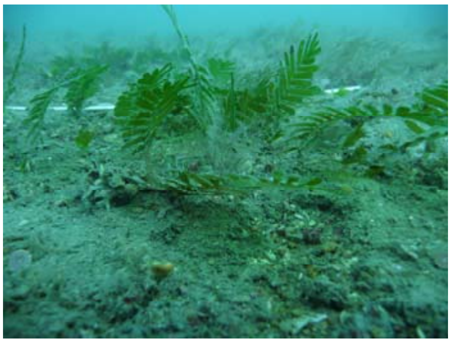
Final Report

Deepwater seagrass dynamics in Hay Point

Measuring variability and monitoring impacts of capital dredging



Katie Chartrand

Michael Rasheed

Tonia Sankey

Department of Primary Industries and Fisheries

Marine Ecology Group

Northern Fisheries Centre

Ports Corporation of Queensland

Marine Ecology Group

Queensland Government Department of Primary Industries and Fisheries

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Katie Chartrand

Michael Rasheed

Tonia Sankey

Marine Ecology Group
Northern Fisheries Centre

Department of Primary Industries and Fisheries
PO Box 5396 Cairns Qld 4870

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Northern Fisheries Centre
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EXECUTIVE SUMMARY

This report details the results of a monitoring program for seagrass, algae and benthic macro-invertebrate communities in the Port of Hay Point conducted from July 2004 to June 2008. The program was commissioned by the Ports Corporation of Queensland Limited (PCQ) as a joint project with the Department of Primary Industries and Fisheries (DPI&F) to aid in planning the expansion of the port and monitoring potential impacts to sensitive fisheries and benthic habitats.

The port expansion had the potential to significantly impact seagrass habitats known to exist in the port. However little was known about the dynamics of low density deepwater seagrass meadows that typified the area. The monitoring program was designed to fill some of the gaps in our knowledge on how these deepwater habitats change naturally through time, their roles in fisheries productivity and their resilience and capacity for recovery from disturbance associated with dredging.

The program consisted of a detailed baseline survey mapping habitats in July 2004 and a monitoring program that assessed changes to marine plants at four locations before, during and after the capital dredging program. A range of survey techniques were used to describe the benthic communities that occurred in the port, including a real time camera system and sled with mini-trawl net towed behind a research vessel and beam trawling to sample fish and crustaceans utilising these habitats. The techniques integrated a large area of seafloor at each site and were ideal for describing patchily distributed benthic habitats that typically occur in offshore areas of Queensland.

Results of the program have provided a unique insight into the dynamics of these deepwater seagrass communities. Seagrasses in the port were naturally highly variable with peak abundances and distribution occurring in winter and spring before seasonal declines over summer. Seagrasses were absent from the survey area between December and June of each year. The capital dredging and resulting extensive dredge plume between May and November 2006 were likely to have stopped the natural seasonal recruitment of seagrasses in 2006. However seagrass had begun to recover within 12 months of the cessation of dredging activity with seasonal seagrass recruitment occurring in the first winter post-dredging (July 2007).

The low density seagrass habitats are of limited direct value to fisheries species as a nursery habitat. Beam trawls conducted in the area found that numbers of commercial prawn and fish species were significantly lower than for dense coastal seagrass meadows sampled in tropical Queensland.

The seagrass meadows present were of a type preferred as food for dugong and may provide a food source for dugong moving along the coast between nearby Dugong Protection Areas (DPA's) to the north and south of the port of Hay Point.

Benthic habitats in the port were typical of those found in other regions that have been surveyed between the mainland and the Great Barrier Reef. There were no areas of unique benthic life discovered within the survey area. Dredging activity did have an impact on benthic macro invertebrate community structure. Sessile taxa (those anchored to the bottom) were particularly impacted by dredge activity likely due to smothering and clogging of their filtering apparatus. Sessile invertebrate abundance recovered at all impacted sites following the cessation of dredging.

While the capital dredging project in the Port of Hay Point had a negative impact on marine plant and benthic macro invertebrate communities during the dredging program, results indicate that these communities and habitats had the capacity to recover within a year of the cessation of dredging activity. It is critical to note that denser coastal seagrass meadows consisting of larger growing species would be unlikely to display the same level of resilience to a similar dredging impact. The reproductive and colonising characteristics of the *Halophila* species that occur in Hay Point means that they have an excellent capacity for recovery from periodic disturbances caused by human activity.

BACKGROUND

The Port of Hay Point is located on the central Queensland coast, approximately 40 km south of Mackay. The port is a major coal exporting facility that services the Dalrymple Bay Coal Terminal (DBCT) and Hay Point Services Coal Terminal (HPSCT). The Ports Corporation Queensland (PCQ) is the authority responsible for the management of the Port of Hay Point. In 2005/2006 the Port of Hay Point exported a total of 81.6 million tonnes of coal (PCQ 2007). The last decade has seen significant development of the port and port facilities with plans to continue expansion to accommodate the growing industrial base and increasing numbers of bulk carriers visiting the Port. As a result of the increase in demand for port usage and product, PCQ have looked to improve the efficiency of the port and associated facilities by increasing the allowable sailing draft of the vessels and lengthening the tidal window of opportunity for entering and departing the port.

To accomplish this, PCQ recently completed capital dredging of a new departure path and apron area at the port and established a new sea disposal site for the resulting dredge spoil. The potential environmental impacts associated with this dredging campaign included the actual dredging activity itself as well as the disposal of dredge spoil. There were numerous key ecological and economical areas that needed to be considered in undertaking this dredging campaign, including the need to minimise impacts on marine habitats and fauna including seagrasses and benthic fauna. Capital dredging commenced on the 9th of May 2006 and ceased on the 17th of October 2006, with further bed levelling conducted through to the 13th of February 2007.

Very little is known about the dynamics of deepwater seagrass and benthic macro invertebrate (BMI) communities or the role they play in primary and fisheries production. It is likely that they vary significantly from year to year and between seasons and are usually considered to be ephemeral in nature.

The expansion of the Port of Hay Point had the potential to significantly impact the seagrass communities known to exist in the Port area. Three major impacts on marine plants were likely:

1. Direct burial from the disposal of spoil.
2. Prolonged shading from high turbidity plume associated with dredging.
3. Direct removal from the dredged areas.

It was estimated that approximately 4,500ha of marine plant habitat could potentially be lost as a result of the proposed works. This was based on the seagrass mapping conducted in July 2004, preliminary hydrodynamic modeling of dredge plumes and the planned location of the spoil grounds. PCQ commissioned DPI&F to conduct a research program to fill some of the gaps in the knowledge on how these deepwater habitats change naturally through time, their roles in fisheries productivity and their resilience and capacity for recovery from disturbance associated with dredging. This project provides both local information on the status of the Hay Point marine environment and information with a broader applicability to aid the decision making process for similar developments that affect deepwater marine plant communities in the future.

The goals of the study were to:

- Study the dynamics of deepwater seagrass habitats and their resilience and capacity for recovery from disturbance associated with dredging.
- Examine the effects of dredging, particularly the impacts of spoil disposal and the turbid dredge plume on seagrass habitats.
- Gather information on the value of these seagrass habitats for fisheries productivity.

METHODOLOGY

Survey Approach

Due to the general lack of knowledge on the dynamics of these deepwater marine plant communities two different approaches to the project were proposed. The decision on which approach to implement depended on the status of the seagrass resources that was revealed in the first sampling event. The two approaches were:

1. **Assess the impacts of dredging on deepwater marine plants and their recovery**

   If substantial areas of seagrass were present in the sampling event prior to dredging, a *Before/After/Control/Impact* (BACI) design to assess the various impacts associated with dredging on marine plants and their recovery would be implemented. BACI survey designs are intended to detect changes from impacts by sampling both before and after an impact occurs, with a control site from which such changes can be measured (Green, 1979).

2. **Dynamics of deepwater marine plant communities**

   If the area of seagrass had declined substantially from that recorded in the July 2004 baseline prior to dredging, a BACI design may not be possible. In this instance the focus of the program would be to investigate the dynamics of deepwater seagrass at Hay Point. This sampling design would detect recruitment and changes in seagrass abundance and species.

The timeline for the study included the original baseline survey conducted in July 2004, as well as two additional baseline surveys carried out as part of the monitoring program prior to capital dredging (Table 1). From May 2006 when dredging began through to February 2007, monitoring surveys were conducted monthly (weather permitting). A total of 16 surveys were conducted from pre-dredge, dredge, and post-dredge time points (Table 1).

Table 1. Schedule of sampling

Dredging Phase	Sampling dates	Beam trawl conducted
Pre-dredge	July 04	-
	Dec 05	-
	Mar 06	✓
Dredge	May 06	✓
	Jul 06	-
	Aug 06	✓
	Sep 06	-
	Oct 06	-
Post-dredge	Nov 06	✓
	Jan 07	✓*
	Mar 07	-
	Jul 07	✓
	Sep 07	-
	Nov 07	✓
	Feb 08	✓
	Jun 08	-

* Survey conducted in early February 2007

Although the impact of dredging on benthic macro invertebrate (BMI) communities was not part of the original aims of this study, the seagrass collection methods also allowed collection of BMI information. As BMI information was likely to enhance the program BMI diversity and abundance was recorded from May 2006 onwards as part of the surveys.

Survey Methods

Deepwater seagrass and BMI were sampled within selected sites in the Hay Point port limits. Four sites were chosen for sampling:

1. Dredge Plume impact site.
2. Dredge Plume control site (Control Inshore).
3. Spoil Ground impact site.
4. Spoil Ground control site (Control Offshore).

The four monitoring sites were located in areas that contained seagrass in the July 2004 baseline study or the December 2005 pre-dredge survey (Map 1 and 2; Rasheed *et al*. 2004a). The dredge plume impact site was to the north of the apron dredging zone, in an area predicted to be affected by high turbidity (GHD 2005). The second impact site was in the new dredge spoil ground and examined the impact of burial by spoil. Changes observed in the impact sites were compared to the two control sites that were expected to be largely unaffected by dredging. The offshore control site was placed in a spot that closely mirrored the environment found in the spoil ground impact site, whilst the inshore control site was chosen as it occurred in a similar depth and distance from shore to the dredge plume impact site. The control sites also allowed natural seasonality and variability to be measured.

Within each site, three replicate blocks were randomly selected with three 100 metre transects sampled within each block. The start and finish of each transect was recorded using a Global Positioning System (GPS) accurate to ± 5.0m. In order to reliably map the major benthic community types and characteristics, methods developed by DPI&F for analysis of deepwater seagrass and benthic communities were used (see Rasheed *et al.* 2001; 2003; 2004b; Coles *et al.* 1996; 2000; 2002) (Map 1). An underwater CCTV camera system with real-time monitor was towed from the DPI&F research vessel “Pearl Bay”. For each transect the camera was towed for 100 metres at drift speed (less than one knot). Footage was observed on a TV monitor and recorded to digital tape. The camera was mounted on a sled that incorporated a sled net 600 mm width and 250 mm deep with a net of 10 mm-mesh aperture (Plate 1). Surface benthos including seagrass and BMI (included in surveys from May 2006 onwards) were captured in the net and used to confirm seagrass habitat, algae and BMI characteristics observed on the monitor. This technique ensured a large area of seafloor ($60m^2$ per transect) was sampled at each site so that patchily distributed marine plant and BMI habitats that typified the survey area were effectively measured. A total of 36 transects were conducted for each survey (Map 1).

Habitat Characterisation

Seagrass

Seagrass was identified in the field from sled samples and from video according to Kuo and McComb (1989). In transects where seagrass presence was noted, seagrass species composition and estimated seagrass percent cover and density were determined from the video record. Identification of seagrass species was confirmed by the presence of seagrass in the sled net.

Above ground biomass was also determined using a modified “visual estimates of biomass” technique described by Mellors (1991) and was based on ten random time frames allocated within the video footage for each site. The video was paused at each of the ten random time frames selected then advanced to the nearest point on the tape where the bottom was visible and sled was stable on the bottom. From this frame, an observer recorded an estimated rank of seagrass biomass and species composition. To standardise biomass estimates, a 0.25 m^2 quadrat scaled to the video camera lens used in the field, was superimposed on the screen. Where seagrass was present in the sled net but not visible in the transect's video footage, the lowest biomass rank (0.05) was assigned to one of the 10 ranks for the transect. On completion of the videotape analysis, the video observer ranked five additional quadrats that had been previously videoed for calibration. These quadrats were videoed in front of a stationary camera, and then harvested, dried and weighed. A linear regression was calculated for the relationship between the observer ranks and the actual harvested value. This regression was used to calculate above ground biomass for all estimated ranks made from the survey sites. Biomass ranks were then converted into above ground biomass estimates in grams dry weight per square metre (g DW m^{-2}). (see Rasheed *et al.* 2001; 2003; 2004b; Coles *et al.* 1996; 2000; 2002).

Algae

Algal type and percent cover was identified according to Cribb 1996. Algae at each site were identified in the sled net into the following five functional groups:

1. *Erect Macrophytes* - macro algae with an erect growth form and high level of cellular differentiation eg. *Sargassum*, *Caulerpa* and *Galaxaura* species.

2. *Erect Calcareous* - algae with erect growth form and high level of cellular differentiation containing calcified segments eg. *Halimeda* species.

3. *Filamentous* - thin thread like algae with little cellular differentiation.

4. *Encrusting* - algae growing in sheet like form attached to substrate or benthos eg. coralline algae.

5. *Turf Mat* - algae that forms a dense mat or turf on the substrate.

The video record for each site was analysed to determine the overall percent cover of algae as well as the relative proportion of the total cover made up of each of the algal functional groups for each site.

Habitat Mapping and Geographic Information System

All survey data was entered into a Geographic Information System (GIS) for presentation of marine plant information. For both baseline surveys (July 2004 & December 2005) maps were generated in the GIS program ArcGIS v.9.2 using information collected at survey sites and satellite images of the Hay Point area rectified and projected using Latitude/Longitude GDA 94.

Three GIS layers were created in ArcGIS to describe Hay Point seagrasses during baseline surveys:

- *Survey transects* – GPS sites marked the beginning and end of the 100m transects containing information on seagrass and algae abundance.
- *Seagrass community types and density* – Area data for seagrass meadows and information on community characteristics were collected. Community types were determined according to overall species composition for July 2004 and December 2005 baseline surveys. A standard nomenclature system was used to name each of the meadows in the survey area. This system was based on the percent composition of biomass contributed by each species within the meadow.
- *Seagrass percent cover* – area data displaying the percentage of sea bed covered by seagrass during baseline surveys divided into three categories, ≤5%, 5 to 20% and ≥ 20%.

During monitoring surveys, one GIS layer was created to describe the presence/absence of Hay Point seagrasses. GPS sites marked the beginning and end of 100m transects containing information on seagrass and algae abundance.

Beam Trawling - Penaeids and Fish Communities

To determine the utilisation of seagrass habitats by invertebrate and fish communities of fisheries value and the potential impacts of dredging on invertebrate and fish communities, night time beam trawling on seagrass habitat areas was conducted (Table 1). In a similar manner to the CCTV sampling, beam trawling was conducted using a BACI design at two impact sites (Dredge Plume and Spoil Ground) and a control site (Control Inshore) within the port (Map 1). Sampling was conducted at approximately 3 monthly intervals (weather dependent). Sampling occurred before and during dredging to examine potential impacts of the dredge plume or spoil burial on invertebrates and fish. Sampling occurred after dredging to examine recovery in the impacted sites compared with the control site.

A beam trawl (1.5 m wide, 0.5 m high with a 2.0 mm mesh) was towed along a 100 m transect (a total of 150m^2 sampled). Three replicate trawls were conducted at each site. Previous studies in north Queensland have shown that this is sufficient to adequately sample the representative fauna (Coles *et al*. 1993).

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 to species or genus level and standard length (tip of snout to last vertebra) measured (mm).

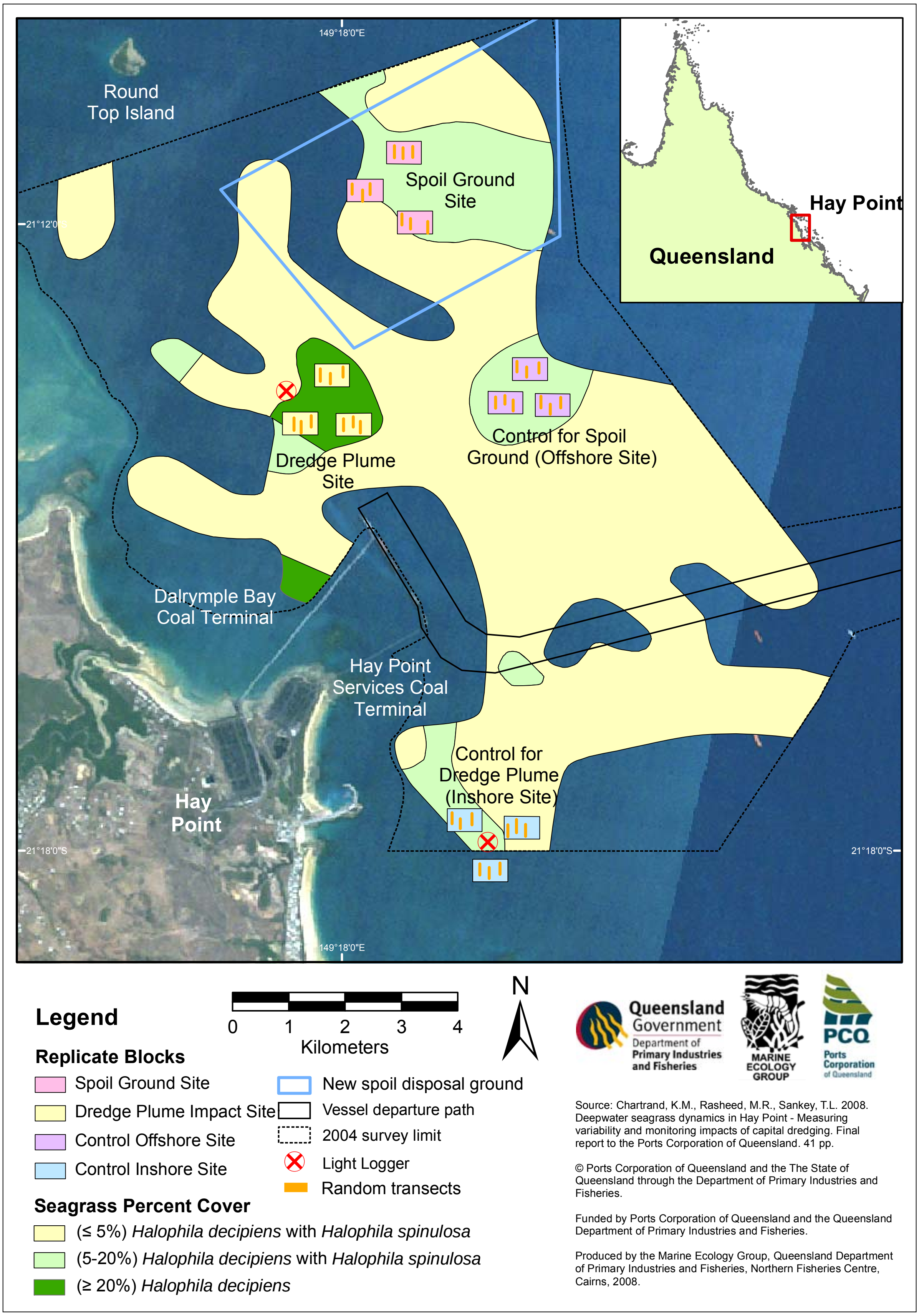
Benthic Macro Invertebrates

BMI were measured in all transects starting in May 2006. BMI visible on the monitor and those collected in the sled net were identified into taxonomic groups in the field. Counts were made of the number of taxa and individuals.

Figure 1. Offshore video sampling sled

Light loggers were deployed by GHD at two sites in the survey area, one adjacent to the dredge plume impact site and one proximate to the control inshore site (Map 1). Light levels were recorded at ten minute intervals starting on the 4th of May 2006, five days prior to dredging activity commencing. The dredge plume site logger was removed on the 27th of October 2006, 10 days post-dredging while the control inshore site logger remained to the 23rd of November 2006.

Map 1. Location of Hay Point survey sites and the presence of seagrass found in July 2004



RESULTS

Following the initial July 2004 baseline there were a total of 15 monitoring surveys conducted within the Port of Hay Point from December 2005 to June 2008. Monitoring surveys were conducted during pre-dredge, dredge, and post-dredge periods (Table 1). During each survey, all transects within each replicate block and site were sampled.

The dominant habitat within the port limits was open substrate with a low percent cover of benthic life. The area of turbid plume from dredging due to re-suspension of sediment was more extensive than initial modelling had predicted. High turbidity was common across the two impact sites, with the visibility at the bottom often non-existent. In addition, the control inshore and control offshore site experienced substantial dredge related turbidity during dredging months.

The two light loggers deployed at the inshore seagrass sampling sites recorded extremely low light levels for the majority of the dredging period. Near the dredge plume site, light levels remained below 50 µE m^{-2} s^{-1} on all but five days of the dredging period with most days recording zero light at the substrate. Only two days during this period exhibited a typical daily irradiance pattern which occurred during the first and last week of dredging activity. At the control inshore site light logger, light remained at typical daily irradiance levels for two weeks into the active dredging period following which light levels dropped to near zero until over a month after dredging ceased.

Seagrass Presence and Trends

Two species of seagrass (from one family) were found in the survey area:

Figure 2.

Family HYDROCHARITACEAE Jussieu:

Halophila decipiens
Ostenfeld

Halophila spinulosa
(R. Br.) Aschers. In Neumayer

Significant areas of deepwater seagrass (>5m below mean sea level) were found within the Port of Hay Point in the baseline benthic survey conducted in July 2004 (Map 1; Rasheed *et al.* 2004a). Seagrass occurred at 56% of the survey sites and formed four individual meadows with a total area of 6,851.9 ha (55.9% of surveyed area) (Table 1; Map 1). Seagrass meadows were dominated by low biomass *Halophila decipiens* with *Halophila spinulosa* occurring at some sites (Table 1, Figure 3, Map 1). While the majority of the area was described by a light *Halophila* meadow there were two smaller patches of moderate *Halophila* meadows adjacent to the old spoil ground and to the north of the coal loading wharves (Map 1). Percent cover of seagrass in the meadows was low ranging from <1% to

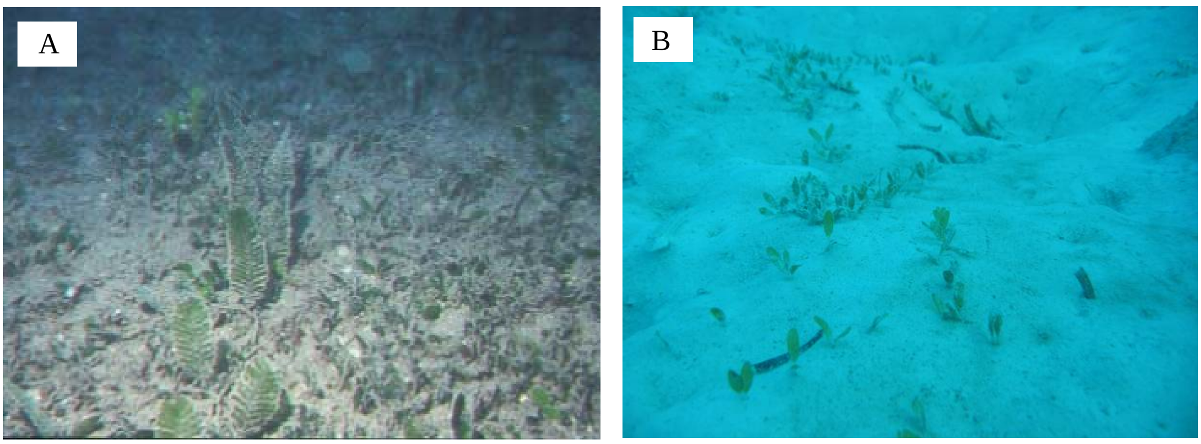
35% of the total bottom area (Map 1; Table 3). The maximum depth recorded for offshore seagrass was 17.9m below MSL for *Halophila decipiens* in meadow 1 (Map 1).

In all subsequent pre dredging and dredge monitoring surveys, seagrass was greatly reduced in its extent from that mapped in the July 2004 baseline survey (Map 1). In the first pre-dredge survey (December 2005), seagrass had reduced to a single *H. spinulosa* meadow of 338.6 ± 155.5 ha in the new spoil ground region (Map 2). By the second pre-dredge survey in March 2006, seagrass had completely disappeared from the survey area. No seagrass was found at any site during dredging from March 2006 until post-dredging in July 2007, when *H. decipiens* was observed in the sled nets at both control inshore and offshore sites (Map 3). *H. decipiens* was the only species detected in all remaining surveys. In September 2007, *H. decipiens* was present at all survey sites (Map 4). Seagrass was recorded during the November 2007 survey at all sites except the dredge plume impact site (Map 5). Seagrass was not observed at any site during the final two surveys of the program in February and June 2008.

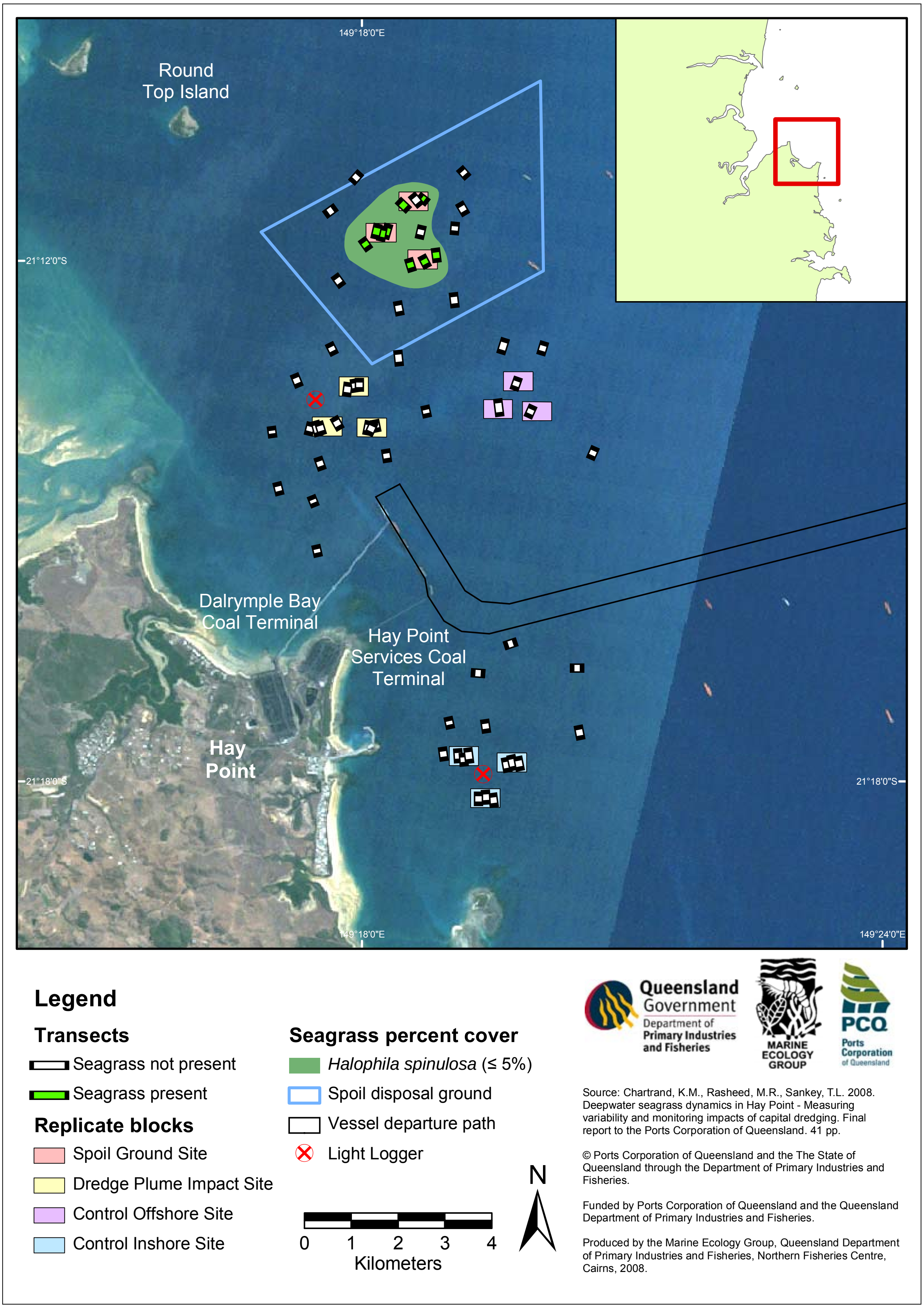
Table 1. Seagrass community types, percent cover, mean above ground biomass and area in the Port of Hay Point July 2004.

Meadow ID	**Community type**	**Mean meadow biomass** (g DW m^{-2} ± SE)	**Number of sites**	**Area ± R** (ha)	**Mean % seagrass cover**
1	Light *Halophila decipiens* with *Halophila spinulosa*	0.2 ± 0.03	68	6397.2 ± 2371.0	2
2	Moderate *Halophila decipiens*	1.4 ± 0.2	5	278.1 ± 238.5	21
3	Light *Halophila decipiens* with *Halophila spinulosa*	0.03	1	133.9 ± 76.0	<1
4	Moderate *Halophila decipiens*	2.8	1	42.7 ± 30.1	35
Total			75	6851.9 ± 2715.6	

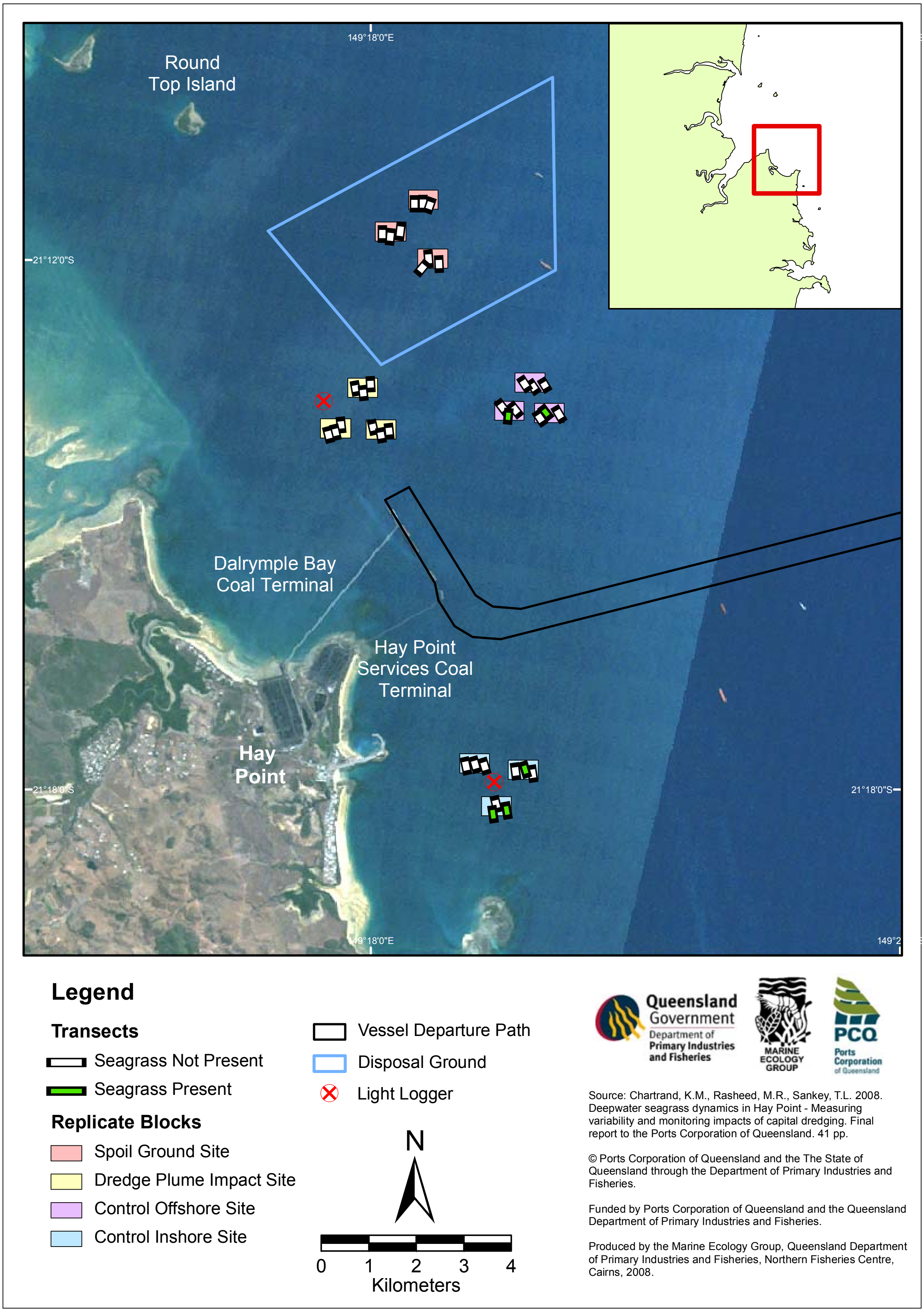
Figure 3. Deepwater seagrass habitats (A) *Halophila spinulosa* / *Halophila decipiens*; (B) *Halophila decipiens*



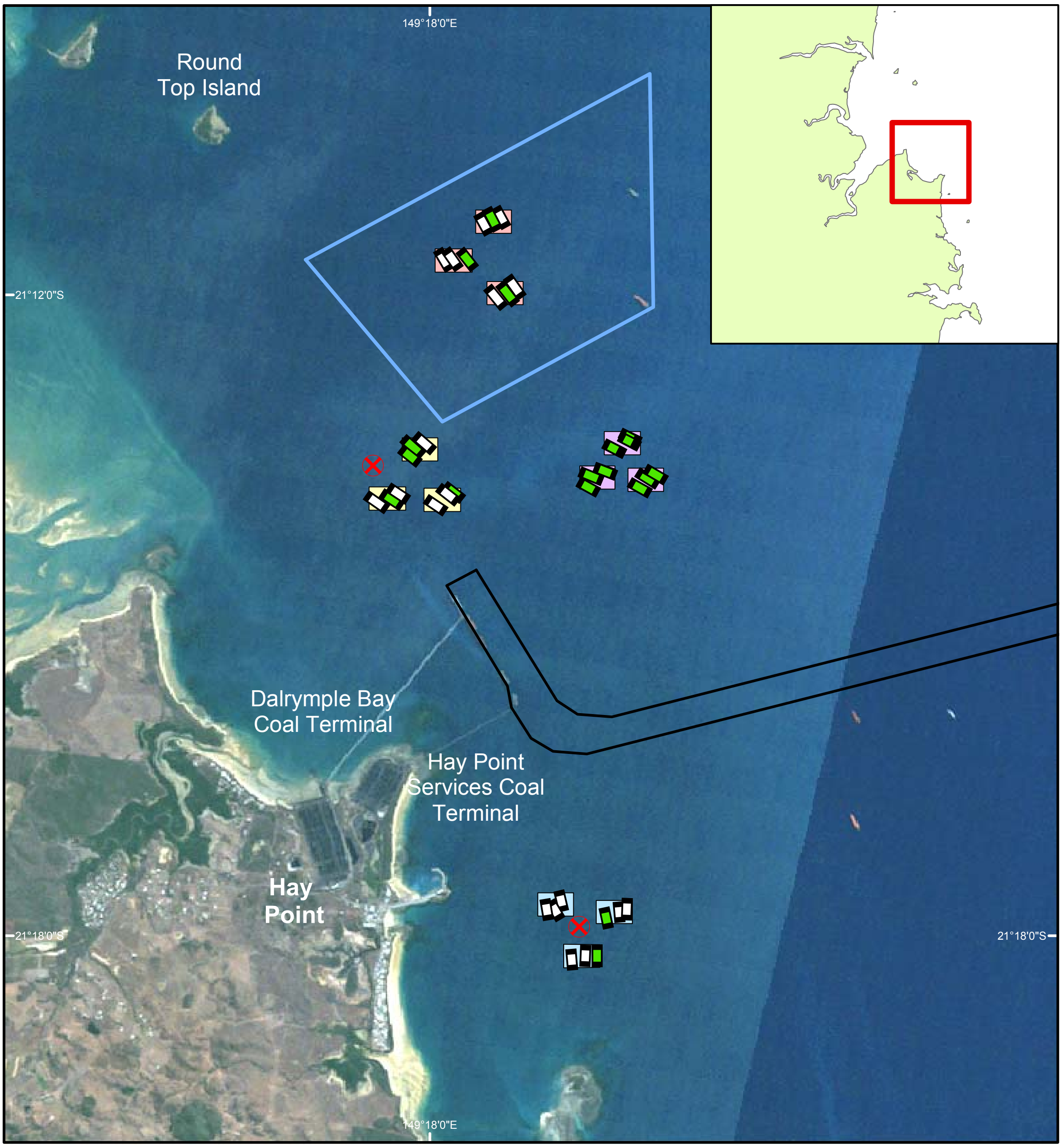
Map 2. Location of sampling sites and seagrass found at Hay Point in December 2005, pre-dredge survey.



Map 3. Location of sampling sites and seagrass present at Hay Point in July 2007, post dredge survey.



Map 4. Location of sampling sites and seagrass present at Hay Point in September 2007, post dredge survey.



Legend

Transects

Seagrass Not Present

Seagrass Present

Replicate Blocks

Spoil Ground Site

Dredge Plume Impact Site

Control Offshore Site

Control Inshore Site

Vessel Departure Path

Disposal Ground

Light Logger

N

0 1 2 3 4

Kilometers

Source: Chartrand, K.M., Rasheed, M.R., Sankey, T.L. 2008. Deepwater seagrass dynamics in Hay Point - Measuring variability and monitoring impacts of capital dredging. Final report to the Ports Corporation of Queensland. 41 pp.

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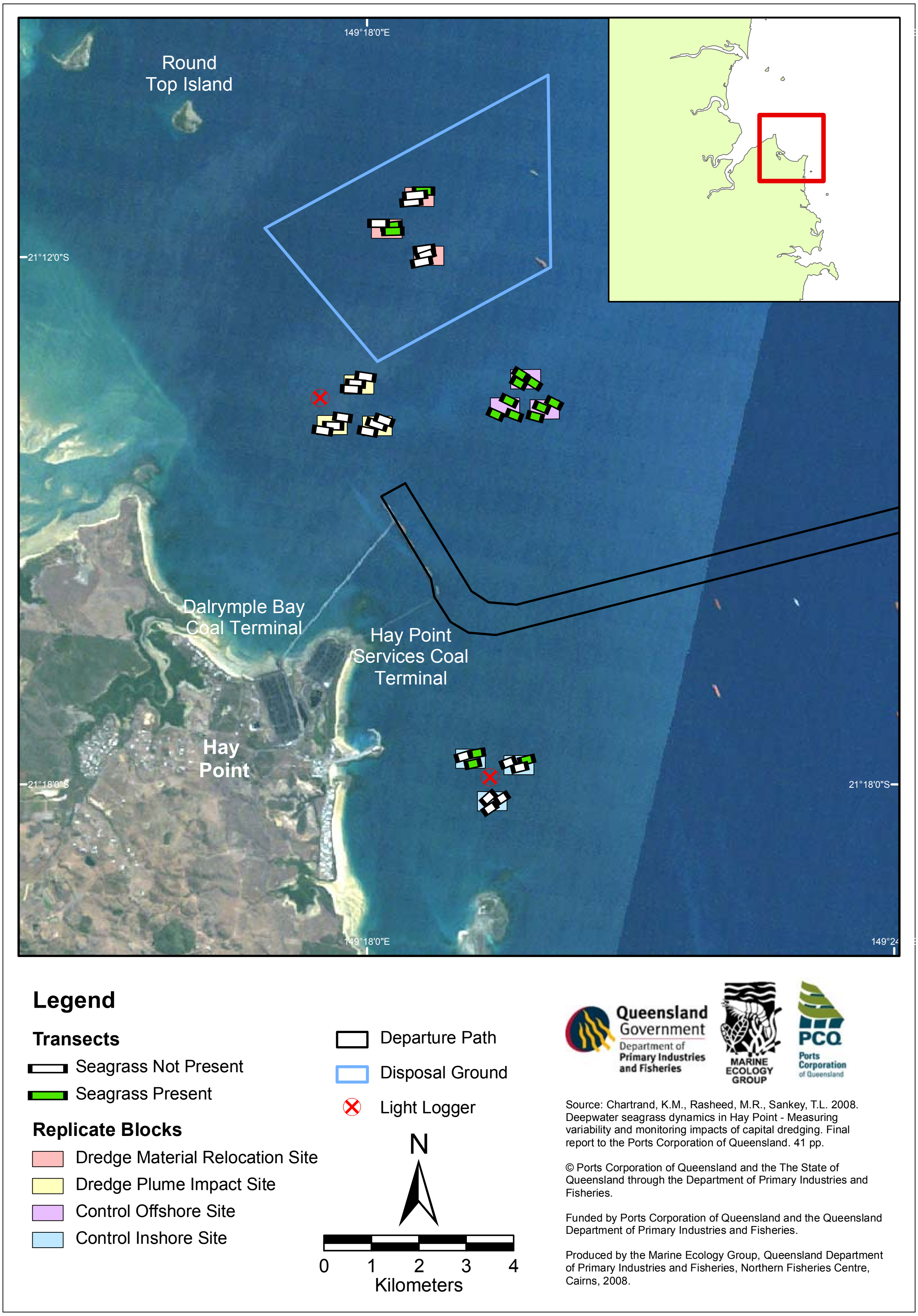
Map 5. Location of sampling sites and seagrass present at Hay Point in November 2007, post-dredge survey.



In the surveys where seagrass was present above ground biomass was typically very low. Above ground biomass was greatest during the December 2005 monitoring in the *H. spinulosa* spoil ground meadow (Table 2). Seagrass biomass was significantly lower during all other sampling events. Following the dredge period, biomass peaked in September 2007 at control offshore sites with 0.066 ± 0.023 g DW m^{-2} of *H. decipiens* followed by the spoil ground, control inshore, and dredge plume site (Table 2). In general, the spoil ground site had the highest biomass during the pre-dredge period (prior to spoil disposal) while the control offshore site had the greatest biomass in the post-dredge period. While seagrass did begin to recover in the post dredge period, biomass remained significantly lower than that recorded prior to dredging, and only one of the two species originally present, *H. decipiens* successfully re-established into the sampling sites.

Table 2. Seagrass mean above-ground biomass (g DW m^{-2}) for monitoring sites at Hay Point, July 2004 – June 2008.

Sampling Date	Presence of Seagrass	Mean Biomass ± SE (g DW m^{-2})			
		Control Offshore	Control Inshore	Dredge Plume	Spoil Ground
July 04	✓	0.3± 0.09	0.4 ± 0.10	1.5 ± 0.16	0.2 ± 0.08
Dec 05	✓	0	0	0	2.67 ± 0.69
Mar 06	×	0	0	0	0
May 06	×	0	0	0	0
Jul 06	×	0	0	0	0
Aug 06	×	0	0	0	0
Sep 06	×	0	0	0	0
Oct 06	×	0	0	0	0
Nov 06	×	0	0	0	0
Jan 07	×	0	0	0	0
Mar 07	×	0	0	0	0
Jul 07	✓	.005 ± .003	.008 ± .004	0	0
Sep 07	✓	.066 ± .023	.005 ± .003	.003 ± .003	.008 ± .004
Nov 07	✓	.023 ± 1.46E^{-10}	.008 ± .004	0	.008 ± .004
Feb 08	×	0	0	0	0
Jun 08	×	0	0	0	0

■ July 2004 survey sites were adjacent to blocks since the block design was not yet established, thus these are only indicative biomass values

Algae

Algal communities occurred in the majority of the survey area (80.4%) during the July 2004 baseline survey enabling algal meadows to be initially mapped (Map 6). Four functional groups were represented during the initial baseline; erect macrophytes, encrusting, erect calcareous, and filamentous algae. Although found widely throughout the survey area, the percentage cover of algae was generally low with more than 70% of algae regions having less than 5% cover. Algal communities were divided into categories based on the percent cover of algae and the community composition. Three density categories were applied in the survey area:

- Low - algae covered less than 5% of the substrate.
- Low/medium - algae covered between 5% and 20% of the substrate.
- Medium - algae covered more than 20% of the substrate.

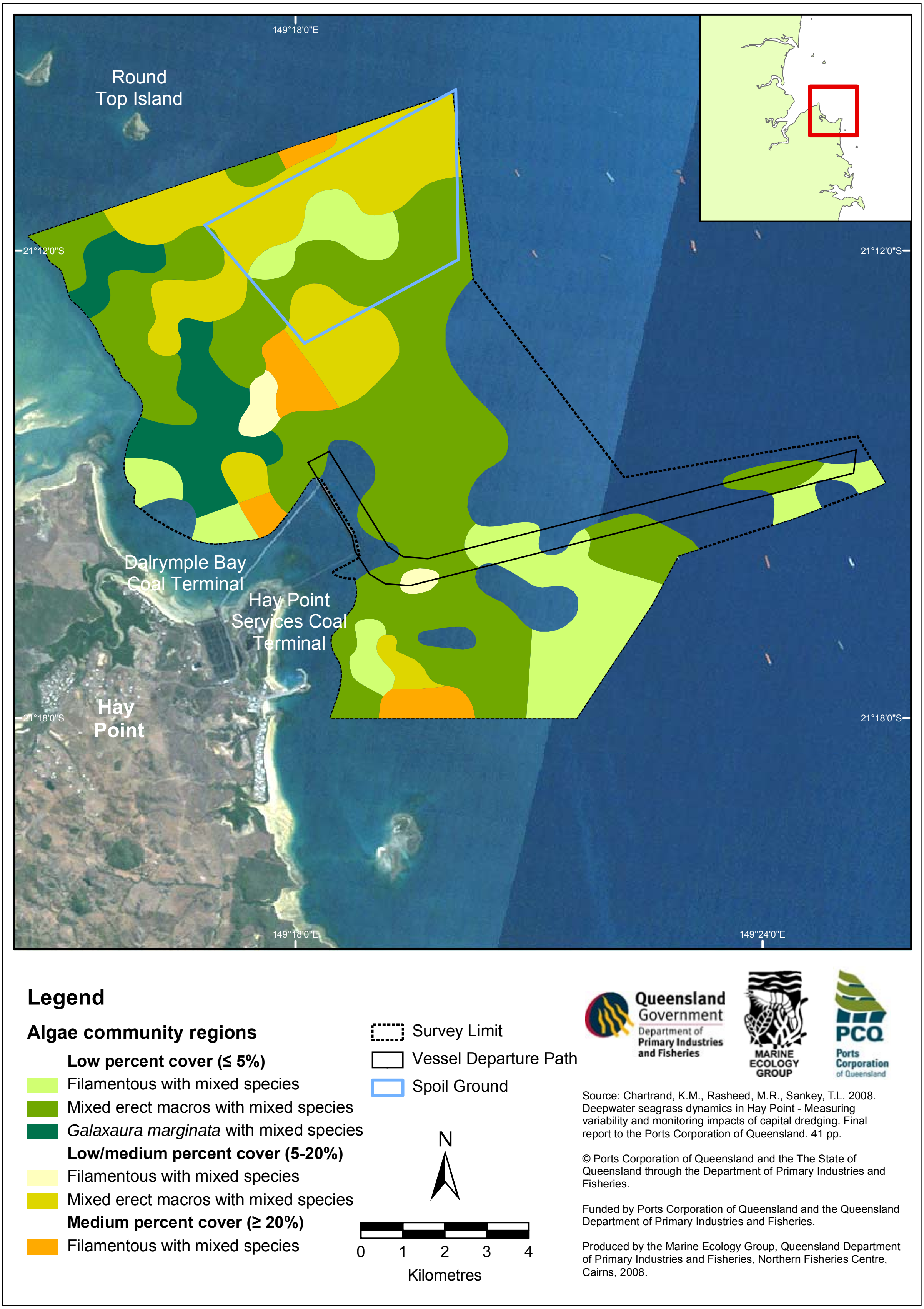
There were six different community types identified within these categories, combining to give twenty-four individual regions in July 2004 (Map 6). The most common groups of algae found were the erect macrophytes and filamentous, which occurred in all three density categories (Map 6). While not all species were identified the most common types of erect macrophytes present were species of *Sargassum*, *Caulerpa*, *Galaxaura, Udotea* and *Hypnea.*

There were six regions in the survey area in July 2004 that had a low/medium percent cover (5-20%) of algae (Map 6). The most common community type was *mixed erect macros with mixed species* (94% of category), with *filamentous with mixed species* making up the other 6% of the category.

Only 3.6% of the total survey area (4 regions) had a medium percent cover (>20%) of algae in July 2004. There was one community type within this category; *filamentous with mixed species*, the major type of algae present being an unidentified filamentous algae. The regions in this category were found adjacent to the main loading wharf, in the proposed spoil disposal ground outside the GBRMP, and adjacent to the northern and southern port limit lines (Map 6).

Following the initial baseline in July 2004, algae only occurred in 13.4% of all transects within the four experimental sites in all successive surveys. When present, the percent cover of algae was generally <1% at all sites, forming a minor component of the marine plant community for the duration of the Port of Hay Point study. The most common groups of algae found were erect macrophytes and erect calcareous. While not all species were identified, the most common types were species of *Sargassum*, *Hypnea*, and *Caulerpa*. During the first dredging month (May 2006), algae was found at both the spoil ground and control inshore sites in small quantities and not detected again until the post-dredge period in September 2007 when it occurred at all sites except the control offshore site. Minimal algae was present during the final three surveys of the area.

Map 6. Algal communities during July 2004 baseline surveys in the Port of Hay Point.



Beam Trawling

A total of 72 beam trawls were conducted within the Port of Hay Point over 8 surveys from March 2006 to February 2008 across three sites: control inshore, dredge plume and spoil ground. The most commonly captured individuals were carridean shrimps, followed by penaeids (prawns), fish and other crustaceans. Molluscs (bivalves, sea hares and gastropods), cephalopods and holothurians were occasionally caught in very low numbers. For this report information for the two commercially and recreationally valuable groups, penaeids and fish is presented.

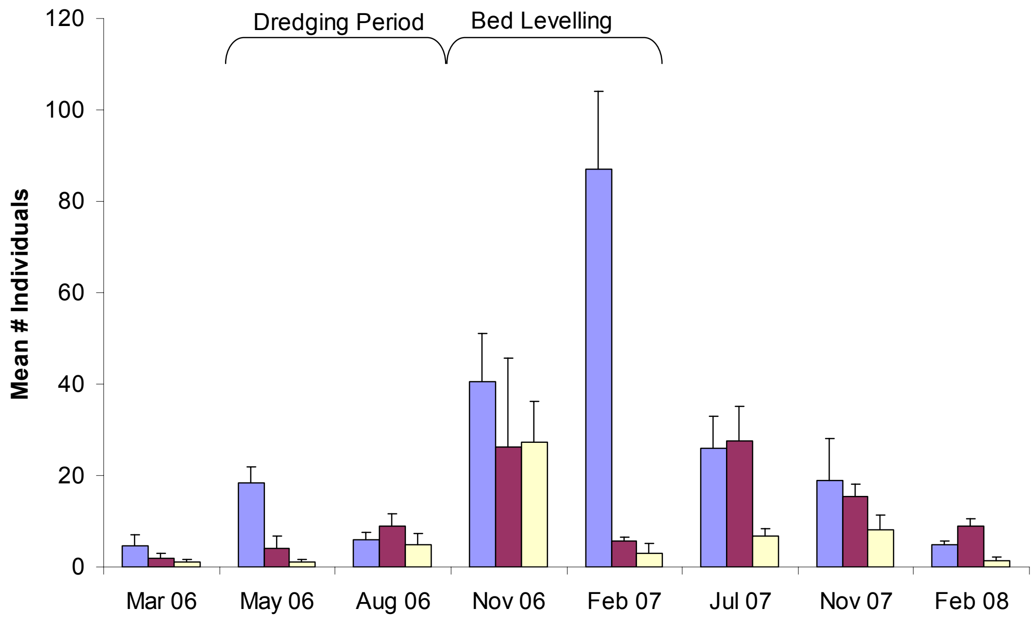
Penaeids (prawns)

A total of 10 species of penaeids from five genera were collected during the course of the trawling surveys, however the majority of these species were commercially unimportant to prawn fisheries (Appendix I). The most frequently caught species over the course of the survey was *Trachypenaeus anchoralis* (the Northern Rough Prawn) which is an incidental component of the commercial fishery along the Queensland coast.

The mean number of penaeids captured across all sites (with the exception of the control inshore site in August 2006) followed an increasing trend during the dredging and bed levelling period (Fig. 4). Generally, higher mean densities of penaeids were recorded in the control inshore site compared with the dredge plume and spoil ground sites in each sampling month during the dredging activities with the spoil ground site having the lowest mean density of penaeids for all trawling surveys (Fig. 4, Appendix Ib). Penaeid abundance peaked in February 2007 at the control inshore site with 87.0 ± 17.1 individuals. During the final trawling survey, mean number of penaeids were similar to densities seen during the pre dredge survey in March 2006 (Fig. 4).

The mean dry weights of penaeids across all sites revealed no obvious trends (Appendix II). While most penaeids captured were juvenile, large adults were infrequently captured and caused bias in the mean dry weight of penaeids across the survey. Penaeids were overall generally small, with mean average carapace lengths ranging from 3.86 ± 0.04 mm to 45.48 ± 1.59 mm (Appendix II).

A.



B.

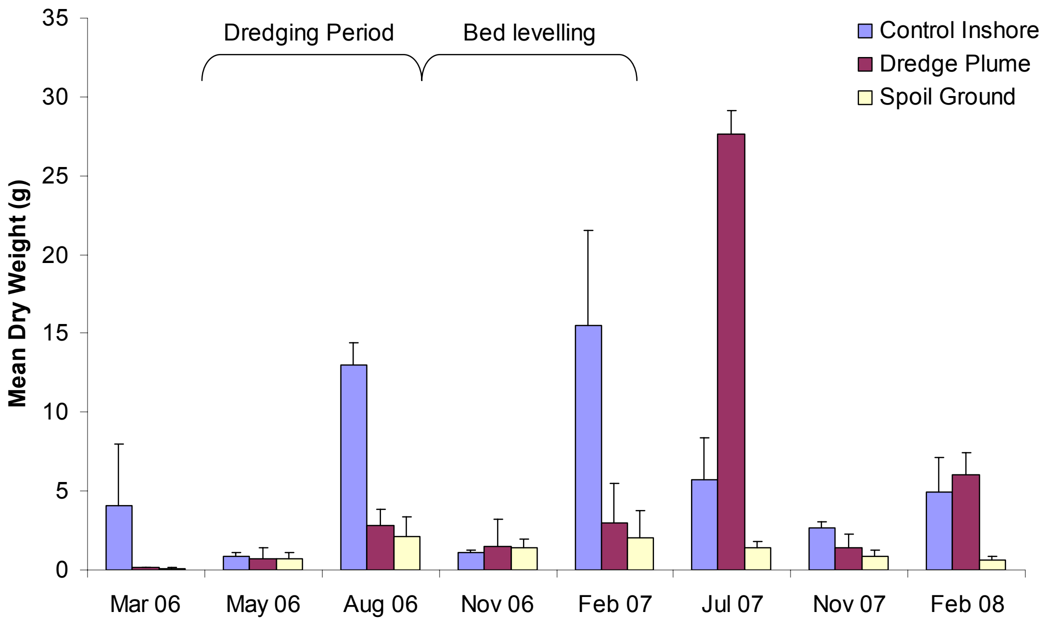


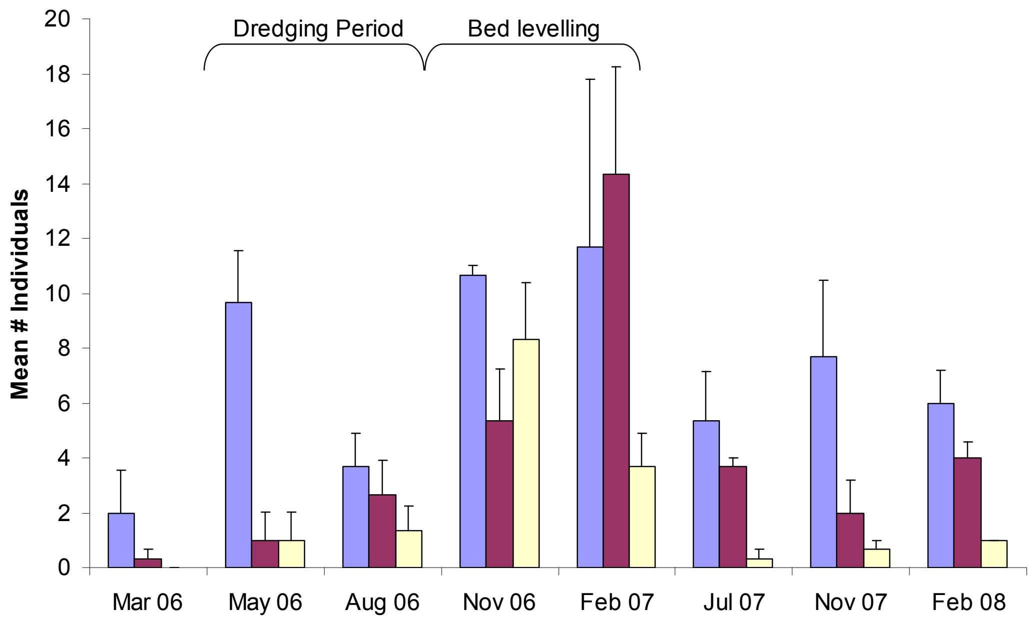
Figure 4. **A)** Mean number of penaeids ± SE at three survey sites (control inshore, dredge plume and spoil ground) surveyed between May 2006 and February 2008. **B)** Mean dry weight of penaeids ± SE at three survey sites (control inshore, dredge plume and spoil ground) surveyed between May 2006 and February 2008.

Fish

A total of 20 families and 32 species of fish were identified from beam trawl catches across all sites from March 2006 to February 2008 (Appendix III). Fish from the Apogonidae family (tongue-sole fish) were the most commonly caught, however the most common species was *Cynoglossus maculipinnis* (cardinal fish) of the family Cynoglossidae (Appendix III). The control inshore site had consistently more fish present than the dredge plume and spoil ground sites with the exception of similar densities between the spoil ground and control inshore sites in February 2007 (Fig. 5a). There was an increasing trend in the mean number of fish caught at all sites from the pre-dredge survey until the end of the bed levelling period followed by a decline in fish abundance during the post-dredge trawling events (Figure 5a).

The mean dry weight of fish caught in the spoil ground was less than both the dredge plume and control inshore sites across all surveys (Fig. 5b) with no fish caught in the spoil ground during the pre-dredge survey (March 2006). The mean dry weight of fish caught at all sites during the pre dredge survey in March 2006 was less than the mean dry weights for all other surveys (Fig. 5b).

A.



B.

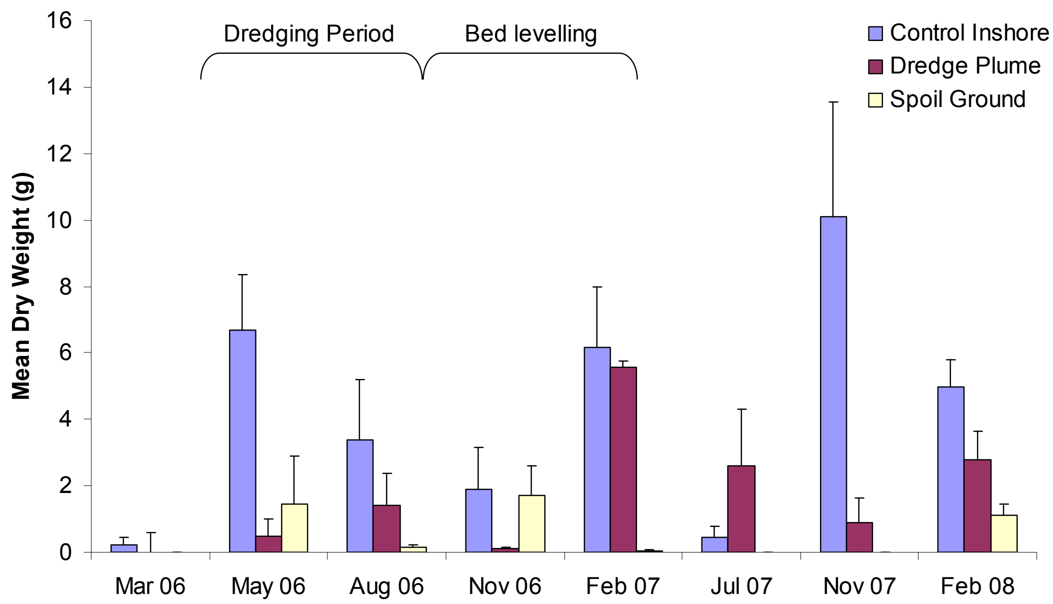


Figure 5. **A)** Mean number of fish ± SE at the three survey sites surveyed between May 2006 and February 2008. **B)** Mean dry weight fish ± SE at the three survey sites surveyed between May 2006 and February 2008.

Benthic Macro Invertebrates

Benthic macro invertebrates (BMI) were found in low densities at all sites and comprised a diverse suite of taxa (Appendix IV & V). For the purposes of this report the BMI were split into two groups: those capable of moving or “motile” organisms; and those anchored to the bottom or “sessile” organisms. Although not invertebrates, any fish captured were included with the motile BMI data.

The mean number (density) of sessile and motile BMI generally increased from May 2006 through until November 2006 for all sites combined after which motile densities generally declined for the remainder of the study while sessile densities further increased until July 2007 and then also declined. Mean densities of motile individuals were higher than sessile BMI. Density of motile BMI peaked in November 2006 with 22.2 ± 3.1 individuals per transect, and in July 2007 for sessile with 23.9 ± 4.2 individuals per transect (Fig. 6).

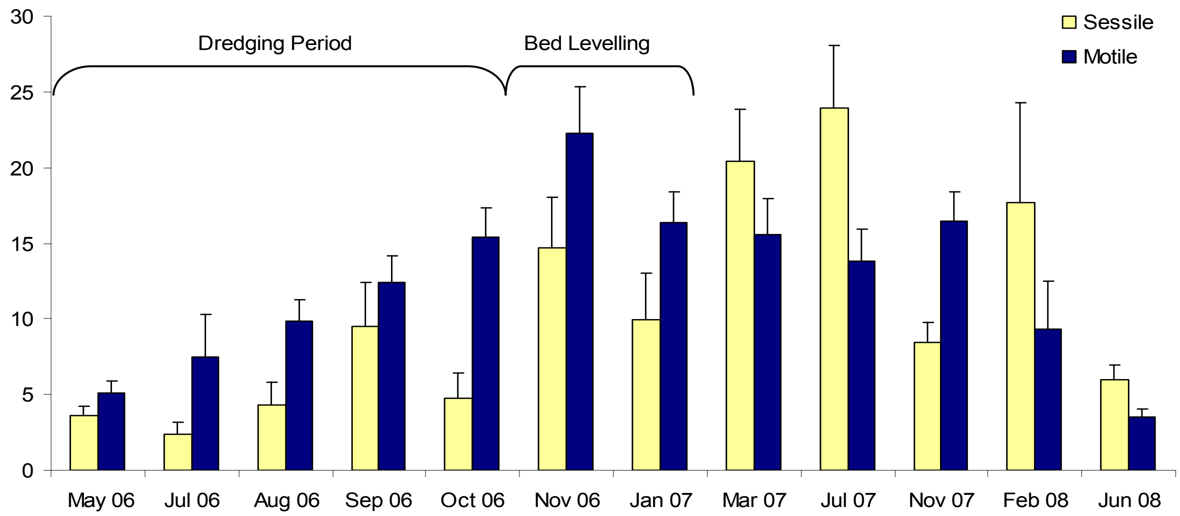


Figure 6. Mean number of sessile and motile BMI ± standard error (SE) per transect over the survey period, May 2006 - June 2008 (all sites combined)

For all surveys combined the mean density of sessile BMI per transect was highest in the control offshore site (16.4 ± 1.8 per transect), followed by the three impacted sites (12.0 ± 2.6 in the spoil ground, 9.0 ± 1.3 at the control inshore site and 4.4 ± 1.1 in the dredge plume). The density of motile BMI was similar between control and impacted sites.

Sessile benthic macro invertebrates (BMI)

From May 2006 to June 2008, 14 taxonomic groups of sessile BMI were identified across all survey sites with encrusting bryozoans being most abundant (Fig. 8, Appendix IV). The Control Inshore, Dredge Plume and Spoil Ground sites were characterised by low densities of sessile BMI (< 5 per transect) during dredging months (Fig. 7). Conversely, the Control Offshore site had consistently higher numbers of sessile BMI between August and November 2006, with a peak of 33.7 ± 2.4 individuals per 60 m^2 (transect) in September 2006. The number of sessile BMI peaked in all other sites after dredging and bed levelling ceased (July in the Spoil Ground and Control Inshore site with 30.1 ± 3.5 and 19.0 ± 1.9 individuals per transect respectively and January in the Dredge Plume with 16.4 ± 3.6 individuals per transect).

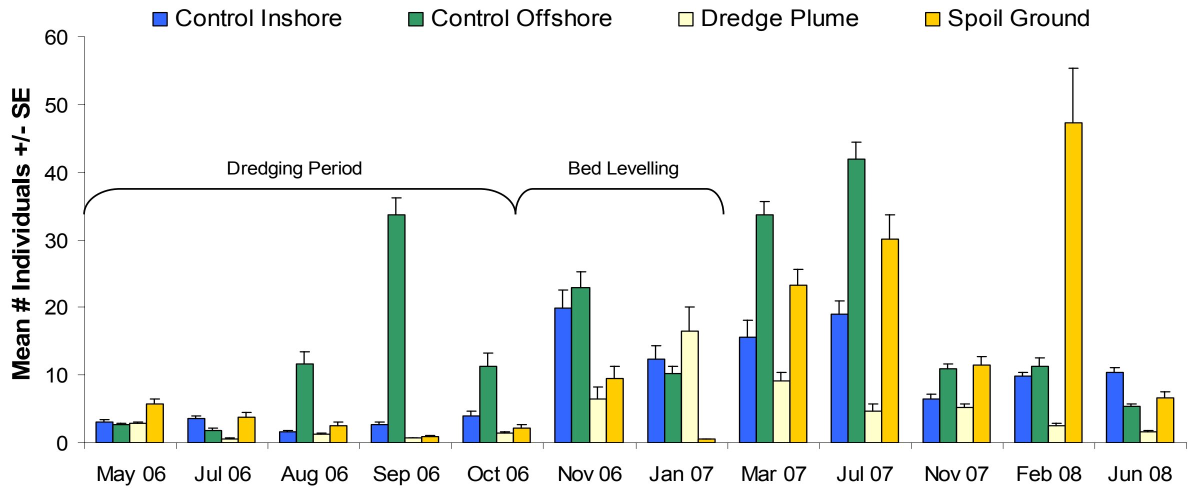


Figure 7. Mean number of sessile BMI ± standard error (SE) at four sites (Control Inshore, Control Offshore, Dredge Plume and Spoil Ground) surveyed between May 2006 and June 2008.

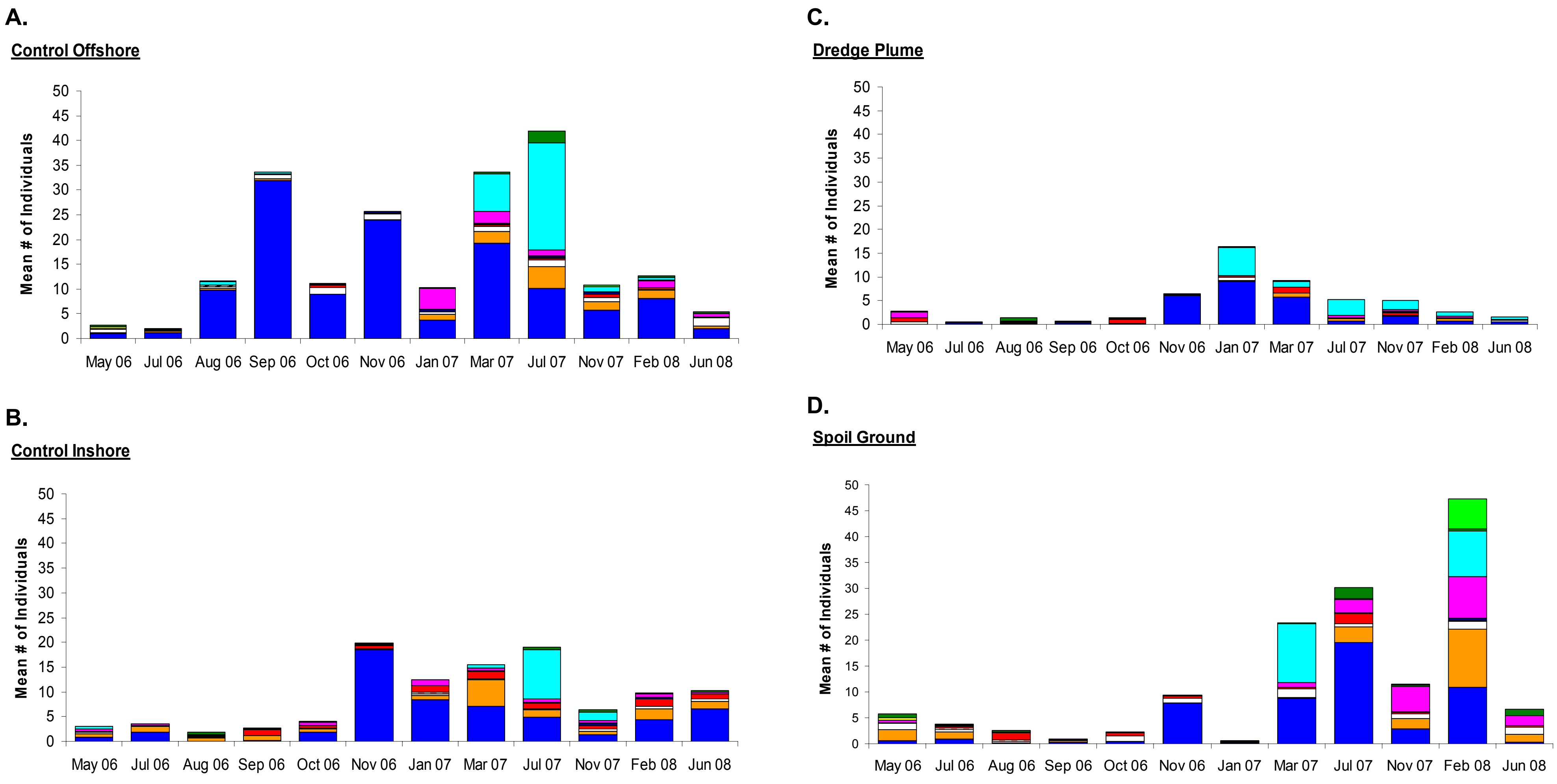
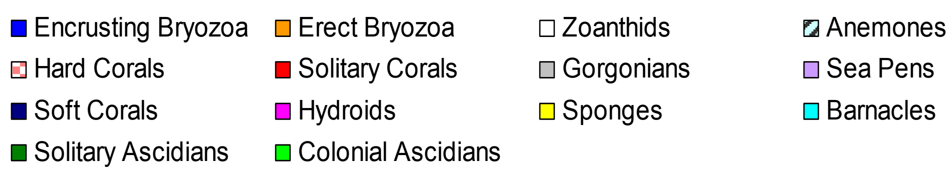


Figure 8. Mean number of sessile BMI by taxonomic group at the four survey sites **A)** Control Inshore, **B)** Control Offshore, **C)** Dredge Plume and **D)** Spoil Ground surveyed between May 2006 and June 2008.



Motile benthic macro invertebrates (BMI)

There were 18 motile taxonomic BMI and fish groups found, with the most abundant being gastropod molluscs, followed by bivalves, brachyurans and echinoids (Appendix V). There was a gradual increase in motile BMI (and fish) density during dredging months (May to October) with the highest densities at most sites recorded during the November 2006 survey (Fig. 9). The control inshore site was found to have the highest average density of motile BMI (16.4 ± 1.5 per 60 m^2). The spoil ground site had consistently lower densities of motile BMI during dredging months, with a slight increase seen post dredging.

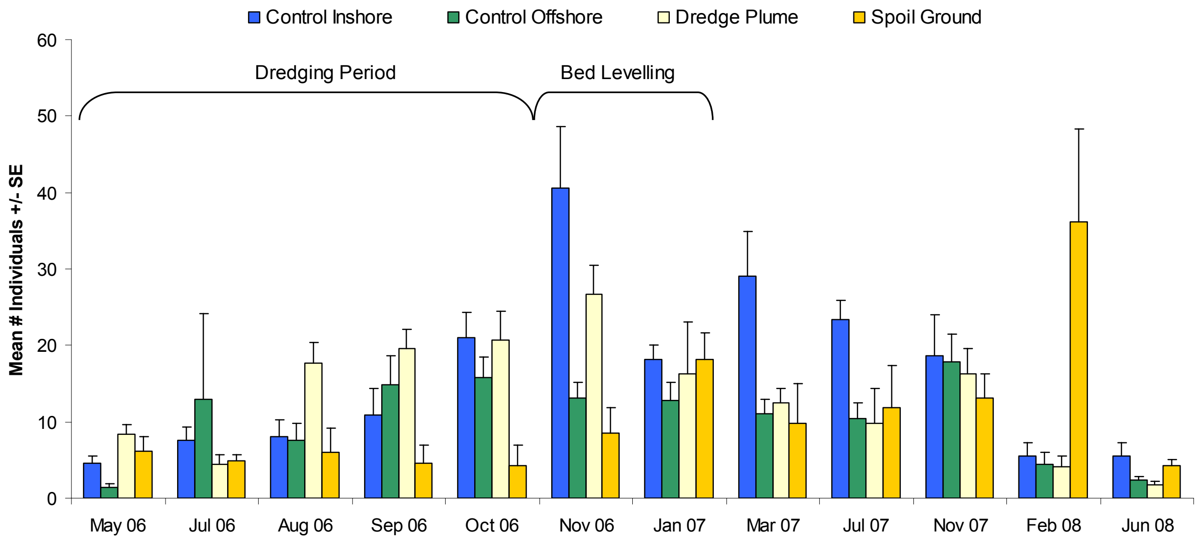


Figure 9. Mean number of motile individuals ± standard error (SE) at sites (Control Inshore, Control Offshore, Dredge Plume and Spoil Ground) surveyed between May 2006 and June 2008.

DISCUSSION

The Port of Hay Point seagrass monitoring program found that the capital works project which occurred from May 2006 to February 2007 had an impact on seagrass meadows and benthic macro invertebrate communities. However seagrass was able to re-establish and begin to recover 9 months after dredging activity ceased (6 months post bed levelling). While seagrass did begin to recover, biomass remained significantly lower than that recorded prior to dredging, and only one of the two species originally present, *H. decipiens* successfully re-established into the sampling sites during the timeframe of the study.

The rate of recovery following a large disturbance event such as dredging depends on several factors: 1) the magnitude of the disturbance 2) the species of seagrass affected 3) the physical and environmental conditions of the affected area and 4) the existence of seed banks that may aid recovery (Carruthers 2002). In Hay Point, the magnitude of disturbance was large and prolonged, there were challenging environmental conditions for seagrass growth (i.e. naturally low light and high wind and wave energy) but the species present were likely to be highly fecund, capable of maintaining a seed bank and of rapid recovery post disturbance.

Throughout the capital dredging project, levels of turbidity were often much higher than original modelling had predicted (GHD 2006) and the extent of the plume regularly encompassed all of the established monitoring sites. This was particularly the case during times of rough seas, high winds and spring tides. As a result, all four of our sites including the two “control” sites were regularly impacted by a turbid plume associated with the dredging. The control inshore site closest to Victor Islet was particularly heavily impacted by high turbidity and sedimentation from dredging and re-suspension. This effectively changed the design of the program to having three impact sites (1 dredge material relocation and 2 plume sites) and one “limited” reference site (control offshore) that received a reduced plume impact.

The constant and prolonged turbidity plume was likely to have created unsuitable conditions for seagrass, impeding normal recruitment back into the survey area during the dredging period. Results from light loggers deployed at some of the sites indicate that no light was reaching the bottom for extended periods of time. It was only following the cessation of dredging in July 2007 that seagrass returned to the study area. Seagrass had recruited to both the shallowest of the four sites (control inshore) and to the site least impacted by the plume during dredging (control offshore). Both sites were likely to have the most rapid return to favourable light for seagrass to re-establish.

The most frequently occurring and abundant seagrass in the Hay Point survey area was *Halophila decipiens* which formed waxing and waning sparse meadows over an area of approximately 4,500 ha. *Halophila decipiens* is adapted to lower light levels and turbid water conditions (Kenworthy *et al*. 1989; Birch & Birch 1984), explaining its presence in this deepwater coastal habitat. The species has morphological and structural features that enable it to maximise its light harvesting capacity in a low light environment giving it a low minimum quantum requirement for growth (Josselyn *et al*. 1986, Ralph *et al.* 2007). However, extreme and chronic low light is also the major limiting factor for a *H. decipiens* deepwater meadow. Studies have found that complete shading — such as a prolonged dredging event — can stimulate changes in the architecture and growth characteristics within 9-14 days and will cause rapid decline in structurally small species like *H. decipiens* after approximately 30-40 days (Longstaff *et al*. 1999, Ralph *et al*. 2007). The prolonged turbidity event around Hay

Point resulted in such low light conditions that the meadow was unable to undergo normal seasonal recruitment or sustain its presence. *H. decipiens* is classically described as a pioneer species, dominating a newly established meadow or following a disturbance event. It tends to thrive in environments where disturbances are frequent and/or environmental conditions are regularly shifting, making conditions unsuitable for maintaining the larger, long-lived seagrass species (Josselyn *et al*. 1986, Kenworthy *et al*. 1989, Preen *et al.* 1995, Kenworthy 2000). Such characteristics of *H. decipiens* may explain the meadow dynamics around Hay Point and the effects of dredging and other disturbance events.

Baseline surveys in the pre-dredge period confirmed that resident meadows are also naturally highly variable. In July 2004, seagrass meadows covered the majority of the survey area (Map 1) but by December 2005 only a small *H. spinulosa* meadow remained (Map 2) and by March 2006 no seagrass was recorded in the region. During the recovery period, *H. decipiens* returned from July until November 2007, after which seagrass was absent. These results suggest peak abundance and distribution depart from the normal seasonal cycle that occurs for shallower coastal seagrass meadows in the region that typically reach their maximum abundance in late spring and summer (eg. McKenzie 1994, Rasheed 1999). Instead, deepwater meadow growth around Hay Point is likely to be shaped by seasonal factors including wind patterns, rainfall, high river flow from proximal catchments, and ensuing chronic turbidity. In particular, reduced wind from July to November was likely to have enhanced the deepwater light environment through a drop in turbidity promoting seagrass expansion prior to seagrass declines in December/January. The increase in wind from February to early winter may hinder growth until the light environment again improves in late winter. The large turbidity plume created during the 2006/2007 seasonal cycle disrupted this typical pattern with resident seagrass meadows unable to recruit back into the area during the expected seasonal peak from July to November 2006. A longer study would be required to confirm these novel seasonal patterns.

Germination of seed is considered to be a crucial life history stage for recovery of a seagrass meadow following a major disturbance (Preen *et al*. 1995, Kenworthy 2000, Hammerstrom *et al*. 2006). *Halophila decipiens* is capable of producing relatively long lived seeds that can lay dormant in the sediment for at least two years and can rapidly colonise when conditions are favourable (McMillan 1991, Hammerstrom and Kenworthy 2003, Hammerstrom *et al*. 2006). Seed banks were not measured over the survey period, however other studies have found the seed reserve of *H. decipiens* (up to 3400 seeds m^{-2}) remains constant even when biomass widely varies (Hammerstrom *et al.* 2006). Its high fecundity and rapid rate of rhizome growth enables it to colonise disturbed areas readily, such as those that may have been caused by the dredging (Preen *et al*. 1995; Kenworthy *et al.* 1989).

Local and regional climate conditions were not likely to explain the observed lack of seagrass recruitment during the dredging campaign. These conditions were within the normal range of the last 50 year climate record for temperature and rainfall data for this region and period (Fig. 7 a,b). The only time points outside of these means were during February 2007 and 2008, when increased rainfall would have been associated with turbid runoff, a typical seasonal event for tropical Queensland. Maximum wind speed was consistently below the mean wind speed record for this area which would suggest a below normal impact on light conditions due to wind-induced turbidity (Fig. 7c).

Seagrass meadows in Queensland are known to be important nursery grounds for commercial prawn and fish species. Coastal seagrass meadows in Cairns Harbour have been estimated to be worth \$A1.2 million $year^{-1}$ to the tiger prawn fishery (Watson 1993). The seagrass meadows of Hay Point however, do not share the same level of physical complexity that makes many coastal meadows such an ideal habitat and in fact, were devoid of any above ground structure for much of the year. While there were some commercially important prawns and fish collected, their abundance was extremely low compared to nearby shallow inshore seagrass habitats where beam trawling has been conducted (Tables 3 & 4, Coles *et al*. 2002). The relatively low abundances of juvenile prawns and fish may be partially explained by the absence or extremely low cover of seagrass during the beam trawling sampling events. There is a strong association of juvenile prawns with shallower coastal seagrass meadows (Lee Long *et al.* 1993) and higher prawn abundances may be found at Hay Point during periods of higher seagrass cover. However, even if seagrasses return, the habitat in the deepwater areas of Hay Point is substantially different to the shallow nursery meadows that have been examined in the past (see Coles *et al.* 2002; Table 3). These low density deeper water meadows may not offer the same nursery habitat quality and they are unlikely to be as productive as denser inshore meadows. The Hay Point area is also more likely to be habitat for adult penaeids than juveniles, as they are known to move to open offshore habitats. Large adult tiger prawns were captured at some sites, however not at levels valuable to the commercial prawn fishery (although sampling equipment used may not have effectively sampled for adult prawns). There was a substantial increase in the numbers of penaeids and fish captured during and immediately following, the completion of capital dredging, compared with the pre-dredge trawl survey (March 2006). This increase was most likely related to seasonal or intra-annual differences in recruitment of the species rather than to dredging. However if further beam trawl surveys were conducted finding higher abundances, it would indicate a link to dredge related impacts. In general, the value of the deepwater seagrass meadows at Hay Point to fisheries is relatively low compared to shallow coastal meadows where denser seagrass supports economically valuable fishery species.

Fish abundances, determined during beam trawl surveys, did not appear to be impacted by the dredging works but rather followed typical seasonal patterns for coastal inshore species in this region. Fish were most abundant during the summer period, independent of the dredging or bed levelling during this time. The lowest biomass at all sites was during the pre-dredge survey, further indicating that the capital works project did not have a large impact on this motile group. Most of the species collected were not of direct commercial or recreational importance, but the diversity and number of fish was likely to provide the basis for a productive ecosystem and food for larger, fast-swimming and commercially important fish that are not usually caught in beam-trawls.

Table 3. 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 Hay Point (2006 & 2007 respectively) and Upstart Bay, Newry Bay, and Ince Bay (1999). *Adopted from Coles et al. 2002*

Location	Meadow	May			October *		
		Count (n)	Biomass (gDW)	Carapace Length	Count (n)	Biomass (gDW)	Carapace Length
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

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

Table 4. Mean number of commercially important penaeid prawns captured per 100m trawl at Hay Point (2006 - 2007) and Upstart Bay, Newry Bay, and Ince Bay (1999). *Adopted from Coles et al. 2002*

Penaeid species	Location			
	Hay Point	Newry Bay	Upstart Bay	Ince Bay
Metapenaeus bennettae	-	3.81	11.38	0.63
Metapenaeus eboracensis	-	18.19	13.06	-
Metapenaeus endeavouri	-	23.88	10.06	0.38
Metapenaeus ensis	0.02	-	4.19	-
Penaeus semisulcatus	0.02	-	0.06	-
Penaeus esculentus	0.07	13.63	32.13	0.25
Penaeus latisulcatus	-	3.25	6.25	1.00
Penaeus longistylus	-	-	4.06	0.13

Despite not having a large economic value for fisheries, the low biomass Halophila meadows that dominated the survey area are the type generally preferred by dugong as a food source due to their nutritionally superior value (Lanyon 1991; Preen 1995, de Iongh *et al.* 1997). Hay Point is close to important dugong feeding areas with Newry dugong protection area to the north and Ince Bay dugong protection area to the south (Coles *et al.* 2002). The Hay Point seagrass meadows may provide a food resource for dugong moving between these locations.

The benthic macro invertebrate (BMI) community was sampled as a “by-product” of the marine plant sampling and while measuring changes to the BMI community was not part of the original objectives, the information collected has provided some interesting results. Analysis has found that numbers of sessile (anchored to the bottom) BMI were higher in the least impacted offshore control site until the cessation of dredging when sessile BMI at other sites showed the beginnings of recovery. However, numbers of sessile individuals were consistently lower in the spoil ground site than other sites even three months after the cessation of dredging. It was likely that sessile individuals were affected by burial from deposit of spoil, clogging of the feeding and respiratory cilia from sedimentation, and by a lack of suitable habitat for recruitment (Erftemeijer & Robin Lewis, 2006 and Schaffelke *et al*, 2005). However, the increase in sessile invertebrates in the spoil ground after all capital works were completed suggests the input of dredge material in the spoil ground area may have provided a fresh source of nutrients and organisms to the site (Fig. 7). Some benthic invertebrates appear to have been able to exploit these inputs during the post-dredge phase to increase biomass and community complexity. Motile BMI did not appear to be affected in the same way and dominated the three sites that were most impacted by dredging. Motile BMI were likely to be able to cope much better with the impacts of dredging and spoil deposition than BMI not capable of movement.

Monitoring in the port of Hay Point in conjunction with similar monitoring programs established in other Queensland port areas has enhanced our understanding of seagrass dynamics enabling more effective management of valuable marine habitat and marine port environments. Information collected assists in planning and managing future developments in coastal areas, particularly new and expanding marine port projects occurring throughout the state. While this report completes the current seagrass investigations at Hay Point there may be advantages in re-assessing some of the sites in the future. Seagrasses had not recovered to the levels seen prior to dredging during the timeframe of the study. Further monitoring would help to confirm the seasonal dynamics observed in the program as well as establish the capacity of the meadow to fully recover from the dredging impacts.

The Port of Hay Point seagrass meadows are temporally and spatially highly dynamic and began to recover relatively quickly following a large disturbance event. Seagrass dynamics and resilience to disturbance in Hay Point should not be considered the case for all seagrass meadows since local physical variables and pressures will inherently shift the outcome in a particular region. It is critical to note that denser coastal seagrass meadows consisting of larger growing species would be unlikely to display the same level of resilience to a similar dredging impact. The Hay Point project highlights the importance of quality baseline information and an understanding of the nature of the seagrass meadow in order to determine its state following both human induced and natural disturbances.

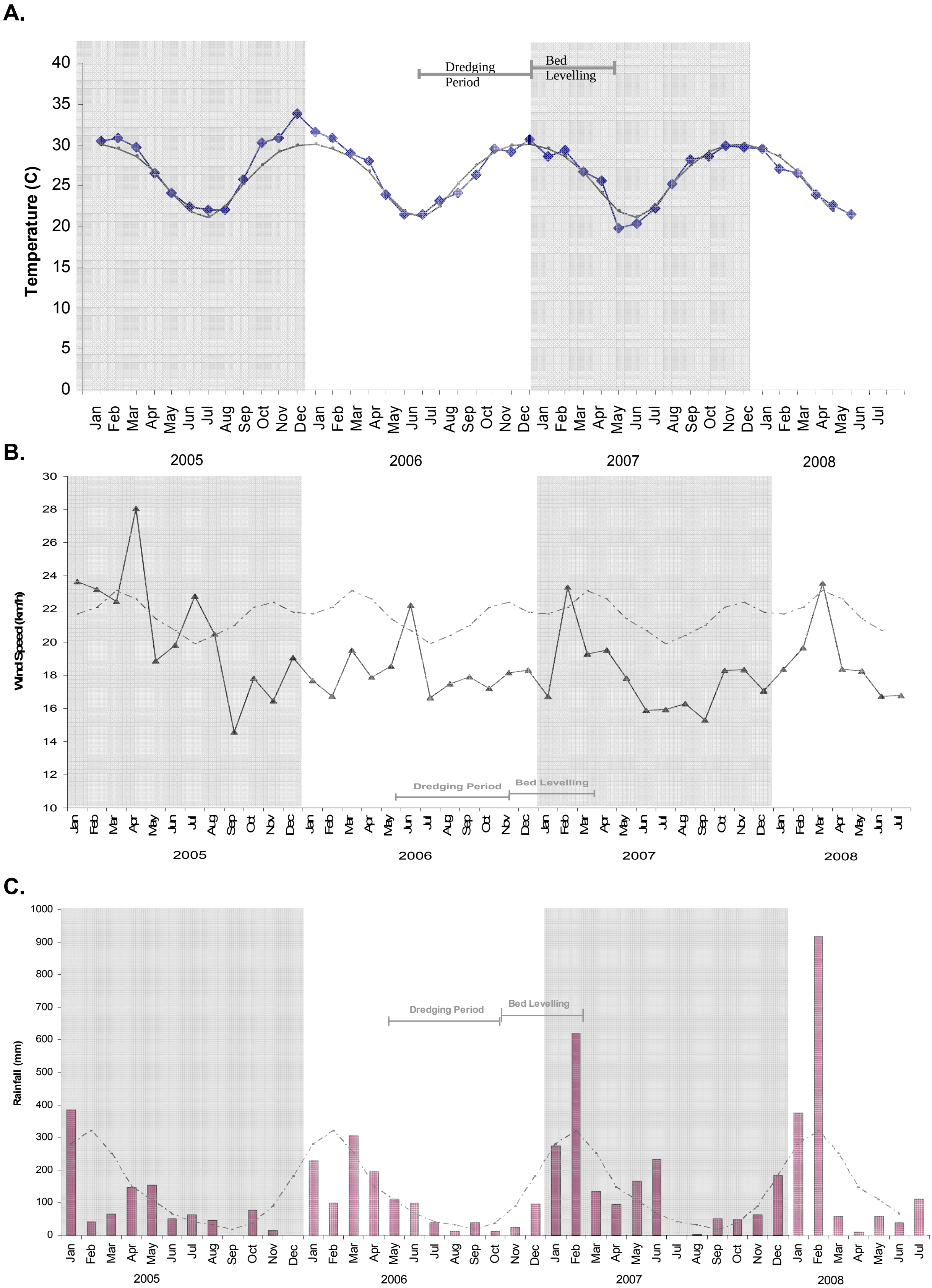


Figure 7. **A.** Mean daily air temperature (ºC) in Mackay over a 24 hour period, 2004-2008 **B.** Average wind speed in Mackay at 3pm **C.** Total daily rainfall (mm) recorded in Mackay over a 24 hour period, 2004-2008. Dotted lines represent the 50 year average for monthly rainfall and maximum air temperature. (Source: Bureau of Meteorology)

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APPENDIX

Appendix Ia: 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)
			Mar/Apr 2006	May 2006	August 2006	November 2006			
Penaeidae	*Trachypenaeus anchoralis*	Northern Rough Prawn	10.17 ± 0.35	9.33 ± 0.16	-	11.65 ± 0.03	Mar/Apr May Aug Nov	9 23 0 122	154
Penaeidae	*Trachypenaeus fulvus*	Brown Rough Prawn	13.64 ± 0.00	-	16.51 ± 0.32	13.41 ± 0.7	Mar/Apr May Aug Nov	1 0 14 2	17
Penaeidae	*Parapenaeopsis cornuta*	Coral Prawn	-	22.76 ± 0.38	23.30 ± 0.00	17.14 ± 2.18	Mar/Apr May Aug Nov	0 3 1 2	6
Penaeidae	*Penaeus semisulcatus*	Grooved Tiger Prawn	-	-	39.44 ± 0.00	-	Mar/Apr May Aug Nov	0 0 1 0	1
Penaeidae	*Penaeus esculentus*	Brown Tiger Prawn	33.82 ± 0.00	-	38.28 ± 0.82	-	Mar/Apr May Aug Nov	1 0 2 0	3
Penaeidae	*Metapenaeus ensis*	Endeavour Prawn	-	-	30.16 ± 0.00	-	Mar/Apr May Aug Nov	0 0 1 0	1
Penaeidae	*Metapenaeopsis* sp.		7.95 ± 0.30	8.10 ± 0.10	11.02 ± 0.13	8.81 ± 0.04	Mar/Apr May Aug Nov	13 38 41 92	184
Penaeidae	*Trachypenaeus* sp.		-	6.67 ± 0.50	-	8.38 ± 0.14	Mar/Apr May Aug Nov	0 5 0 19	24
Penaeidae	*Penaeid* sp.		-	3.86 ± 0.037	-	4.88 ± 0.05	Mar/Apr May Aug Nov	0 5 0 42	47

Appendix Ib. Mean carapace length (mm) ± standard error of penaeid species in February, July and November, 2007 and February 2008 across all sites and total monthly count for each species.

			Mean Carapace Length (mm)				Monthly Count and Total Numbers		
Family	**Species**	**Common Name**	**Feb 2007**	**Jul 2007**	**Nov 2007**	**Feb 2008**	**Monthly Count**		**Total N**
Penaeidae	*Trachypenaeus anchoralis*	Northern Rough Prawn	13.16 ± 0.22	11.21 ± 1.04	17.81 ± 3.48	22.48 ± 1.44	Feb 2007 Jul 2007 Nov 2007 Feb 2008	176 26 6 13	221
Penaeidae	*Trachypenaeus fulvus*	Brown Rough Prawn	21.60 ± 1.46	-	-	15.82 ± 1.36	Feb 2007 Jul 2007 Nov 2007 Feb 2008	11 - - 3	14
Penaeidae	*Parapenaeopsis cornuta*	Coral Prawn	22.12 ± 1.74	27.92 ± 0.00	28.91 ± 1.75	-	Feb 2007 Jul 2007 Nov 2007 Feb 2008	2 1 - 6	9
Penaeidae	*Penaeus semisulcatus*	Grooved Tiger Prawn	23.21 ± 0.00	-	-	-	Feb 2007 Jul 2007 Nov 2007 Feb 2008	1 - - -	1
Penaeidae	*Penaeus esculentus*	Brown Tiger Prawn	36.19 ± 1.30	35.94 ± 22.91	45.48 ± 1.59	-	Feb 2007 Jul 2007 Nov 2007 Feb 2008	4 2 - 2	8
Penaeidae	*Metapenaeus ensis*	Endeavour Prawn	-	-	-	-	Feb 2007 Jul 2007 Nov 2007 Feb 2008	- - - -	0
Penaeidae	Metapenaeopsis sp.		6.21 ± 0.31	14.69 ± 0.56	13.16 ± 0.64	15.66 ± 0.75	Feb 2007 Jul 2007 Nov 2007 Feb 2008	17 153 120 27	317
Penaeidae	Trachypenaeus sp.		12.97 ± 2.05	11.00 ± 0.00	-	-	Feb 2007 Jul 2007 Nov 2007 Feb 2008	2 1 - -	3
Penaeidae	Penaeid sp.		5.00 ± 0.52	-	8.15 ± 0.65	-	Feb 2007 Jul 2007 Nov 2007 Feb 2008	37 - 2 -	39

Appendix Ib (continued).

			Mean Carapace Length (mm)				Monthly Count and Total Numbers		
Family	Species	Common Name	Feb 2007	July 2007	Nov 2007	Feb 2008	Monthly Count		Total N
Penaeidae	*Penaeus merguiensis*	Banana Prawn	25.57 ± 0.00	-	-	-	Feb 2007 Jul 2007 Nov 2007 Feb 2008	1 - - -	1
Penaeidae	*Trachypenaeus curvirostris*	Southern Rough Shrimp	19.27 ± 0.57	-	-	-	Feb 2007 Jul 2007 Nov 2007 Feb 2008	2 - - -	2
Penaeidae	*Trachypenaeus granulosus*	Coarse Shrimp	12.62 ± 0.58	16.81 ± 3.72	-	-	Feb 2007 Jul 2007 Nov 2007 Feb 2008	38 4 - -	42
Penaeidae	*Penaeus latisulcatus*	Western King Prawn	38.20 ± 0.00	-	-	-	Feb 2007 Jul 2007 Nov 2007 Feb 2008	1 - - -	1

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Appendix II. Mean carapace length (mm) ± standard error of penaeids by site and total monthly count across all sites.

Site	Mean Carapace Length (mm)				Monthly Count and Total Numbers		
	March/April 2006	May 2006	August 2006	November 2006	Monthly Count		Total N
Control Inshore	11.47 ± 1.87	8.11 ± 0.49	18.01 ± 2.29	10.22 ± 0.26	Mar/Apr 2007 May 2007 Aug 2007 Nov 2007	14 57 18 125	214
Dredge Plume	7.29 ± 1.87	8.52 ± 1.52	11.39 ± 1.43	10.44 ± 0.05	Mar/Apr 2007 May 2007 Aug 2007 Nov 2007	6 14 27 81	128
Spoil Ground	8.14 ± 3.16	20.59 ± 1.85	14.32 ± 1.24	7.39 ± 0.56	Mar/Apr 2007 May 2007 Aug 2007 Nov 2007	3 3 15 73	94
	Feb 2007	**July 2007**	**November 2007**	**February 2008**	**Monthly Count**		**Total N**
Control Inshore	12.98 ± 0.21	13.19 ± 0.78	13.91 ± 1.10	22.82 ± 2 04	Feb 2007 Jul 2007 Nov 2007 Feb 2008	264 81 53 17	415
Dredge Plume	16.62 ± 1.45	16.40 ± 0.83	12.82 ± 1.01	18.77 ± 1.40	Feb 2007 Jul 2007 Nov 2007 Feb 2008	18 86 49 30	183
Spoil Ground	22.58 ± 2.71	17.56 ± 0.99	12.94 ± 0.95	18.95 ± 4.39	Feb 2007 Jul 2007 Nov 2007 Feb 2008	10 20 26 4	60

Appendix III. Fish species count from March 2006 to February 2008 across sites (sites only listed where species was present) and total monthly count for each species. CI = control inshore CO = control offshore DP = dredge plume SG = spoil ground

Species/Family	Site	Date								sum (N)
		2006				2007			2008	
		Mar	May	Aug	Nov	Feb	Jul	Nov	Feb	
Apogon ellioti (Flagfin cardinal fish). Apogonidae.	CI	0	0	0	1	0	1	0	0	2
	DP	0	0	0	1	6	0	1	0	8
	sum	0	0	0	2	6	1	1	0	10
Apogon nigrippinis (Two eyed cardinal fish). Apogonidae	SG	0	0	0	1	0	0	0	0	1
	sum	0	0	0	1	0	0	0	0	1
Apogon poecilopterus (Pearly finned cardinal fish). Apogonidae.	CI	0	0	0	0	2	0	2	0	4
	sum	0	0	0	0	2	0	2	0	4
Apogon quadrifasciatus (Broad banded cardinal fish). Apogonidae.	CI	0	0	0	0	6	0	0	0	6
	DP	0	0	0	0	1	0	0	0	1
	sum	0	0	0	0	7	0	0	0	7
Apogon septemstriatus (Seven banded cardinal fish). Apogonidae.	CI	0	4	0	4	4	4	0	1	17
	DP	0	0	0	7	0	3	0	5	15
	SG	0	0	0	5	0	0	0	0	5
	sum	0	4	0	16	4	7	0	6	37
Apogon sp. Apogonidae.	CI	0	1	0	9	6	0	3	0	19
	DP	0	0	0	4	1	0	0	0	5
	SG	0	0	0	6	0	0	1	0	7
	sum	0	1	0	19	7	0	4	0	31
Apogon sp.1 (Single banded cardinal fish). Apogonidae.	CI	0	0	0	1	0	0	0	0	1
	sum	0	0	0	1	0	0	0	0	1

Ariidae (catfish)	CI	0	0	0	0	1	0	0	0	1
	sum	0	0	0	0	1	0	0	0	1
Arnoglossus waitei (Waite's left eye flounder). Bothidae.	CI	0	0	0	2	0	0	0	0	2
	SG	0	0	0	1	0	0	0	0	1
	sum	0	0	0	3	0	0	0	0	3
Bathycallionymus moretonensis (Ocellated dragonet). Callionymidae.	SG	0	0	1	0	0	0	0	0	1
	sum	0	0	1	0	0	0	0	0	1
Bothidae (flounder).	CI	0	0	0	0	0	0	1	1	2
	DP	0	0	0	0	0	0	0	1	1
	sum	0	0	0	0	0	0	1	2	3
Callionymidae (dragonet).	CI	0	0	0	0	0	1	2	0	3
	sum	0	0	0	0	0	1	2	0	3
Centriscus scutatus (Grooved razor fish)	CI	1	0	0	0	0	0	0	0	1
	sum	1	0	0	0	0	0	0	0	1
Cynoglossus maculipinnis (Tongue-sole). Cynoglossidae.	CI	1	4	6	3	4	1	5	6	30
	DP	0	2	4	0	1	0	0	4	11
	SG	0	0	0	2	0	0	0	1	3
	sum	1	6	10	5	5	1	5	11	44
Cynoglossus sp. Cynoglossidae.	SG	0	2	0	0	0	0	0	0	2
	sum	0	2	0	0	0	0	0	0	2
Elates ransonneti (Dwarf flathead). Platycephalidae.	CI	0	0	0	0	1	0	0	0	1
	sum	0	0	0	0	1	0	0	0	1
Engyprosopon grandisquama (Mottled wide eyed flounder). Bothidae.	CI	0	1	0	0	0	0	0	0	1
	SG	0	0	0	1	0	0	0	0	1
	sum	0	1	0	1	0	0	0	0	2

Balistidae (Triggerfish).	CI	0	0	0	0	0	0	1	0	1
	sum	0	0	0	0	0	0	1	0	1
Clupeidae	CI	0	0	0	1	0	0	0	0	1
	sum	0	0	0	1	0	0	0	0	1
Ophichthidae (Snake eel)	CI	0	7	2	0	0	1	1	0	11
	DP	0	0	0	0	3	5	3	0	11
	sum	0	7	2	0	3	6	4	0	22
Platycephalidae (Flathead).	CI	0	0	0	1	0	1	4	0	6
	DP	0	0	0	0	0	0	1	0	1
	sum	0	0	0	1	0	1	5	0	7
Scorpaenidae (Scorpion fish)	CI	0	1	0	1	2	0	1	0	5
	sum	0	1	0	1	2	0	1	0	5
Synodontidae (lizard fish).	CI	0	0	0	0	2	0	1	0	3
	DP	0	0	0	0	3	0	0	0	3
	sum	0	0	0	0	5	0	1	0	6
Gerres subfasciatus (Banded silver biddy). Gerreidae.	SG	0	0	1	0	0	0	0	0	1
	sum	0	0	1	0	0	0	0	0	1
Gobidae	CI	0	0	0	7	2	0	0	0	9
	DP	0	0	0	0	3	0	0	0	3
	sum	0	0	0	7	5	0	0	0	12
Inegocia japonica (Japanese flathead). Platycephalidae.	CI	0	5	0	0	1	0	0	0	6
	sum	0	5	0	0	1	0	0	0	6
Larval fish	CI	1	1	1	3	0	4	4	5	19
	DP	0	0	3	2	12	1	1	0	19
	SG	0	1	2	6	2	1	0	0	12
	sum	1	2	6	11	14	6	5	5	50

Leiognathus elongatus (Elongate ponfish). Leiognathidae.	CI	0	0	2	0	0	4	0	0	6
	DP	0	0	0	0	2	0	0	0	2
	SG	0	0	0	0	7	0	0	0	7
	sum	0	0	2	0	9	4	0	0	15
Lutjanus sp. (juvenile)	CI	0	0	0	0	1	0	0	0	1
	sum	0	0	0	0	1	0	0	0	1
Muraenidae (Moray eel).	CI	0	1	0	0	0	0	0	0	1
	sum	0	1	0	0	0	0	0	0	1
Muraenesox cinereus (Daggertooth pike conger).	CI	0	0	0	0	0	0	0	2	2
	sum	0	0	0	0	0	0	0	2	2
Nemipterus isacanthus (Ornate threadfin bream).	CI	0	0	0	0	3	0	0	0	3
	DP	0	0	0	0	1	0	0	0	1
	sum	0	0	0	0	4	0	0	0	4
Saurenchelys sp. (Duck bill eel). Nettastomatidae.	CI	0	0	0	0	2	0	0	0	2
	sum	0	0	0	0	2	0	0	0	2
Ophichthus melanochir (Black finned snake eel). Ophichthidae.	DP	0	0	0	0	2	0	0	0	2
	sum	0	0	0	0	2	0	0	0	2
Papilloculiceps nematophthalmus (Fringe eyed flathead).	CI	0	0	0	0	0	0	0	5	5
	sum	0	0	0	0	0	0	0	5	5
Paramonacanthus filicauda	SG	0	0	0	0	0	0	1	0	1
	sum	0	0	0	0	0	0	1	0	1
. *Parapercis clathrata* (Spothead grubfish). Pinguipedidae	DP	0	0	0	0	0	0	0	1	1
	sum	0	0	0	0	0	0	0	1	1

Parpercis deplospilus (Grubfish). Pinguipedidae.	CI	2	5	0	0	0	0	0	0	7
	DP	0	1	0	0	0	0	0	0	1
	SG	0	0	0	2	1	0	0	0	3
	sum	2	6	0	2	1	0	0	0	11
Psettina gigantea (Rough scaled flounder).	CI	0	0	0	0	1	0	0	0	1
	sum	0	0	0	0	1	0	0	0	1
Repomucenus calcaratus (Spotted dragonet). Callionymidae.	DP	0	0	0	0	0	0	1	0	1
	sum	0	0	0	0	0	0	1	0	1
Repomucenus sublaevis (Multifilament dragonet). Callionymidae.	SG	0	0	0	1	0	0	0	0	1
	DP	0	0	0	0	1	0	0	0	1
	sum	0	0	0	1	1	0	0	0	2
Secutor insidiator (Pugnose ponyfish).	DP	0	0	0	0	7	0	0	0	7
	sum	0	0	0	0	7	0	0	0	7
Selaroides leptolepis (Yellowstripe scad).	SG	0	0	0	0	0	0	0	2	2
	sum	0	0	0	0	0	0	0	2	2
Siphamia sp. (cardinal fish). Apogonidae.	DP	0	0	1	2	0	0	0	0	3
	CI	1	0	0	0	0	0	0	0	1
	sum	1	0	1	2	0	0	0	0	4
Suggrundus macracanthus (Large spined flathead).	CI	0	0	0	0	0	1	0	0	1
	sum	0	0	0	0	0	1	0	0	1
Total		12	72	46	148	182	56	68	68	652

Appendix IV. Mean number of sessile BMI per 60 m2 per month from May 2006 to June 2008. Total (N) is the total number of individuals recorded across all sampling events. CI = Control Inshore, CO = Control Offshore, DP = Dredge Plume, SG = Spoil Ground

Common name	Site	Date												Mean and total number caught	
		2006						2007				2008		Mean # caught per sample per site	Total (N)
		May	Jul	Aug	Sep	Oct	Nov	Jan	Mar	Jul	Nov	Feb	Jun		
Anemones	CI	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CO	0.1	-	0.3	-	-	-	-	-	-	-	-	-	0.03	0.4
	DP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SG	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ascidians	CI	-	-	0.4	0.1	0.1	0.2	-	0.11	0.44	0.44	0.11	0.33	0.19	2.24
	CO	0.3	-	0.2	0.1	0.2	-	0.1	0.44	2.33	0.11	0.25	0.22	0.36	4.26
	DP	-	-	0.7	-	0.2	-	0.2	0.11	-	-	-	-	0.1	1.21
	SG	0.2	-	0.2	0.1	0.6	0.2	-	-	2.11	0.22	0.33	1.22	0.43	5.19
Barnacles	CI	0.6	-	-	-	-	-	-	0.56	10.0	1.67	-	-	1.07	12.82
	CO	-	-	0.6	0.3	-	-	-	7.56	21.67	1.0	0.63	-	2.65	31.75
	DP	0.1	-	-	-	-	0.3	6.0	1.33	3.38	2.0	0.78	0.56	1.2	14.44
	SG	-	-	-	-	-	-	-	11.44	-	-	8.89	-	1.69	20.33
Encrusting bryozoans	CI	0.8	1.8	-	0.3	1.8	18.4	8.3	7.0	4.89	1.33	4.44	6.56	4.64	55.62
	CO	1.0	1.1	1.0	32.0	8.9	21.3	3.7	19.22	10.11	5.78	8.13	2.11	9.53	114.35
	DP	-	0.4	0.2	0.3	0.1	6.1	9.1	5.67	0.63	1.67	0.78	0.56	2.12	25.49
	SG	0.4	0.9	0.1	0.3	0.7	7.9	0.2	8.78	19.56	2.89	10.89	0.33	4.41	52.94
Erect bryozoans	CI	0.8	1.3	0.7	1.0	0.8	-	0.9	5.44	1.44	0.67	2.11	1.56	1.39	16.72
	CO	0.2	0.2	0.3	0.2	-	-	1.2	2.44	4.33	1.67	1.63	0.44	1.05	12.61
	DP	-	-	-	-	-	-	0.1	0.89	0.63	0.22	0.44	-	0.19	2.28
	SG	1.2	1.4	-	0.3	0.9	-	-	0.11	3.0	2.0	11.22	1.44	1.8	21.58
Gorgonians	CI	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DP	-	-	-	-	-	-	-	-	-	0.11	-	-	0.01	0.11
	SG	0.1	-	-	-	0.1	-	-	-	-	-	-	-	0.02	0.2
Hard coral	CI	-	-	-	-	-	-	0.2	-	-	-	-	-	0.02	0.2
	CO	0.1	-	-	0.1	-	-	-	-	-	-	-	-	0.02	0.2
	DP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SG	-	0.2	0.3	-	-	-	-	-	-	-	-	-	0.04	0.5

Hydroids	CI	0.4	0.3	0.1	0.1	0.7	0.1	1.1	0.44	0.67	0.56	0.56	0.33	0.45	5.36
	CO	0.1	-	-	-	0.2	-	4.2	2.33	1.11	-	1.38	0.56	0.82	9.88
	DP	1.2	-	-	-	-	-	-	-	0.5	0.33	0.33	0.11	0.21	2.48
	SG	0.2	0.2	0.2	-	0.2	-	-	0.89	2.56	4.78	8.0	1.89	1.58	18.91
Porifera (sponges)	CI	0.1	-	-	0.1	-	-	-	0.11	-	-	0.11	-	0.04	0.42
	CO	0.2	0.1	-	-	-	-	-	-	-	-	0.13	0.11	0.04	0.54
	DP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SG	0.2	0.1	-	-	0.2	-	-	-	0.11	0.11	-	-	0.06	0.72
Sea pens	CI	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CO	-	-	-	-	-	-	-	0.11	0.22	-	-	-	0.03	0.33
	DP	-	-	0.1	-	-	-	-	-	-	-	-	-	0.01	0.1
	SG	-	-	-	-	-	-	-	-	-	-	-	0.11	0.01	0.11
Soft coral	CI	0.1	-	0.2	-	-	0.1	0.1	0.11	0.11	0.44	0.33	0.11	0.13	1.61
	CO	-	-	-	-	-	0.2	0.6	0.22	0.33	0.56	-	-	0.16	1.91
	DP	0.1	-	0.1	0.1	0.1	0.1	-	-	0.13	0.22	-	-	0.07	0.85
	SG	-	0.1	-	-	0.1	-	0.1	-	0.22	0.11	0.44	-	0.09	1.08
Solitary coral	CI	-	-	0.1	1.1	0.6	0.8	1.3	1.67	1.22	0.78	1.56	1.0	0.84	10.12
	CO	-	0.1	-	-	0.6	0.3	-	0.33	0.33	0.56	0.25	0.22	0.22	2.69
	DP	0.8	0.1	0.1	-	0.9	0.2	0.3	1.11	-	0.44	0.11	-	0.34	4.07
	SG	-	0.3	1.3	-	0.7	0.4	0.1	0.22	2.0	0.33	0.11	0.22	0.47	5.69
Zoanthids	CI	0.3	0.1	0.1	-	0.1	0.2	0.4	0.11	0.22	0.44	0.56	0.44	0.25	2.98
	CO	0.6	0.2	0.4	0.9	1.3	1.0	0.4	1.0	1.44	0.89	0.25	1.67	0.84	10.05
	DP	0.4	0.1	0.1	0.2	0.1	-	0.7	0.11	-	0.11	0.11	0.33	0.19	2.27
	SG	1.1	0.4	0.3	0.1	1.0	0.9	0.1	1.78	0.56	0.89	1.56	1.44	0.84	10.12

Appendix V. Mean number of motile BMI per 60 m2 per month from May 2006 to June 2008. Total (N) is the total number of individuals recorded across all sampling events. CI = Control Inshore, CO = Control Offshore, DP = Dredge Plume, SG = Spoil Ground

Common name	Site	Date												Mean and total number caught	
		2006						2007				2008		Mean # caught per sample per site	Total (N)
		May	Jul	Aug	Sep	Oct	Nov	Jan	Mar	Jul	Nov	Feb	Jun		
Asteroid	CI	0.67	0.67	0.25	0.22	0.22	0.38	-	-	-	-	-	0.33	0.23	2.74
	CO	-	0.78	1.0	0.44	0.22	0.11	-	-	-	-	-	0.11	0.22	2.67
	DP	0.11	0.44	-	-	0.22	0.11	-	-	0.22	0.33	0.33	-	0.15	1.78
	SG	0.22	0.22	0.11	0.11	0.11	-	-	0.33	-	0.11	-	0.22	0.12	1.44
Bivalve	CI	-	0.33	2.63	3.22	3.44	2.75	2.67	0.78	0.75	1.89	0.33	0.78	1.63	19.57
	CO	0.11	0.22	1.0	0.89	2.78	2.0	1.67	1.22	0.44	0.22	1.22	0.11	0.99	11.89
	DP	1.78	0.11	1.89	2.89	5.78	6.67	0.44	0.11	1.56	1.0	0.89	0.22	1.94	23.33
	SG	0.67	0.33	0.22	0.67	0.78	3.56	2.0	1.44	0.78	1.44	1.13	0.22	1.1	13.24
Brachyura	CI	0.56	0.44	1.13	1.0	1.22	1.88	2.44	0.78	1.13	3.0	0.44	1.0	1.25	15.01
	CO	0.22	2.56	1.33	1.0	0.67	1.11	1.56	1.44	0.33	2.89	7.33	0.44	1.74	20.89
	DP	1.56	0.11	2.78	1.67	2.0	2.22	0.44	0.33	3.89	1.44	1.44	0.33	1.52	18.22
	SG	1.67	1.22	0.22	0.22	0.33	4.11	2.44	1.78	0.78	2.11	0.75	1.11	1.4	16.75
Carid	CI	-	-	-	-	-	-	0.67	-	0.13	-	0.11	-	0.08	0.9
	CO	-	-	-	0.11	-	0.22	-	0.44	0.22	-	0.11	-	0.09	1.11
	DP	-	-	-	0.22	0.22	0.33	0.11	-	0.44	-	0.11	-	0.12	1.44
	SG	-	-	-	-	-	0.78	0.89	0.56	-	0.11	-	-	0.19	2.33
Cephalopoda	CI	0.11	-	-	-	-	-	-	0.11	-	-	-	-	0.02	0.22
	CO	-	0.11	-	-	-	-	-	-	-	0.22	-	-	0.03	0.33
	DP	-	-	-	-	-	-	-	-	-	0.11	-	-	0.01	0.11
	SG	0.11	-	-	-	-	-	-	-	-	-	-	-	0.01	0.11
Chiton	CI	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SG	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Crinoid	CI	0.11	0.11	-	-	-	0.13	-	-	-	-	-	0.11	0.04	0.46
	CO	-	-	-	-	-	0.11	0.11	-	-	0.11	-	-	0.03	0.33
	DP	-	-	-	-	-	-	0.11	0.11	-	-	-	0.11	0.03	0.33
	SG	-	-	-	-	0.22	-	-	0.33	-	0.11	-	0.33	0.08	1.0

Echinoid	CI	0.89	-	1.13	0.67	0.22	0.13	0.11	-	-	0.11	-	0.44	0.31	3.69
	CO	0.22	0.33	0.56	0.44	1.56	-	0.11	0.11	0.11	1.0	-	-	0.37	4.44
	DP	1.0	11.22	2.78	3.11	1.78	0.22	-	-	0.56	0.56	0.22	-	1.79	21.44
	SG	0.33	0.89	0.89	0.56	0.11	2.22	0.78	0.22	0.33	0.22	-	0.11	0.56	6.67
Gastropod	CI	-	0.44	2.0	2.11	5.0	5.25	6.33	3.78	1.63	7.22	3.33	1.0	3.17	38.1
	CO	0.22	0.56	1.56	5.0	3.56	2.33	5.44	4.56	0.22	2.78	-	0.44	2.22	26.67
	DP	2.33	0.33	3.0	4.89	3.67	5.44	0.78	2.11	7.0	2.78	3.22	0.11	2.97	35.67
	SG	0.33	0.78	0.44	1.44	1.22	2.67	4.78	5.67	3.11	2.78	2.25	0.33	2.15	25.81
Holothuroid	CI	-	-	-	0.22	0.22	0.13	0.11	-	-	-	-	0.11	0.07	0.79
	CO	-	0.11	-	-	0.11	-	0.11	0.11	0.11	0.11	-	-	0.06	0.67
	DP	-	-	-	0.44	0.33	0.22	0.11	0.22	-	0.33	-	-	0.14	1.67
	SG	0.67	-	-	0.22	0.11	0.22	-	-	-	-	-	-	0.1	1.22
Isopod	CI	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SG	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Motile bryozoa	CI	0.67	1.22	-	-	-	0.13	-	-	-	-	-	-	0.17	2.01
	CO	-	0.22	-	-	0.11	1.22	-	0.22	0.44	-	0.33	-	0.21	2.56
	DP	0.11	-	0.22	-	-	-	1.0	0.44	-	-	-	-	0.15	1.78
	SG	0.22	-	3.44	1.11	0.89	-	-	-	-	-	-	-	0.47	5.67
Ophiuroid	CI	-	-	0.13	-	0.89	0.25	0.11	-	0.13	-	-	-	0.13	1.5
	CO	-	-	0.22	0.11	0.44	0.33	-	0.11	-	-	-	0.22	0.12	1.44
	DP	0.22	0.11	1.44	1.33	0.11	0.67	-	0.11	0.11	-	0.11	-	0.35	4.22
	SG	0.44	-	0.44	-	-	0.11	0.22	-	-	-	0.25	0.56	0.17	2.03
Penaeid	CI	0.22	0.67	0.63	0.56	-	-	0.89	-	0.38	0.44	-	0.11	0.32	3.89
	CO	-	0.56	0.11	-	0.11	0.11	0.22	0.11	0.11	-	-	0.44	0.15	1.78
	DP	0.33	-	0.11	0.33	0.11	0.44	-	-	0.44	-	0.22	0.44	0.2	2.44
	SG	0.44	0.13	-	-	-	0.22	1.0	0.33	0.22	0.44	-	0.22	0.25	3.01
Pisces	CI	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SG	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Sea hare	CI	-	-	0.13	0.11	0.22	-	-	-	-	-	-	-	0.04	0.46
	CO	-	0.11	-	-	-	-	-	-	-	-	-	-	0.01	0.11
	DP	0.22	-	-	-	0.11	-	-	-	-	-	-	-	0.03	0.33
	SG	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soft mollusc	CI	-	-	-	-	-	-	-	-	-	0.56	-	-	0.05	0.56
	CO	-	-	-	-	-	0.11	-	-	-	1.22	-	-	0.11	1.33
	DP	-	-	-	-	-	0.56	-	-	0.33	-	-	-	0.07	0.89
	SG	-	-	-	-	-	0.22	-	-	-	1.11	-	-	0.11	1.33
Stomatopod	CI	-	-	-	-	-	-	0.22	-	0.13	-	-	-	0.03	0.35
	CO	-	0.22	-	-	-	0.11	-	-	0.11	-	0.22	-	0.06	0.67
	DP	0.22	-	-	-	-	0.22	0.22	-	-	-	-	-	0.06	0.67
	SG	-	0.11	-	-	-	1.33	0.67	-	-	-	-	-	0.18	2.11
Unsegmented worms	CI	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SG	-	-	-	-	-	-	-	-	-	-	-	-	-	-