port areas in the region such as Mackay (2 species; (Rasheed *et al.* 2001) and Hay Point (2 species; (Chartrand *et al.* 2008). However unlike Hay Point and Mackay, Abbot Point also contained shallow coastal meadows (Rasheed *et al.* 2005).

The deepwater seagrass meadows also contained species more commonly found in shallow sub-tidal and intertidal areas such as *Halodule uninervis, Cymodocea rotundata*, and in 2005, *Syringodium isoetifolium*. The presence of these species in deeper areas of Abbot Point may be an indication of comparatively low turbidity in the area allowing greater seagrass depth penetration (Rasheed *et al.* 2005).

The majority of the area covered by the deepwater meadows was dominated by *Halophila spinulosa*. This species has been found to be highly shade adapted (Campbell *et al.* 2008), hence its ability to thrive in deeper water where low light conditions prevail.

Seasonal quarterly monitoring found seagrass meadows at Abbot Point to be highly dynamic with respect to both seasonality and annual variability. Seagrass was at maximum biomass in the dry season, and was lowest in the wet season, with biomass generally higher in 2008. Such seasonality is similar to patterns observed elsewhere in Queensland and throughout the Indo-Pacific (Erfteheijer and Herman 1994; McKenzie 1994; Rasheed 2004). The period of September and November 2008 was when seagrass reached its highest observed biomass (at four of the five coastal monitoring meadows), but then declined until June 2010. The inter- and intra-annual variability observed at Abbot Point is most likely the result of climate variability, with coastal rainfall and river plumes observed to be one of the major drivers of seawater turbidity throughout the region (Devlin and Schaffelke 2009). Other likely potential natural stressors include intertidal air exposure, and air temperature that have been observed to drive seagrass variability in a number of locations in Queensland (Chartrand and Rasheed 2009; Thomas *et al.* 2010).

Productivity of seagrass meadows at Abbot Point as a result of changes in community biomass and growth were also observed to have resultant patterns of seasonality, with seagrass most productive in September and least productive in February.

Seagrass fauna productivity

Seagrass meadows at Abbot Point contained an abundant and diverse fauna with many species being of economic importance in terms of their value to commercial and recreational fisheries. This abundance was consistent and in some incidences high, relative to other similar studies in Queensland (see Table 16). Although seagrass fauna was quantified, small beam trawl surveys are selective and do not provide a complete assessment of the motile faunal communities. Beam trawls under-sample large fast swimming and pelagic fish species such as Jacks, Travallies, and Mackeral. Such large species are likely to utilise the abundant small crustacean and fish fauna as a feeding resource whilst making diel and tidal migrations into the seagrass (Unsworth *et al.* 2007). Carridean shrimp were also abundant within seagrass at Abbot Point, such fauna are also important food resources for a range of larger fauna. Data therefore confirms that seagrass at Abbot Point do have fisheries economic value.

Seagrass meadows at Abbot Point are also of those species likely to play a role in feeding for dugong (IUCN red listed as vulnerable) and green turtle (IUCN red listed as endangered). Other large and ecologically important species such as the Humpback Whale (*Megaptera novaeangliae*), the Manta Ray (*Manta birostris*), the Bottlenose Dolphin (*Tursiops* sp.) and a number of unidentified shark species were also observed in proximity of the Port of Abbot Point during seagrass monitoring surveys.

Table 16. Mean number of individuals, biomass, and carapace length (± SE) per trawl of penaeid prawns (all species pooled) collected by beam trawl during May and October surveys at Abbot Point (2008 & 2009), Hay Point (2006 & 2007), Upstart Bay, Newry Bay, and Ince Bay (1999).

Values for Hay Point from Chartrand et al 2008 and for Upstart, Newry and Ince Bay adopted from Coles et al. 2002

Location	Meadow	May			October		
		Count (n)	**Biomass (gDW)**	**Carapace Length**	**Count (n)**	**Biomass (gDW)**	**Carapace Length**
Abbot Point*	Deepwater; Low biomass *Halophila/Halodule*	603	4.67 ± 0.64	9.96 ± 0.18	192	2.73 ± 0.59	12.38 ± 0.35
Abbot Point*	Shallow/Coastal; Low Biomass *Halodule*	35	0.79 ± 0.19	11.58 ± 1.05	1	2.12	34.62
Hay Point**	Deepwater; Low biomass *Halophila*	8.22 ± 3.09	0.77 ± 0.24	8.72 ± 0.55	14.22 ± 2.41	1.64 ± 0.41	13.30 ± 0.62
Upstart Bay	Shallow/Coastal; High Biomass *Zostera capricorni*	374.75 ± 7.72	4.93	5.10 ± 0.04	168.5 ± 2.09	24.25	9.21 ± 0.11
Newry Bay	Shallow/Coastal; High Biomass *Zostera/Halodule*	182.25 ± 2.28	3.42	5.48 ± 0.05	78.75 ± 0.65	7.45	7.85 ± 0.15
Ince Bay	Shallow/Coastal; Low Biomass *Halodule*	9.25 ± 0.84	0.225	6.03 ± 0.76	4.67 ± 0.15	0.165	6.11 ± 0.67

**Abbot Point beam trawls were conducted on the 24th of April 2009 and the 4th November 2008*

***Hay Point beam trawls were conducted on the 1st of November 2007*

Seagrass Meadow Resilience

Understanding the capacity of a seagrass meadow to be resilient to future stressors requires knowledge of the ability of the plants to recover after a loss. The present study finds that there were strong differences between meadow types and species in their capacity for recovery and the mechanisms employed to recolonise disturbances.

Coastal meadows dominated by *Halodule uninervis* were likely to have a strong reliance on asexual reproduction for recovery from losses. Flowering and fruiting for this species was rarely seen at the Abbot Point sites and seeds in the sediment were also very rare. Where adult plants remain, small scale disturbances were able to recover through rhizome extension from the surrounding meadow within four to six months. However where recovery from surrounding seagrasses was prevented by a border (simulating larger scale seagrass loss), seagrasses were unable to recover to pre-disturbance state during these experiments. Long-term recovery in the absence of rhizome or asexual propagules (seagrass fragments) would therefore be dependent on the external supply of seeds rather than *in situ* seed reserves

The high reliance of Abbot Point *Halodule uninervis* meadows on asexual colonisation is similar to other studies conducted within shallow coastal, high density reef meadows on reef platforms and muddy estuaries of Far North Queensland (Rasheed 1999; Rasheed 2004). Similar to the Abbot Point meadows, these study sites also had either very low densities of seeds stored within the sediments (Rasheed 1999) or rare occurrences of flowering and fruiting (Rasheed 2004). A lack of seeds is often thought to stem from a lack of available gametes due to original colonisation by plants of mostly one sex (Clarke and Kirkman 1989; Rasheed 2004). However this is not always the case for tropical seagrass meadows in Queensland, with other *Halodule uninervis* meadows recording very high seed densities (commonly average >2000 per m^2)(Inglis 2000; McKenzie and Unsworth 2009), emphasising the need to understand local differences in meadow characteristics to understand resilience and capacity for recovery.

In contrast to *Halodule uninervis*, the deepwater *Halophila spinulosa* meadow recovered quickly (within 3 months) through a combination of sexual and asexual reproduction, indicating a greater capacity for meadow recovery from larger scale disturbances. Within three months, shoot densities had recovered to levels not significantly different to the controls in both bordered and borderless cleared plots. Seed densities of *Halophila spinulosa* were unfortunately not monitored due to their small size, but this experiment indicates that either such seed banks were present or rapid recruitment of seeds from the nearby adult population occurred. Evidence of flowering and fruiting for this species was observed as well as the general rapid recovery of *H. spinulosa* in the broader Abbot Point region following storm and flooding related seagrass losses in early 2009.

Seagrasses commonly have a range of species specific life histories and physiological adaptations enabling adaptation to different niches. Species such as *Halophila ovalis* are commonly termed pioneer species (Birch and Birch 1984), as they are considered one of the early colonising seagrass species in a succession to a climax community. Seagrass recovery at Green Island in the Great Barrier Reef followed such a successional pattern (Rasheed 2004). The present study recorded similar initial colonisation (site 2), where the original community contained only *Halodule uninervis,* but four months after clearing (September 2008), recovering plots contained two pioneer species, *Halophila ovalis and Halophila spinulosa*. Prior to the widespread storm related losses of all seagrasses in May 2009, these pioneering species were still present in recovering plots at higher densities than prior to seagrass removal, indicating that while overall shoot density had recovered within four months, the species still hadn’t returned to the pre-disturbance state.

Implications for Port Management

Results of two years of quarterly surveys indicate that seagrasses in the Port of Abbot Point were generally in a healthy state but at risk from a range of stressors including poor coastal water quality and seasonal storm events. Their persistence adjacent to the port indicates that they have the ability to co-exist with the current levels of port activities. 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.

Although current port activities do not appear to have had a significant impact on seagrasses in the local area, poor coastal water quality and climate variability are well documented sources of stress in the coastal environment of the Great Barrier Reef region (McKenzie and Unsworth 2009; De'ath and Fabricius 2010). The continued presence of elevated nutrients and suspended sediments in the coastal seasonal flood plumes of the GBR catchments means that seagrasses may already be living in conditions close to the limits of their environmental tolerance (i.e. poor light availability), restricting their level of resilience to future stressors.

Dredging and shipping activities have commonly been observed in many locations to damage seagrass (Erftemeijer and Lewis 2006). Persistent turbid plumes over a sustained period have also been shown to be detrimental to deepwater seagrasses in north Queensland, with recovery only beginning 12 months after the removal of the stressor (Chartrand *et al.* 2008). Activities that further reduce the availability of light to seagrass (i.e. turbidity plumes and sedimentation), negatively impact upon seagrass growth and productivity, influencing their continued viability (Ralph *et al.* 2007). Although such a causative link between seagrass loss and reduced light availability is well established (Erftemeijer and Lewis 2006), the interacting environmental stresses of high turbidity, climate variability and poor water quality are poorly understood in tropical coastal environments such as the Port of Abbot Point.

Experiments on seagrass recovery from controlled loss at Abbot Point provided an indication of the likely long-term impact of anthropogenic loss of seagrass in the area. If large scale loss of seagrass were to occur, some level of recovery would be possible, particularly by species such as *Halophila spinulosa* that appear to have available seed reserves. However, meadows dominated by *Halodule uninervis* that are likely to rely on asexual meadow recovery are unlikely to have a capacity to recover quickly from large losses where the majority of the adult population is removed. It would be critical then to manage any future dredging operations in a way that ensures the continued survival of the adult population to provide the basis of recovery for this species. Large scale losses of seagrasses in other locations within Queensland have taken at least 3 to 5 years to completely recover after the environment has returned to its baseline. Some seagrass meadows at Abbot Point if lost, may take many years to recover, with implications for a range of ecologically and economically important fauna.

Seagrass health and impact mitigation and management monitoring

Long-term seagrass monitoring has been used successfully throughout the state of Queensland as a valuable tool in the management of the health of the marine environment in a range of industrial and commercial ports (Chartrand and Rasheed 2009; Unsworth and Rasheed 2010). Data collected annually has been valuable in separating the impacts of natural versus anthropogenic stressors and informed future long-term planning strategies. Given the dynamic nature of seagrasses at Abbot Point described in this report, a long-term monitoring program at Abbot Point would be an important means of informing future environmental management and determining the sustainability of port activities. Such monitoring commonly utilises measures of seagrass at the seasonal maximum and at Abbot Point, any annual long-term monitoring should therefore be conducted between September and November.

While an annual program provides good information for planning and overall environmental health, it is probably insufficient to be used as an effective tool for managing and mitigating impacts and recovery from a major capital dredging program. Under these circumstances a more frequent and targeted program would be required to provide sufficient resolution to assess and manage impacts and recovery. The proposed developments at the Port of Abbot Point that include extensive dredge programs (both in terms of volume of dredge material and duration of dredge operations) pose a potential increased threat to seagrasses and the wider environmental health of the Port. Separating the natural versus anthropogenic impacts of such a major development and any future recovery is an important component of developing appropriate mitigation and management strategies. A monitoring program that used a statistically powerful Before After Control Impact (BACI) design that took consideration of potential extent of any dredge plume would be required. Such monitoring can also be used as part of a reactive dredge management program, based on the use of water quality thresholds (Sofonia and Unsworth 2010). Given the highly dynamic seasonal nature of seagrasses at Abbot Point described in the current report, seagrasses would need to be monitored at a temporal resolution sufficient to incorporate such seasonal change (ie quarterly). The sites established as part of these studies would be suitable to form the basis of such a program if required.

Conclusion

Seagrass meadows at the Port of Abbot Point are highly productive and provide habitat and food for a range of important fauna. These seagrass meadows are highly dynamic, with some habitats having a higher capacity for recovery from loss than others. They are currently subject to a range of anthropogenic and natural threats potentially reducing their resilience to increased 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 program presented here can form the basis of a seagrass assessment and monitoring strategy to aid in the management of dredge related impacts

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APPENDIX

Appendix 1.

A. Results of one-way ANOVA tests and comparison of means (LSD) (of meadows that were significantly different) for mean above-ground biomass of coastal monitoring meadows in the Port of Abbot Point: March 2005 & March 2008 – June 2010. Dates that share the same letter are not significantly different (P<0.05). Meadow 8 not analysed due to small sample sizes

March 05 & March 08 – June 2010 Comparisons					
Meadow 3**	**DF**	**SS**	**MS**	**F**	**P**
Between years	8	34.789	4.34863	3.78	<0.05
Within years	100	114.939	1.14939		
Total	108	149.728			
Meadow 5*	**DF**	**SS**	**MS**	**F**	**P**
Between years	5	6.76393	1.35279	6.15	<0.05
Within years	27	5.94118	0.22004		
Total	32	12.7051			
Meadow 7*	**DF**	**SS**	**MS**	**F**	**P**
Between years	5	23.3792	4.67584	5.57	<0.06
Within years	52	43.6817	0.84003		
Total	57	67.0609			
Meadow 9*	**DF**	**SS**	**MS**	**F**	**P**
Between years	8	5.6571	0.70714	1.67	NSD
Within years	107	45.2616	0.42301		
Total	115	50.9187			

*Data was square root transformed

**Data was log10 transformed

NSD – no significant difference detected

Meadow 3		**Meadow 5**		**Meadow 7**	
Mar 05	0.09**a**	**Mar 05**	0.03**b**	**Mar 05**	0.06*
Feb/Mar 08	3.71**ab**	**Feb/Mar 08**	0.05**b**	**Feb/Mar 08**	2.84*
Jul 08	4.55**a**	**Jul 08**	1.57**a**	**Jul 08**	3.72**ab**
Sept 08	8.91**a**	**Sept 08**	1.54**a**	**Sept 08**	6.7**a**
Nov 08	6.98a**b**	**Nov 08**	1.30**a**	**Nov 08**	2.87**abc**
Apr/May 09	3.34a**b**	**Apr/May 09**	np	**Apr/May 09**	1.68**bcd**
Aug 09	2.76b**c**	**Aug 09**	np	**Aug 09**	0.43**cd**
Dec 09	1.59**c**	**Dec 09**	0.005**b**	**Dec 09**	1.0**d**
Jun 10	0.84ab**c**	**Jun 10**	0.06*	**Jun 10**	0.76**bcd**

np – meadow not present

*Only 1 site in meadow therefore removed from analysis

Appendix 1 cont.

B. Results of one-way ANOVA tests and comparison of means (LSD) (of meadows that were significantly different) for mean above-ground biomass of offshore monitoring sites in the Port of Abbot Point: March 2005 & March 2008 – June 2010. Dates that share the same letter are not significantly different (P<0.05). Meadow 8 not analysed due to small sample sizes

March 05 & March 08 – June 2010 Comparisons					
Site 1*	**DF**	**SS**	**MS**	**F**	**P**
Between years	6	0.85342	0.14224	3.55	<0.01
Within years	51	2.04168	0.04003		
Total	57	2.89510			
Site 2**	**DF**	**SS**	**MS**	**F**	**P**
Between years	6	6.74147	1.12358	1.40	NSD
Within years	36	28.8857	0.80238		
Total	42	35.6271			
Site 3*	**DF**	**SS**	**MS**	**F**	**P**
Between years	7	38.6875	5.52678	4.50	<0.05
Within years	64	78.6282	1.22857		
Total	71	117.316			

*Data was square root transformed

**Data was log10+1 transformed

NSD – no significant difference detected

Site 1*		Site 3*	
Mar 05	0.08**ab**	**Mar 05**	3.98**bc**
Feb/Mar 08	0.04**b**	**Feb/Mar 08**	3.28**bc**
Jul 08	0.17**a**	**Jul 08**	3.31**abc**
Sept 08	0.02**b**	**Sept 08**	5.10**ab**
Nov 08	0.11**ab**	**Nov 08**	11.07**a**
Apr/May 09	0.0006**b**	**Apr/May 09**	0.34**c**
Aug 09	0.07**ab**	**Aug 09**	0.45**c**
Feb 10	n/a	**Feb 10**	n/a
Jun 10	np	**Jun 10**	0.77**bc**

np – meadow not present

n/a – February 2010 sampling not included in analysis

*Rejection level of alpha=0.01 used

Appendix 2.

A. Results of Repeated Measures ANOVA for mean shoot density (shoots m^{-1}) (all species pooled) between time and within treatments, and One-way ANOVA between treatments and within time at Recovery Site 1.

		Significance Testing			Pairwise tests									
		DoF	**F**	**P**	**May 08 vs Jul 08**	**May 08 vs Sept 08**	**May 08 vs Nov 08**	**May 08 vs May 09**	**Jul 08 vs Sept 08**	**Jul 08 vs Nov 08**	**Jul 08 vs May 09**	**Sept 08 vs Nov 08**	**Sept 08 vs May 09**	**Nov 08 vs May 09**
Between Time and Within Treatments	**Clear no-border (CLNB)**	4,14	30.7	**<0.001**	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05		<0.05	<0.05
	Clear border (CLB)**	4	9.5	**<0.05**										
	Control no-border (CNB)		10.5	**<0.01**					<0.05		<0.05			
	Control border (CB)	4,14	5.2	**<0.05**							<0.05			
					CB vs CLNB	**CB vs CLB**	**CNB vs CLNB**	**CNB vs CLB**	**CB vs CLNB**	**CLB vs CLNB**				
Between Treatments and Within Time	**May 08***	3	9.6	**<0.05**										
	July 08	3,11	4.7	**<0.05**										
	Sept 08*	3	6.3	>0.05										
	Nov 08	3,11	4.2	>0.05										
	May 09*	np	np	np										

np – no seagrass present
*Kruskall-Wallis one-way ANOVA on ranks
** Friedman repeat measures ANOVA on ranks used

Appendix 2 cont.

B. Results of Repeated Measures ANOVA for mean shoot density (shoots m^{-1}) (all species pooled) between time and within treatments, and One-Way ANOVA between treatments and within time at Recovery Site 2

		Significance Testing			Pairwise tests					
		DoF	**F**	**P**	**May 08 vs Sept 08**	**May 08 Vs Nov 08**	**May 08 Vs May 09**	**Sept 08 vs Nov 08**	**Sept 08 vs May 09**	**Nov 08 vs May 09**
Between Time and Within Treatments	**Clear no-border (CLNB)**	3,11	7.7	**<0.05**		<0.050				<0.050
	Clear border (CLB)	3,11	1.0	NSD						
	Control no-border (CNB)	3,11	5.1	**<0.05**						
	Control border (CB)	3,11	9.9	**<0.01**			<0.05			<0.05
					CB vs CLNB	**CB vs CLB**	**CNB vs CLNB**	**CNB vs CLB**	**CB vs CLNB**	**CLB vs CLNB**
Between Treatments and Within Time	**May 08**	3,11	57.8	**<0.001**	<0.05	<0.05	<0.05	<0.05	<0.05	
	Sept 08	3,11	6.0	**<0.05**				<0.05		<0.05
	Nov 08	3,11	6.0	**<0.05**				<0.05		
	May 09**	3	9.3	**<0.05**						

NSD – no significant difference detected

** Friedman repeat measures ANOVA on ranks used

Appendix 2 cont.

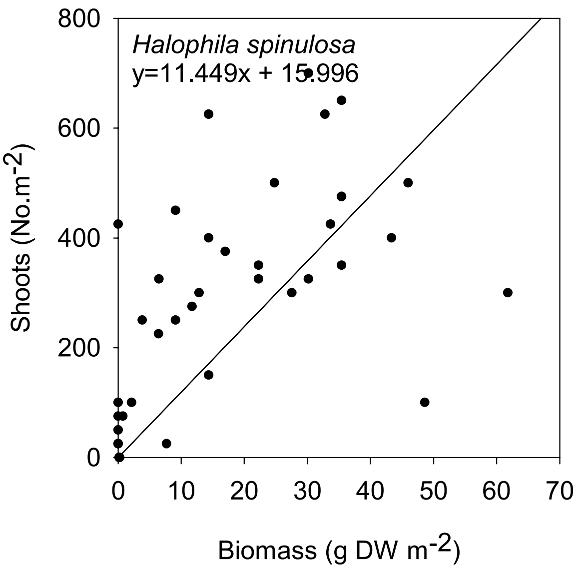
C. Results of Repeated Measures ANOVA for mean shoot density (shoots m^{-1}) (all species pooled) between time and within treatments, and One-Way ANOVA between treatments and within time at Recovery Site 3

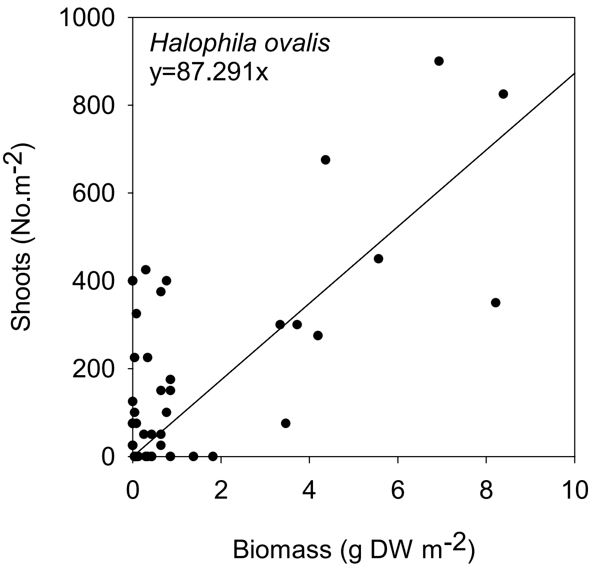
		Significance Testing			Pairwise tests					
		DoF	**F**	**P**	**May 08 Vs Sept 08**	**May 08 Vs Nov 08**	**Sept 08 Vs Nov 08**			
Between Time and Within Treatments	**Clear no-border (CLNB)**	2,8	14.6	**<0.05**		<0.05				
	Clear border (CLB)	2,8	19.0	**<0.01**		<0.05	<0.05			
	Control no-border (CNB)	2,8	43.3	**<0.01**						
	Control border (CB)	2,8	2.7	**<0.05**	<0.05	<0.05				
					CB vs CLNB	**CB vs CLB**	**CNB vs CLNB**	**CNB vs CLB**	**CB vs CLNB**	**CLB vs CLNB**
Between Treatments and Within Time	**May 08***	3	9.778	**<0.05**						
	Sept 08	3,11	1.660	NSD						
	Nov 08	3,11	0.4	NSD						
	May 09	np	np	np						
	Aug 09	np	np	np						

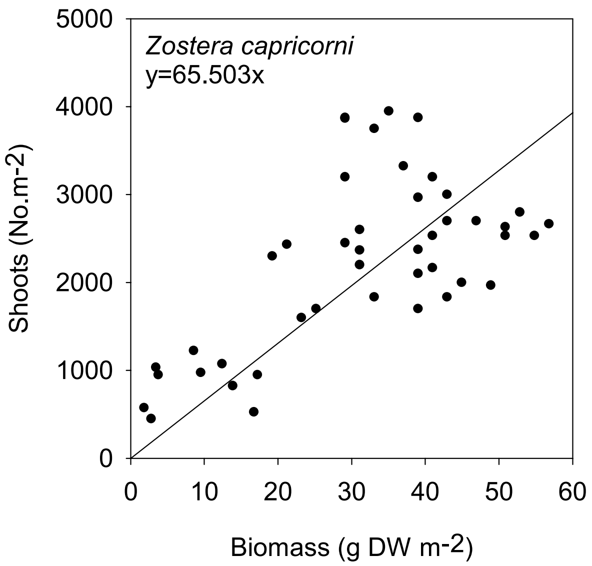
np – no seagrass present
NSD – no significant difference detected
*Kruskall-Wallis one-way ANOVA on ranks

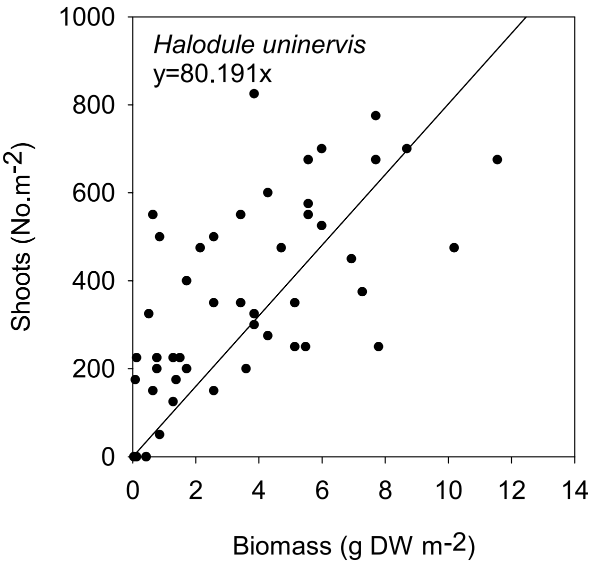
Appendix 3.

Seagrass shoot to above ground biomass relationships utilised in productivity calculations determined for four species. All relationships were determined at Abbot Point except for *Zostera capricorni* which was determined at Pelican banks, Gladstone Harbour, Queensland 2009.









Appendix 4: Mean carapace length (mm) ± standard error of Penaeid species in Mar/Apr, May, August and November, 2007 across all sites and total monthly count for each species.

Family	Species	Common Name	Mean Carapace Length (mm) (Range of Lengths)				Monthly Count 2006		Total (N)
			Sept 2008	Nov 2008	Apr 2009	August 2009			
Penaeidae	*Trachypenaeus anchoralis*	Northern Rough Prawn	19.7 ± 0	13.11 ± 4.77 (7.46 – 27.34)	12.7 ± 0.57 (6.5 – 32.06)	11.88 ± 0	Sept 2008 Nov 2008 Apr 2009 Aug 2009	1 4 83 1	89
Penaeidae	*Trachypenaeus curvirostris*	Southern Rough Shrimp	-	-	27.05 ± 4.75 (22.3 – 31.8)	-	Sept 2008 Nov 2008 Apr 2009 Aug 2009	- - 2 -	2
Penaeidae	*Trachypenaeus granulosus*	Coarse Shrimp	-	-	11.31 ± 0.43 (6.36 – 17.35)	21.4 ± 0	Sept 2008 Nov 2008 Apr 2009 Aug 2009	- - 43 1	44
Penaeidae	*Trachypenaeus* sp.		-	-	7.45 ± 0.13 (5.13 – 12.66)	-	Sept 2008 Nov 2008 Apr 2009 Aug 2009	- - 121 -	121
Penaeidae	*Penaeus esculentus*	Brown Tiger Prawn	-	-	51.66 ± 2.39 (49.27 – 54.04)	39.62 ± 0	Sept 2008 Nov 2008 Apr 2009 Aug 2009	- - 2 1	3
Penaeidae	*Penaeus latisulcatus*	Western King Prawn	49.89 ± 2.49 (47.4 - 52.37)	34.62 ± 0	-	-	Sept 2008 Nov 2008 Apr 2009 Aug 2009	2 1 - -	3

Penaeidae	*Metapenaeopsis* sp.		14.00 ± 0.60 (4.15 – 29.85)	12.36 ± 0.35 (4.08 – 27.70)	9.87 ± 0.16 (4.64 – 25.6)	13.11 ± 0.40 (4.94 – 39.08)	Sept 2008 Nov 2008 Apr 2009 Aug 2009	120 188 318 137	763
Penaeidae	*Parapenaeopsis cornuta*	Coral Prawn	-	-	11.34 ± 1.13 (4 – 26.6)	23.33 ± 1.75 (18.36 – 26.19)	Sept 2008 Nov 2008 Apr 2009 Aug 2009	- - 37 4	41
Penaeidae	*Penaeid* sp.		11.7 ± 0	-	7.17 ± 0.28 (4.41 – 11.5)	-	Sept 2008 Nov 2008 Apr 2009 Aug 2009	1 - 32 -	33

Appendix 5. Mean carapace length (mm) ± standard error of Penaeids for each site and date and total monthly count across all sites.

Site	Mean Carapace Length (mm)				Monthly Count and Total Numbers		
	Sept 08	Nov 08	Apr 09	Aug 09	Monthly Count		Total N
Site 1 (Inshore)	49.89 ± 2.49	34.62 ± 0	10.97 ± 1.14	26.59 ± 3.53	Sept 08 Nov 08 Apr 09 Aug 09	2 1 35 5	43
Site 2 (Offshore)	14.14 ± 0.70	11.49 ± 0.49	9.42 ± 0.38	11.96 ± 0.42	Sept 08 Nov 08 Apr 09 Aug 09	93 103 235 81	512
Site 3 (Control)	13.69 ± 1.08	13.41 ± 0.49	10.29 ± 0.16	14.84 ± 0.69	Sept 08 Nov 08 Apr 09 Aug 09	29 89 368 58	544

Appendix 6. Fish species and family group abundances at three seagrass sites in Abbot Point.

			Sep-08			Nov-08			Apr-09			Aug-09		
Species	**Common name**	**Family**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Adventor elongatus	Sandpaper Velvetfish	Aploactinidae	0	0	0	0	0	0	0	0	0	0	0	3
Apogon cauitiensis	Yellow cardinal fish	Apogonidae	0	0	1	2	1	0	0	0	0	0	0	2
Apogon nigripinnis	Two eyed cardinal fish	Apogonidae	0	0	0	4	0	2	0	0	0	2	0	0
Apogon semilineatus	Blacktip Cardinal fish	Apogonidae	0	0	0	0	0	0	0	0	0	0	0	3
Apogon septemstriatus	Seven banded cardinal fish	Apogonidae	0	0	0	0	23	6	0	1	6	1	0	5
Apogon sp.	Cardinalfish	Apogonidae	0	2	0	1	0	0	0	0	0	0	0	0
Apogonidae spp.	Cardinalfish	Apogonidae	4	0	0	2	10	11	0	0	0	0	0	0
Rhabdamia cypselura	Schooling Cardinal fish	Apogonidae	0	0	0	0	0	0	0	0	0	0	0	8
Rhabdamia gracilis	Luminous cardinalfish	Apogonidae	0	0	0	3	0	0	0	0	0	0	0	2
Sphaeramia versicolor	Sea urchin cardinalfish	Apogonidae	0	0	0	1	0	0	0	0	0	0	0	0
Bleniidae spp.	Blenny	Bleniidae	0	0	0	0	0	0	0	0	0	1	0	0
Meiacanthus grammistes	Linespot Fangblenny	Bleniidae	0	0	0	0	0	0	0	0	0	0	0	1
Engryprosopon grandisquama	Spot-tail wide-eyed flounder	Bothidae	0	0	0	0	0	0	0	0	0	0	0	9
Bothidae spp.	Flounder	Bothidae	2	0	2	0	0	0	3	2	0	0	0	1
Psettina gigantea	Rough scaled flounder	Bothidae	0	0	0	0	0	13	0	0	0	0	0	0
Pseudorhombus argus	Peacock flounder	Bothidae	0	0	0	0	2	0	0	0	0	0	0	0
Pseudorhombus dupliciocellatus	Three twin spot flounder	Bothidae	0	0	0	0	0	1	0	0	0	0	0	0
Pseudorhombus elevatus	deep flounder	Bothidae	0	0	0	0	0	16	0	0	0	0	1	0
Pseudorhombus jenynsii	Small Tooth Flounder	Bothidae	0	0	0	0	0	0	0	0	0	0	0	1
Pseudorhombus quinqoucellatus	five-eyed flounder	Bothidae	0	0	0	0	2	0	0	0	0	0	0	0
Pseudorhombus spinosus	Spiny flounder	Bothidae	0	0	0	0	0	0	0	0	1	0	0	0
Bathycallionymus moretonensis	Ocellate Dragonet	Callionymidae	0	0	0	0	0	0	0	0	0	0	4	0
Callionymidae spp.	Dragonet	Callionymidae	0	0	0	0	2	1	0	1	0	0	0	0
Centriscus scutatus	Grooved razor fish	Centriscidae	0	0	0	0	0	0	0	3	0	0	0	0
Cynoglossus maculpinnis	Tongue Sole	Cynoglossidae	0	2	0	0	8	0	0	1	0	0	1	1
Fistularia commersonii	Smooth flutemout	Fistulariidae	0	0	0	0	0	1	0	0	0	0	0	0
Gobiidae spp.	Goby	Gobiidae	0	0	0	0	1	0	0	0	0	1	0	0
Priolepis semidoliatus	Head-barred goby	Gobiidae	0	0	1	0	0	0	0	0	0	0	0	0
Leiognathus elongatus	Elongate ponyfish	Leignathidae	0	0	0	0	0	3	0	0	0	0	0	0
Acreichthys sp.		Monocanthidae	0	0	0	0	0	0	0	0	0	0	0	2
Monacanthidae spp.	Leatherjacket	Monocanthidae	0	1	0	0	1	0	0	0	0	0	1	1
Paramonacanthus choirocephalus	Hairfinned leatherjacket	Monocanthidae	0	0	0	0	1	3	0	0	0	0	0	0
Paramonacanthus japonicus	Japanese leather jacket	Monocanthidae	0	0	0	0	0	2	0	0	0	0	0	0

Appendix 6 cont. Fish species and family group abundances at three seagrass sites in Abbot Point.

			Sep-08			Nov-08			Apr-09			Aug-09		
Species	**Common name**	**Family**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Larval Fish	NA	NA	3	1	3	1	38	48	0	0	2	5	0	20
Saurenchelys sp.	Duckbill eels	Nettastomatidae	0	0	0	0	0	0	0	0	0	0	0	1
Ostraciidae spp.	Boxfish	Ostraciidae	0	0	1	0	0	0	0	0	0	0	0	0
Paralichthyidae spp.	Flounder	Paralichthyidae	0	0	0	0	0	6	0	0	0	0	0	0
Parapercis deplospilus	Double spot grubfish	Pinguididae	1	2	7	0	15	1	0	1	6	0	0	8
Cymbacephalus nematophthalmus	Fringe-eyed Flathead	Platycephalidae	0	0	0	0	0	0	0	0	0	0	0	3
Platycephalidae spp.	Flathead	Platycephalidae	0	0	0	0	0	6	0	2	0	3	0	0
Onigocia spinosa	Midget Flathead	Platycephalidae	0	0	0	0	0	0	0	0	0	0	2	2
Papilloculiceps nematopthalmus	Fringe-eyed flathead	Platycephalidae	0	1	0	0	15	8	0	0	8	0	0	0
Sorsogona tuberculata	Heart headed flathead	Platycephalidae	0	0	0	0	0	4	0	0	0	0	0	0
Suggrundus sp.2	Black-banded flathead	Platycephalidae	0	0	0	0	3	0	0	0	0	0	0	0
Pictichromis paccagnellae	Royal Dottyback	Pseudochromidae	0	0	0	0	0	0	0	0	0	0	0	3
Neocentropogon sp.	Waspfish	Scorpaenidae	0	0	0	0	0	2	0	0	0	0	0	0
Serranidae spp.	gropers	Serranidae	0	0	0	0	2	0	0	0	0	0	0	0
Argyrops spinifer	Frypan snapper	Sparidae	0	0	0	0	0	1	0	0	0	0	0	0
Synodontidae spp.	Lizard fish	Synodontidae	0	0	0	0	0	1	0	0	0	0	0	0
Saunda sp.2	Grey Lizardfish	Synodontidae	0	0	0	0	2	0	0	0	0	0	0	0
Saurida nebulosa	Clouded lizard fish	Synodontidae	0	0	0	0	7	0	0	0	0	0	0	0
Tetraodontidae spp.	Toad fish	Tetraodontidae	0	0	0	0	0	0	1	0	0	2	0	0
Lagocephalus sceleratus	Silver Toadfish	Tetraodontidae	0	0	0	0	0	0	0	0	0	0	0	3
Torquigener hicksi	Hick's toadfish	Tetraodontidae	0	0	0	1	0	0	0	0	0	0	0	0
Torquigener whitleyi	Whitley's toadfish	Tetraodontidae	1	0	0	0	0	0	0	0	0	0	0	0