Cape Lambert Port B Development

BENTHIC PRIMARY PRODUCER HABITAT (BPPH) MONITORING REPORT (SUBTIDAL)

Revision 2

20 August 2009

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The baseline results are based on four separate surveys, one in each season over a 12 month period.

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Executive Summary

Large areas of sand dominate the marine benthos in the Cape Lambert region. Interspersed within these are areas of hard substrate that contain Benthic Primary Producers Habitat (BPPH) including corals, macroalgae and turf algae (SKM 2008a). The purpose of this study was to quantify the spatial and temporal variability of corals, macroalgae and turf algae, (the most commonly found BPPH in the Cape Lambert region) prior to dredging for the Cape Lambert Port B development.

The BPPH monitoring program was implemented at 13 sites from July 2008 to May 2009. Underwater video was used to collect data on benthic cover at each site in July and October 2008, and February and May 2009. This included coverage of macroalgae, turf algae, coral growth forms, sand, rock etc. Algae were also harvested from the seafloor, weighed and identified to record the composition of algal species. Coral health was assessed by monitoring changes in coral mortality of sixty corals permanently tagged at each monitoring site. The coral mortality monitoring has been designed to adequately detect changes of 3% coral morality.

Seventy-six species of algae were recorded from 30 families and 54 genera. A new genus was recorded for the region *Rhodogorgon* sp. which has previously not been described in Western Australia. Many of the algae in the region are common to other tropical areas.

There was a high degree of spatial and temporal variability in terms of algal composition among sites over the monitoring period. Species that displayed marked seasonality included *Asparagopsis taxiformis* and *Stypopodium flabelliforme* with peaks in biomass recorded in October 2008. Benthic cover also varied being driven by differences in coral and algal cover among sites and sampling events. Seasonally shifting sand sheets at some inshore sites affected the amount of hard substrate available for algal recruitment.

Turf algae had generally colonised most hard substrata, other than corals, and was the dominant benthic cover type with values ranging from 6 to 63% cover. Live coral cover ranged from 8% at Cape Lambert West to 60% at Delambre Island. Coral cover was highest at Delambre Island, Bezout Island, Pelican Rock and Dixon Island East and was dominated by massive and encrusting growth forms. Macroalgal cover ranged from 0 to 25%. Differences in benthic cover among sites and sampling occasions were driven by varying percent cover of macroalgae, turf algae, coral and sand.

Environmental variables (temperature, turbidity and sedimentation) from the same locations were analysed to assist in explaining differences in the composition of algae and benthic cover. Results showed the environmental variables to be highly correlated to the biological data at some sites but there were also large differences with little or no relationship at other sites. Some sites showed groupings in environmental variables generally due to being in geographically similar locations.

The results of the coral mortality measured during the surveys showed variability both within and among the sites with all sites having less than 10% mortality from July 2008 to May 2009. An increase in coral bleaching was detected at three sites during the February 2009 survey compared with October 2008. This was not unusual given the higher water temperatures in summer. Within three months the coral bleaching had returned to previous levels.

Corals and algae are important benthic primary producers in coral reef habitats that may be highly variable in time and space. Understanding this variability presents challenges in setting measurable and achievable targets for environmental management and impact assessment. To detect any impacts related to dredging their magnitude would have to be larger than the variability recorded to date in the surveys.

Based on the findings of this study it can be concluded that the methodology used in these surveys is considered a suitable technique for any further monitoring. That is, the use of benthic transects to characterise the broader habitat types at each site and assess changes in percent cover of benthic types (corals and algae), the use of quadrats to sample macroalgae and assess changes in algal composition, and the use of coral mortality measures are all considered suitable techniques. These measures have provided the necessary information to understand variability in BPPH at the sites monitored in the Cape Lambert region and can be analysed with water quality data in the future to investigate potential links between dredging and changes in BPPH.

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1. Introduction

1.1. Overview

The Cape Lambert Port B development (the Port B development) involves the construction of new ore handling, processing and export facilities adjacent to the existing Cape Lambert operations. The Port B development includes both marine and onshore works. Up to 16 million cubic metres (Mm^3) of material will be dredged and relocated to offshore spoil grounds. **Figure 1.1** presents an overview of the proposed wharf and dredging areas associated with the Port B development.

In June 2008, Rio Tinto commissioned SKM to conduct a baseline Benthic Primary Producer Habitat (BPPH) and Coral Health Monitoring Program. Benthic primary producers are marine plants such as seagrasses, algae and mangroves but include invertebrates such as scleractinian corals, which acquire a significant proportion of their energy from symbiotic microalgae (Environmental Protection Authority 2004). The BPPH also includes the ecological units they support.

This subtidal study constitutes part of an overarching baseline monitoring program described in the Port B Dredging and Spoil Disposal Management Plan (SKM 2008b). The larger program includes a seasonal baseline intertidal study (SKM 2009a) and a comprehensive water quality monitoring program (SKM 2009b). This report details the findings of one year (July 2008 to June 2009) of subtidal monitoring including measures of coral mortality, the composition of algal assemblages and the composition of benthic cover (i.e. cover of corals, algae, sand, rock etc) at sites in the Cape Lambert region.

1.2. Study objectives

The purpose of this study was to quantify the spatial and temporal variability of corals and algae (the most commonly found BPPH in the Cape Lambert region) prior to dredging for the Cape Lambert Port B development. Key findings from the work could then be incorporated into the proposed methodology for the final monitoring plans for the Cape Lambert Port B development dredging program. This was undertaken by means of the following tasks:

- identifying appropriate response variables to measure when monitoring macroalgae and turf algae;
- designing a statistically powerful survey methodology that allows detection of natural change and impacts associated with the proposed dredging program;
- conducting field surveys of subtidal reef habitats to describe BPPH and any damage or stress at those locations; and

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- conducting analysis of data and reporting, as well as preparation of inputs to Dredging and Spoil Disposal Management Plan (DSDMP) and future monitoring programs where appropriate.

The specific objectives of the monitoring program were to:

- quantify the natural spatial and temporal variation of coral mortality prior to the commencement of dredging;
- provide a quantitative measure of existing coral health in the Cape Lambert region;
- better understand potential impacts to other BPPH (as per Strategy 1 in the Port B Dredge Spoil Disposal Management Plan) (SKM 2008b);
- build a dataset that records 'natural' variation in BPPH; and
- develop field methods to monitor BPPH and to assist in determining possible quantitative BPPH threshold values.

1.3. Monitoring BPPH

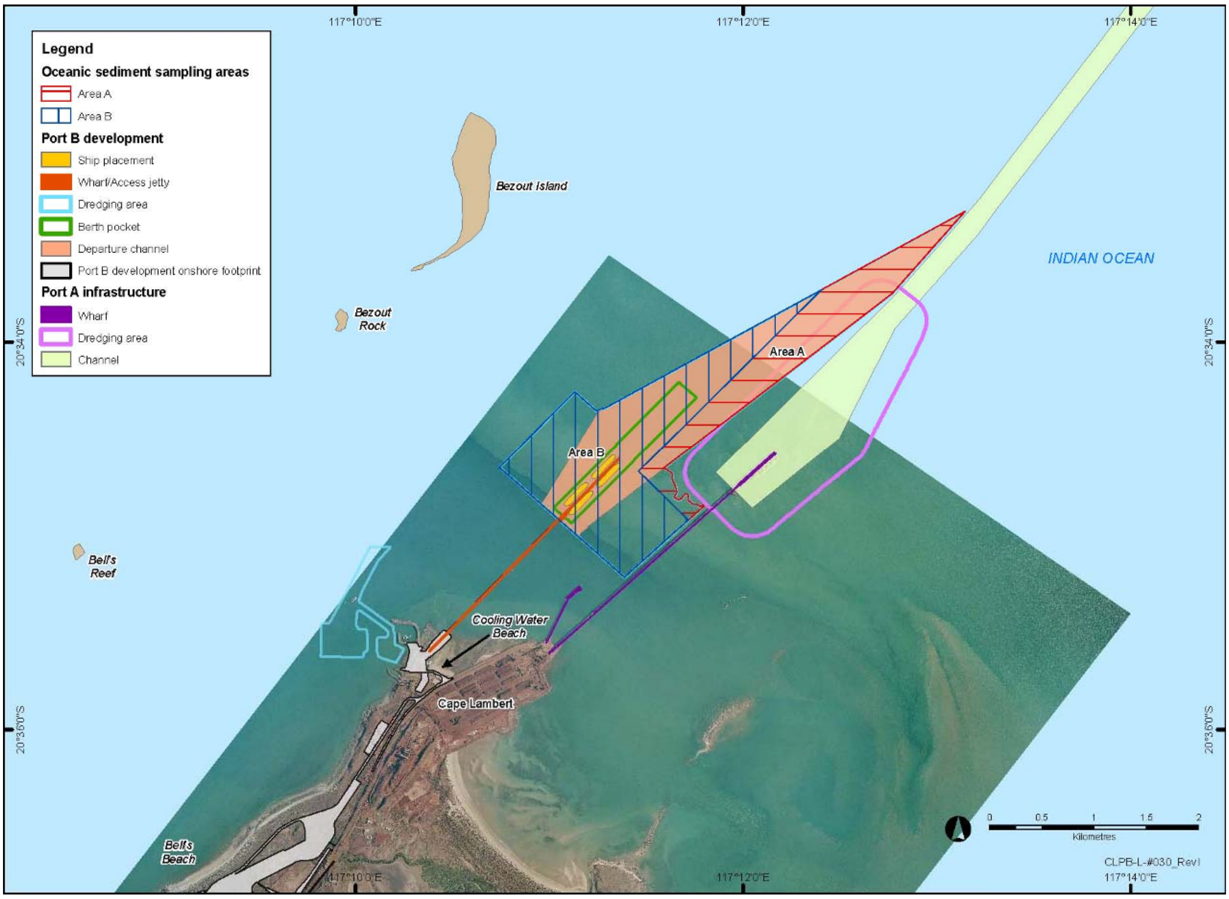
Based on the SKM BPPH survey in March/April 2008, which investigated the abundance and distribution of subtidal benthic habitats in the Cape Lambert region (SKM 2008a) corals, macroalgae and turf algae inhabit hard substrates in the Cape Lambert region. The monitoring methods previously used by SKM at Cape Lambert (Stoddart and Stoddart 2005; MScience 2007) can detect changes in the natural mortality of corals; however, they will not detect changes in the benthic cover of algae and corals or the species composition of turf algae or macroalgae. Therefore, additional methods were implemented in these surveys that were based on 'best practice' monitoring techniques, taken from the scientific literature (Hill and Wilkinson 2004; Jokiel, et al. 2005; Houk and Van Woesik 2006; Kohler and Gill 2006; Westera, et al. 2007). These techniques (as detailed in **section 2 Methods**) provide the tools to collect appropriate baseline information on the cover and composition of algae and corals in the Cape Lambert region. The methods that were implemented follow the 'best practice' approach adopted by the Environmental Protection Authority (Environmental Protection Authority 2004) in BPPH Guidance Statement No 29.

The EPA has defined acceptable levels of loss in certain areas of the marine environment (Environmental Protection Authority 2004). Of most relevance to Cape Lambert are the Category D and E area. Category D is defined as a non-designated area within which a cumulative loss of 5% is deemed acceptable. Category E is defined as a Development Area (e.g. inner port areas) where a 10% cumulative loss is deemed acceptable. Given the defined percentage loss prescribed in the Guidance Statement (Environmental Protection Authority 2004) it is important that these amounts can be measured against background variability and any monitoring must be able to detect these levels of change. The EPA has also adopted a general approach to measuring coral mortality in which increases in mortality may trigger a management response. This involves being able to detect small changes in coral partial mortality.

The abundance of sessile benthic organisms and the distribution of BPP habitats can vary greatly as a result of natural processes such as disturbance (Gilmour and Smith 2006), competition (McCook, et al. 2001; Wernberg and Connell 2008) and recruitment (Stiger and Payri 2005; Gaylord, et al. 2006). Change can be unpredictable, due to the occurrence of periodic cyclones, or may vary seasonally due to variation in temperature, nutrient levels, sedimentation or transport of propagules (Airoldi 1998; Lapointe, et al. 2004; Done, et al. 2007; Gilmour, et al. 2007).

Some genera of algae have also been shown to be seasonal including many that are present in the Cape Lambert region (e.g. *Stypopodium*, *Asparagopsis*, *Sargassum* and *Turbinaria*) (Stiger and Payri 1999a; Stiger and Payri 1999b; Lirman and Biber 2000; Padilla-Gamino and Carpenter 2007; Ateweberhan, et al. 2008). Seasonal variability must be accounted for when assessing any potential impacts upon BPPH.

In essence, the natural spatial and temporal variability in BPPH may be larger than the acceptable cumulative loss amounts prescribed in the BPPH Guidance Statement (Environmental Protection Authority 2004).



- **Figure 1.1: Cape Lambert Port B Development showing the proposed wharf and dredging areas**

2. Methods

2.1. Project design

This section outlines the monitoring protocols that were used to assess the marine BPPH (coral, macroalgal and turf algal communities) and coral partial mortality in the vicinity of the Port B development.

BPPH sampling was conducted in July and October 2008, and February and May 2009 to investigate natural patterns of spatial and temporal variability in algal assemblages and benthic cover. Coral partial mortality sites were established in July 2008, and consequently sampled in October 2008, and February and May 2009. The sites were located in shallow water generally between 4 and 9 m. Tidal range in the region is approximately 6 m. The 13 sites assessed were the same as those used to collect water quality data for the Marine Water Quality Baseline Monitoring Program (SKM 2009b) (**Table 2.1** and **Figure 2.1**). Each survey took six days to complete all 13 sites.

The survey sites are within approximately 15 km of Cape Lambert with Delambre Island being the farthest at 18 km from the Port B development dredge area. Dolphin Island and Depuch Island are potential reference sites that may be monitored, if required, once dredging commences (SKM 2008c) (**Figure 2.2**).

Data from the Cape Lambert Port B Marine Water Quality Baseline Monitoring Program (SKM 2009b) were analysed to provide an understanding of interactions between physical environmental factors (turbidity, sedimentation, and water temperature) and the biological communities.

The monitoring protocol has been developed specifically to ensure high quality data collection and analyses to assist in the management of any potential impacts from dredging. For the BPPH sampling data collection, sample processing and statistical analysis techniques were based on accepted monitoring protocols that have been used in Western Australia (Wernberg et al. 2003; Keesing and Heine 2005; Toohey 2007) and recent experience in monitoring the effects of dredging (Westera et al. 2008a) and algal communities (Westera et al. 2008b) in Western Australia. For the coral partial mortality measures the monitoring protocol was based on methods that have been used in monitoring the potential effects of dredge operations in the Dampier and Cape Lambert regions (Stoddart and Stoddart 2005; MScience 2007).

The configuration of sites will enable comparison of the algal and coral communities at different distances from the Port B development and any future effect of the dredging operations (i.e. to assist in any determination of whether sites near to the dredging operations respond differently to those further away). For each site the dominant coral community types have been defined

(**Table 2.1**). In the future, monitoring sites may be allocated a site function that relates to how they will be used in the assessment of impacts. This is summarised below.

- Impact sites are those sites predicted to be at greatest risk to coral mortality or changes in BPPH due to their proximity to the dredge or disposal footprint. Sediment plume modelling (GEMS 2008) has predicted impacts associated with the turbidity and elevated sedimentation rates at these sites. While modelling has predicted elevation of turbidity above background, coral mortality or BPPH loss will not necessarily occur at these sites.
- Influence sites are those sites predicted to experience anomalous turbidity levels (above background) at some stage during the dredging program. No net loss of corals or BPPH is predicted at these sites.
- Reference sites will be used to assess natural changes in coral health during the dredging program. Sediment plume modelling (GEMS 2008) has indicated that these sites will not be impacted or influenced by above background sedimentation rates or increased turbidity associated with the dredging program. However, the modelling has predicted that these reference sites lie within the zone of theoretical detection (that is, at one or more times during the dredging program they will experience an increase in total suspended solids (TSS) of 1 mg l^{-1}). These low level TSS elevations are typically no more than one or two hours in duration (SKM 2009c) and therefore the modelling has not predicted any longer term alterations of the background water quality at these sites (SKM 2009c). As all monitoring sites typically show fluctuations in TSS (as NTU) much greater than 1 mg l^{-1} for similarly short durations it is highly unlikely these small and short term fluctuations in TSS will have any impact on corals and other BPP.

The BPPH sampling methods used have also been successfully implemented elsewhere on the West Australian coast including Ningaloo Reef, Jurien, Marmion, Hamelin Bay, the South West Capes region and the Recherché Archipelago (Wernberg et al. 2003; Babcock et al. 2005; Kendrick et al. 2005; Westera et al. 2008b). The methods account for different spatial scales and include: transects of 25 m^2 to measure the cover and composition of algae, coral, seagrass, rock and sand; quadrats of 0.25 m^2 to measure algal biomass and species composition; and digital still photography to provide fine scale data on algal cover and composition. Transects are sampling areas of fixed length and width that are determined using a tape measure; quadrats are square sampling devices that are placed on the seafloor to digitally photograph and then harvest algae from within a fixed area. The statistical procedures used (**Section 2.5**) will enable the detection of potential change in algal and coral communities at those sites sampled within the Cape Lambert region and also the establishment of baselines to measure change in the marine environment on a regional scale. The methods for measuring coral partial mortality were developed by MScience

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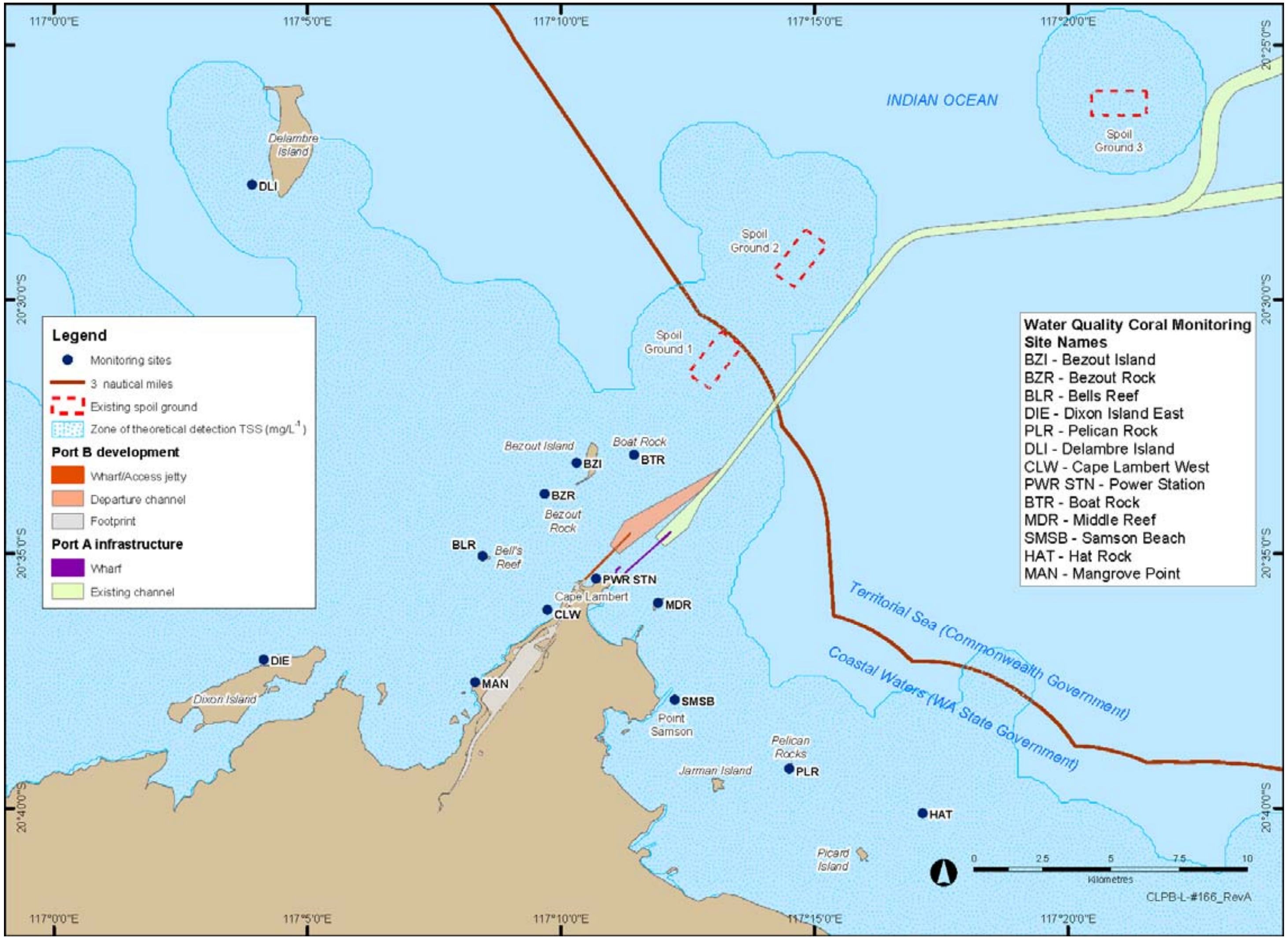
(2007). Although the monitoring will be capable of detecting changes in BPPH and coral mortality, it will not necessarily be able to relate them directly to dredging.

- **Table 2.1: Site locations in the Cape Lambert region**

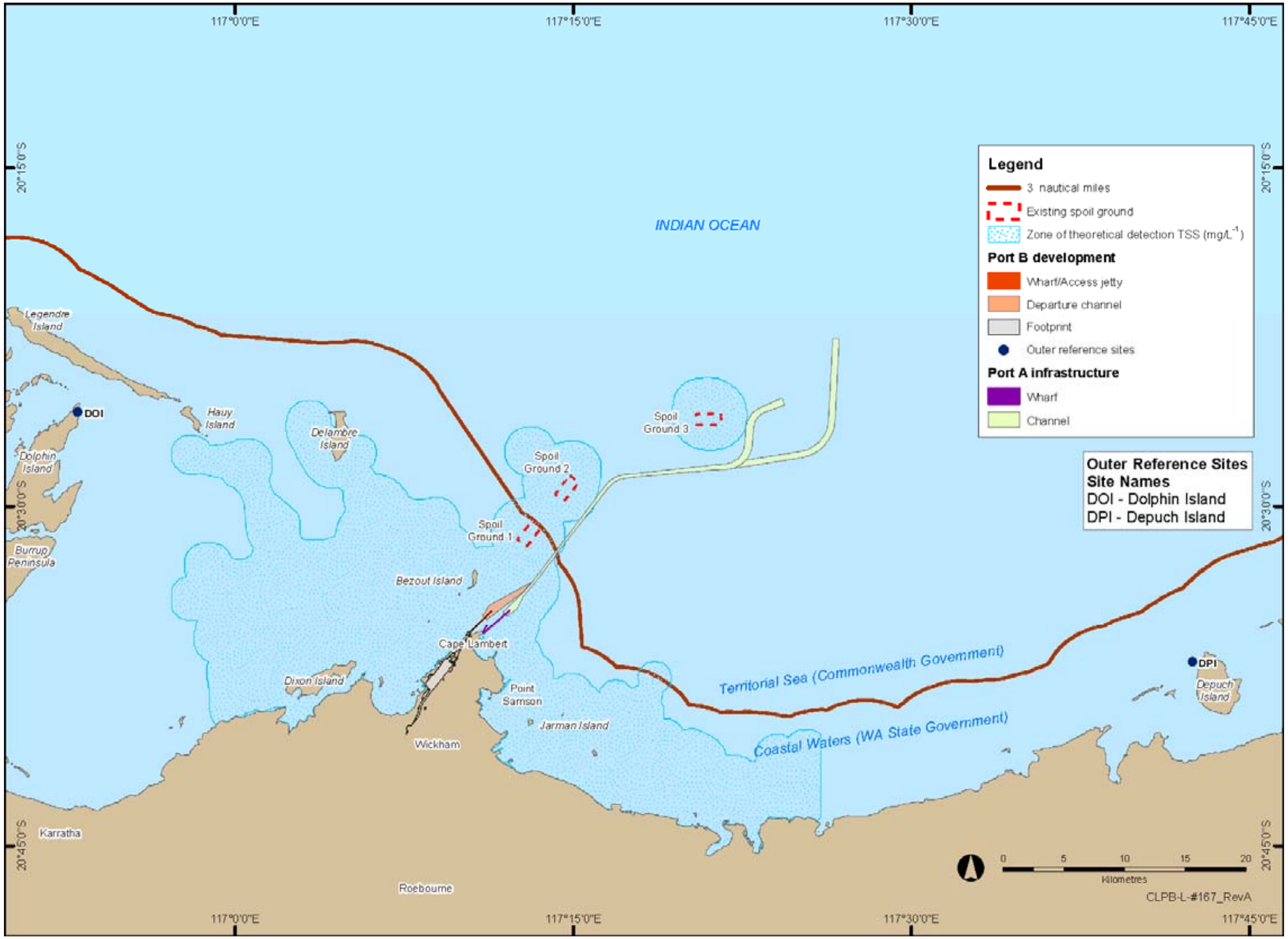
Site Name	Site code	Average depth (m)	Latitude	Longitude	Community type
Bells Reef	BLR	3	20°35´052¨S	117°08´456¨E	Porites
Boat Rock	BTR	9	20°33´750¨S	117°10´621¨E	Faviid
Bezout Island	BZI	3	20°33´213¨S	117°10´311¨E	Acropora/ Pavona
Bezout Rock	BZR	4	20°33´823¨S	117°09´682¨E	Faviid/ Turbinaria/ Porites
Cape Lambert West	CLW	4	20°36´090¨S	117°09´756¨E	Turbinaria/ Acropora
Dixon Island East	DIE	8	20°37´084¨S	117°04´143¨E	Faviid/Porites/Turbinaria
Delambre Island	DLI	9	20°27´736¨S	117°03´916¨E	Acropora/Faviid
Hat Rock	HAT	6	20°40´105¨S	117°17´136¨E	Faviid/Porites
Mangrove Point	MAN	3	20°37´555¨S	117°07´988¨E	Faviid/Porites
Middle Reef	MDR	5	20°35´817¨S	117°11´862¨E	Porites/Turbinaria/ Faviid
Pelican Rock	PLR	6	20°39´249¨S	117°14´415¨E	Faviid/ Porites
Power Station	PWR	6	20°35´440¨S	117°10´685¨E	Faviid/ Porites
Samson Beach	SMSB	4	20°37´337¨S	117°11´890¨E	Turbinaria

Note: Coordinates are in WGS 84 format



- **Figure 2.1: Sampling sites for algae, benthic cover and coral partial mortality (blue circles)**

Note: See ***Table 2.1*** *for site details.*



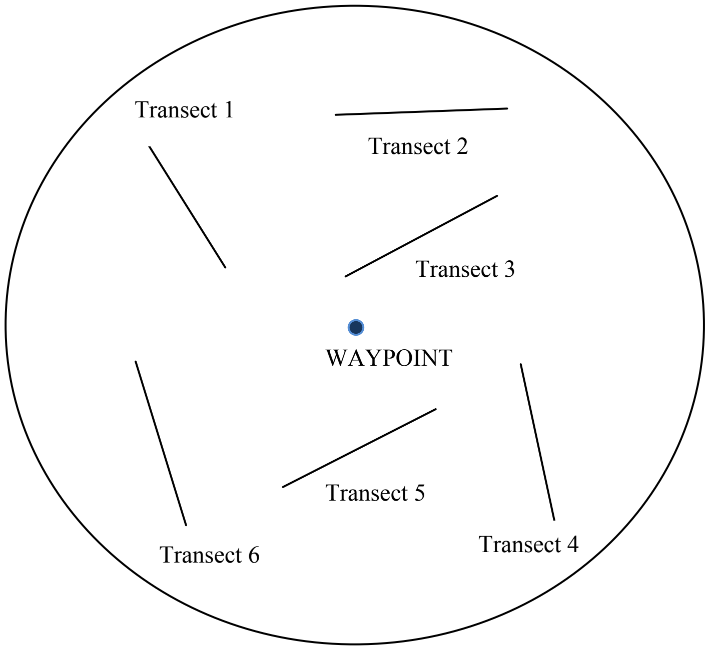
- **Figure 2.2: Potential reference monitoring sites (blue circles) at Dolphin Island (DOI) and Depuch Island (DPI)**

2.2. BPPH Benthic cover – Video transects

Benthic cover was measured using underwater video techniques to assess the percent cover of macroalgae, turf algae, coral, rock, sand, seagrass or other benthic type at each site (**Table 2.2**). Video footage was taken using a video camera with a light setup to overcome potentially poor visibility due to suspended sediment. Lights were positioned to minimise backscatter from any suspended particles. In-water trials were performed to ensure the highest quality footage. Video footage was captured as .avi files and stored for analyses.

The video camera was held approximately 0.5 m above the substrata and moved along six replicate 25 m transects at each site by SCUBA diver (**Figure 2.3**). Before commencing the dive a field sheet was photographed with the site name, date and time. Transects were haphazardly placed within approximately 50 m of the site waypoint. Haphazard placement of transects ensured characterisation of the larger reef community and was logistically more efficient than permanent transects as there was no time spent relocating permanent markers on subsequent dives. Haphazard sampling of this nature has been widely implemented in similar marine surveys (McClanahan 1997; McField et al. 2001; Griffin et al. 2003).

To ensure the video footage was of high quality for analyses, the speed at which the diver swam the video along the transect was limited to less than 0.15 m sec^{-1} (or 3 minutes per transect). This has also been shown in other studies to be the optimum speed to record underwater video transects (Houk and Van Woesik 2006).



- **Figure 2.3: Example configuration of transects within each site**

Notes: transects are haphazardly located and will be different at each site and each sampling event; radius from waypoint is approximately 50 m.

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- **Table 2.2: Categories used to characterise benthic cover at the field sites**

Benthic category	Description
Algae	
Encrusting algae	Encrusting algae, generally red coralline species
Macroalgae	Large algae greater 5 mm high
Turf algae	Fine algae, generally filamentous smaller than 5 mm
Corals	
Branching	Branching corals
Corymbose	Corymbose corals
Digitate	Digitate corals
Encrusting	Encrusting corals
Foliose	Foliose coral
Fungid	Fungid corals
Massive	Massive corals
Soft Coral	Soft coral
Submassive	Submassive corals
Tabulate	Tabulate corals
Other	
Bleached coral	Coral that is obviously bleached – white in colour
Invertebrates	Invertebrates (seastars, urchins, ascidians etc)
Dead coral	Recently dead coral
Rock/ bare substrate	Rock or bare substrate with no algae or coral
Rubble	Rubble, broken coral or small rocks
Sand	Sand
Seagrass	Seagrass, generally *Halophila* spp.
Sponge	Sponges
Unknown	Unknown could not be identified

Note: coral categories are the same as those used in previous work for Rio Tinto (SKM 2008a).

From the video footage of each transect, 20 randomly-selected frames were analysed and substrate cover grouped into 12 broad categories (**Table 2.2**). Video footage was analysed using the AVTAS computer video analysis software to determine the substrate cover type under 10 points on each frame. Twenty frames were analysed from each transect amounting to a total of 200 points per transect (1200 points per site).

Ten transects were conducted at Delambre Island in February 2008 to test that the level of replication and the transect sizes were capable of capturing the range of benthic types present.

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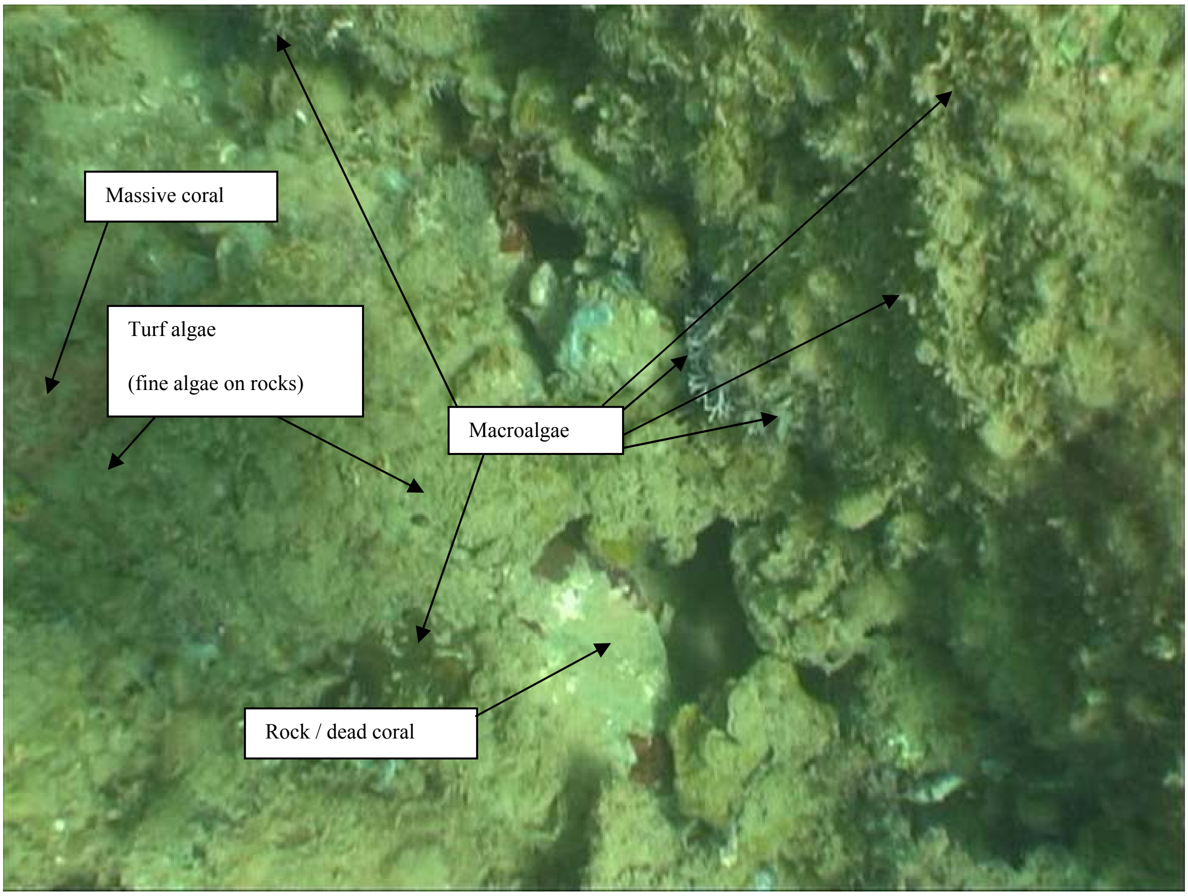
Delambre Island was appropriate for this test as it has a larger number of benthic types and coral growth forms than other sites and might therefore require greater spatial replication than other sites. Thus results from this site (in terms of a minimum number of transects) would be applicable to sites with less diversity of benthic types. Species accumulation plots from Delambre Island indicated that 6 replicate transects would capture more than 95% of the benthic categories.

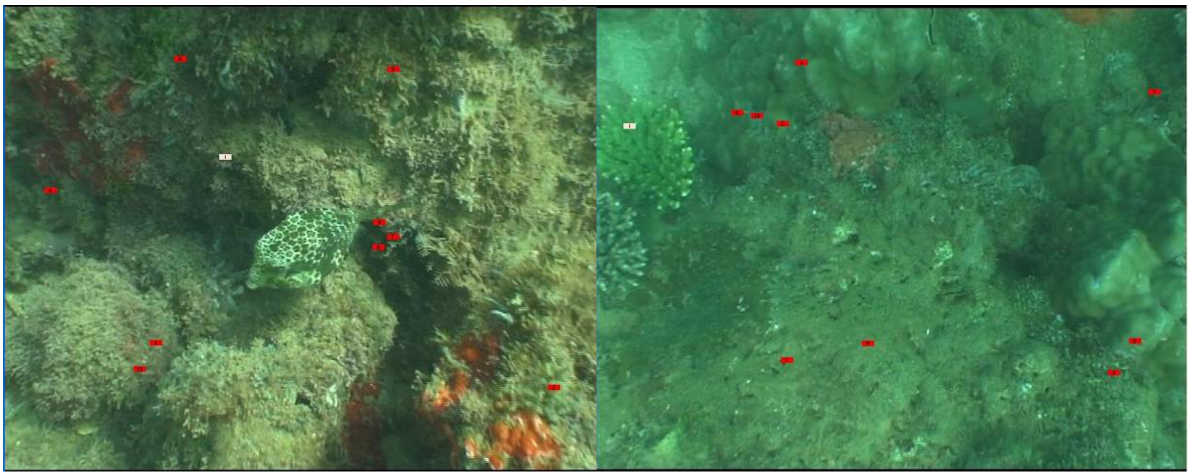
Species-accumulation plots have also shown this to be an optimum level of replication for benthic sampling in other locations (Westera, et al. 2008c). Based on other work (Houk and Van Woesik 2006) it is anticipated that a change of 30% in algal or coral cover with 80% power can be detected applying this approach. Houk and Van Woesik (2006) regarded this as an optimal sampling strategy in coral reef environments. Increases in univariate statistical power may be achievable with greater replication but, given the level of natural variability recorded at Cape Lambert (see **Section 3 Results**), a large number of additional replicates would likely be needed for only a marginal increase in power. Additionally, the power estimates do not apply to multivariate statistical analyses (Somerfield, et al. 2002).

The measurement of benthic cover on scales of tens of square metres allows extrapolation of data from quadrats to a larger area. The algal composition (described below) and benthic cover data can be used in combination to estimate the biomass of different algal types, or the gross benthic primary production, on a larger scale (100s of m^2) at each site. However, primary production estimates would require the use of experimental data from other studies that have quantified productivity. Benthic cover measures are a necessary component of monitoring that aims to detect changes at these scales. The use of quadrats alone yields information about the nature of an algal community on a scale of less than a metre and may overlook other habitat types within the site. Benthic cover measures (along transects) enable an assessment of the habitat characteristics of an area, which may influence fish or invertebrate assemblages, and the use of video provides a lasting record that can be re-analysed if necessary and compared with ongoing data collections to assess changes in marine communities over time. Measurements on this scale are sometimes overlooked in ecological studies where great emphasis is placed on fine scale measurements within quadrats or very coarse scales using aerial photography or remote sensing to map habitats.

The categories used for benthic cover classification and analyses were: macroalgae (larger erect algae), turf algae (fine filamentous species generally smaller than 5 mm), hard coral (defined by growth form), soft coral, seagrass, sponges, sand and rock (**Table 2.2**, **Figure 2.4** and **Figure 2.5**). Benthic cover data were analysed using multivariate statistical analyses that can be compared among sites and sampling events to assess the variability of the algal and coral communities.



- **Figure 2.4: Reference images of some of the benthic types: macroalgae; turf algae; coral massive; and rock / dead coral from a video frame**



- **Figure 2.5: Frame grabs from the AVTAS video analysis software used to evaluate percent cover of benthic types**

Note: rectangles are the randomly generated points (10 on each frame) under which the cover type (see ***Table 2.2****) is recorded.*

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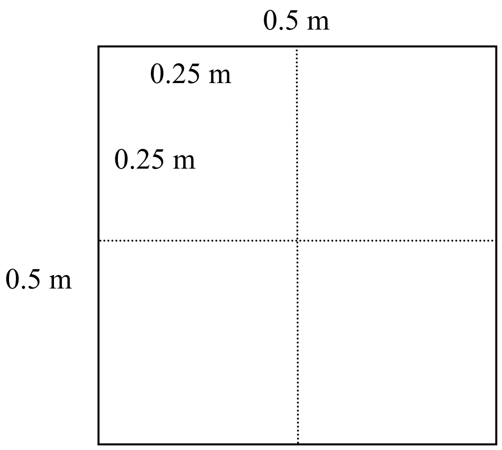
2.3. BPPH – Composition of algae and algal photoquadrats

Algae were collected from quadrats of 0.5 x 0.5 m (0.25 m^2) (n = 6) that were haphazardly placed on the reef. Quadrat placement was stratified on algae, i.e. if the placement resulted in the quadrat being on sand or predominantly coral, it was again haphazardly placed until it was on hard substrate dominated by algae. At the scale of a quadrat, the interest lies in the composition of algae and should not attempt to encompass all benthic types as this is done with the benthic transects. Stratified haphazard sampling such as this is widely used in marine surveys (Nichols 1982; McCormick and Choat 1987; Friedlander and Parrish 1997).

Prior to harvesting the algae, digital images were taken of the quadrat. Firstly, two images were taken of the whole 0.5 x 0.5 m (0.25 m^2) quadrat. Then a close-up image of each quarter of the quadrat was taken (i.e. an area of 0.25 x 0.25 m or 0.0625 m^2) (**Figure 2.6**). These photoquadrats provide a higher quality image than is achievable using video alone and reference images that can be used to aid species identifications and analyses for percent cover (**Figure 2.7** and **Figure 2.8**).

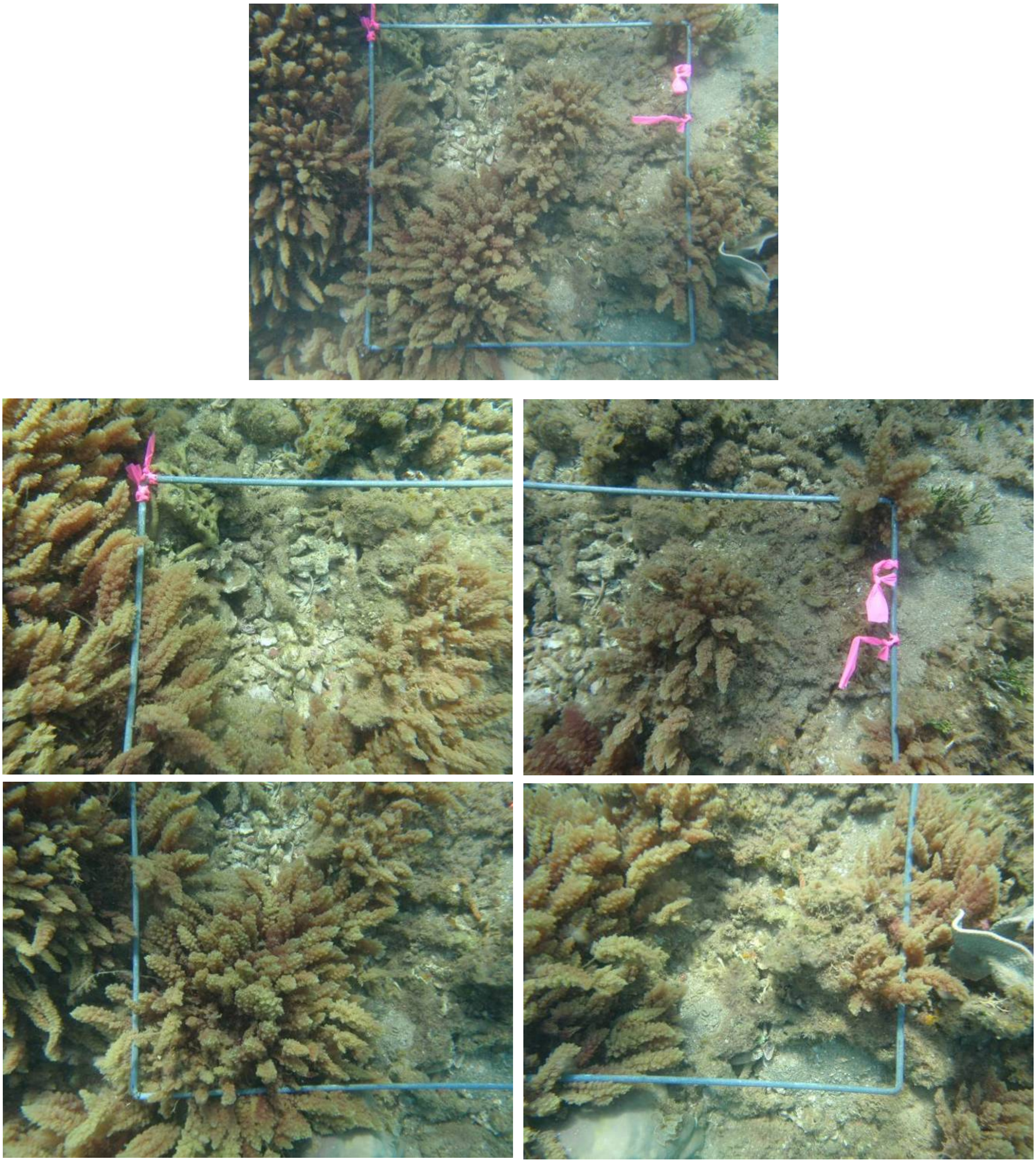
Macroalgae were removed from the substrate within the 0.5 x 0.5 m quadrat and placed into a large labelled calico bag. A scraper was then used to remove a minimum of three samples of the underlying substrate with turf algae attached and this was placed in a smaller calico bag. The turf samples were used for species identification but not weighed for biomass estimates. Instead presence / absence data on turf algae were added to the biomass measures for macroalgae for the analyses. Turf algae are too fine to be harvested quantitatively (per unit area) underwater as the fine pieces are caught by currents and rapidly drift away from the diver. The smaller bags were placed into the larger calico bag for each individual quadrat and placed in a catch bag for return to the surface. After each dive, the bag numbers were written onto a field sheet recording site, date and time. The bags were placed into a cool box with ice packs for transport to a laboratory. The algae were then sorted to species and wet weighed to determine the composition of algae (the number of species and their weight). Identifications were done by an algal taxonomist. Algal collections for this work were conducted under a Department of Fisheries “Licence to Take Fish for Scientific Purposes - number 05-09.”

Eleven quadrats were collected at Delambre Island in February to test that the level of replication was capable of capturing the range of benthic types. Species accumulation plots indicated that six samples captured approximately 92 % of the species likely to be recorded.



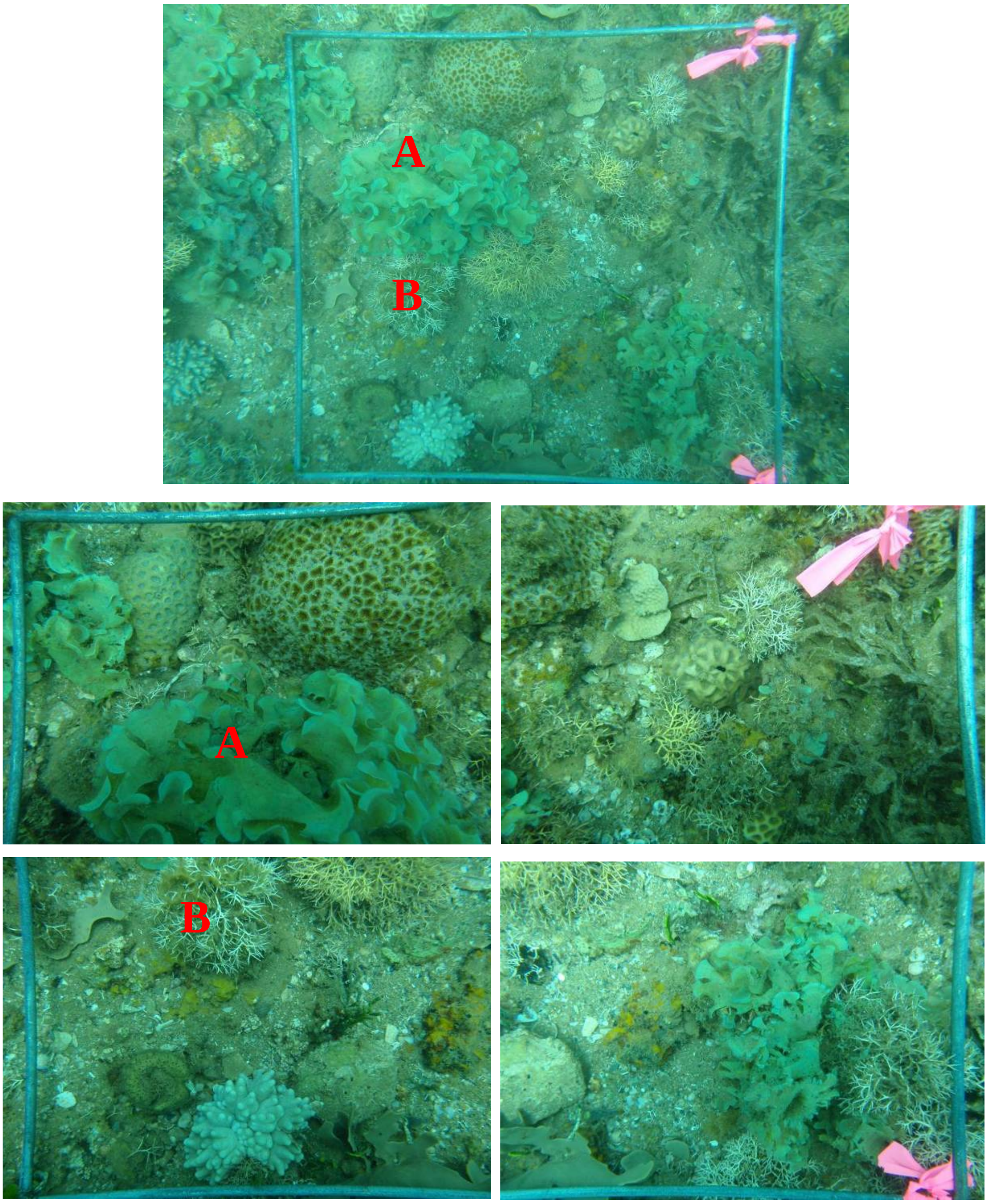
- **Figure 2.6: Schematic diagram of quadrat for harvesting algae**

Notes: dotted lines indicate the 4 quadrants of 0.25 x 0.25 m that are photographed.



- **Figure 2.7: Cape Lambert West (October 2008) - Configuration of algal photoquadrats taken at each site prior to harvesting the algae**

*Note: Abundant macroalgae (*Asparagopsis taxiformis*) which was present in October but not July*



- **Figure 2.8: Samson Beach (October 2008) - Configuration of algal photoquadrats taken at each site prior to harvesting the algae**

Notes: A – Stypopodium flabellilforme*; and B –* Amphiroa *sp;* S. flabelliforme *was abundant in October but not July.*

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2.4. Coral partial mortality measures

Coral partial mortality is a measure of the percentage of an individual coral that has died. Such mortality may result from changes in water temperature (Jones 2008), disease (Yarden, et al. 2007), sedimentation (Fernandez and Perez 2008), turbidity (Cooper, et al. 2008) or predation (Cumming 1999).

Measures of coral partial mortality were made at each of the 13 sampling sites by tagging and photographing sixty corals at each site. The corals were selected to ensure where possible that:

- the colonies were representative of each site in terms of size, condition and position with respect to the seabed;
- at each site corals from up to five species or genera were selected (where possible considering species diversity and abundance at the site);
- species or genera varied from highly sensitive species (such as *Acropora*) to less sensitive species (such as *Porites*), whenever such species were present in sufficient numbers; and
- the selection of species was evenly balanced with no one group dominating the other.

At each site, a target of a minimum of 50 tagged corals were inspected to determine the percent live coral cover as this was the minimum number required for the statistical analyses. This subset was chosen from the 60 tagged corals (to allow for damage/loss of some coral colonies, incorrect identifications or unusable photographs). The individual corals were identified by a metal reinforcing bar and numbered tag that was hammered into the reef adjacent to the each coral. To further assist in the identification of the tagged corals the divers used waterproof identification cards with colour images of the tagged corals.

Coral mortality was assessed by analysing high resolution digital still images of the tagged corals. The colony image was used to assess coral mortality using Coral Point Count with Excel Extensions (CPCe) (Kohler and Gill 2006). This software was developed by the US National Coral Reef Institute (Dania Beach, Florida) and is used by numerous organisations including US National Oceanic and Atmospheric Administration (NOAA) to estimate percentage cover of corals. This method of assessment was also used during the Cape Lambert Port A coral health monitoring program (MScience 2007).

The images were imported into CPCe and the boundary of each coral colony overlaid by a symmetrical 9 by 9 point grid. The points landing outside the coral boundary were excluded from the analyses while the points landing within the coral boundary were classified into major and sub-categories (**Table 2.3**). Images of the classification groups are found in **Figure 2.9** to **Figure 2.15**.

To calculate coral mortality, the major groups “Coral” and “Bleached coral” represent live coral while all the other major groups represent coral mortality. Bleached corals are still regarded as living and if stressful conditions subside they can regain their zooxanthellae (Marshall and Schuttenberg 2006). They may however suffer sub-lethal effects such as reduced growth rates in the interim.

There was also a major group classified as Tape, Wand and Shadow. This included points that landed within the coral boundary but the coral was not visible because it was obstructed by an object (i.e. a numbered tag or a shadow over that part of the coral). These points were not included in calculations of partial coral mortality.

- **Table 2.3: Coral classification categories**

Major categories	**Coral**	**Bleached coral**	**Dead coral**	**Sediment**	**Algae**	**Fauna**
Sub categories	Coral Pigment response Diseased coral	Bleached	Dead coral Recently dead coral	Fine sediment Sand Shell Rubble	Turf algae Macro algae Other algae	Bivalve Black borer Borer Drupella Hydroids Soft coral Sponges Other fauna

- **Figure 2.9: Examples of the major category – Coral**

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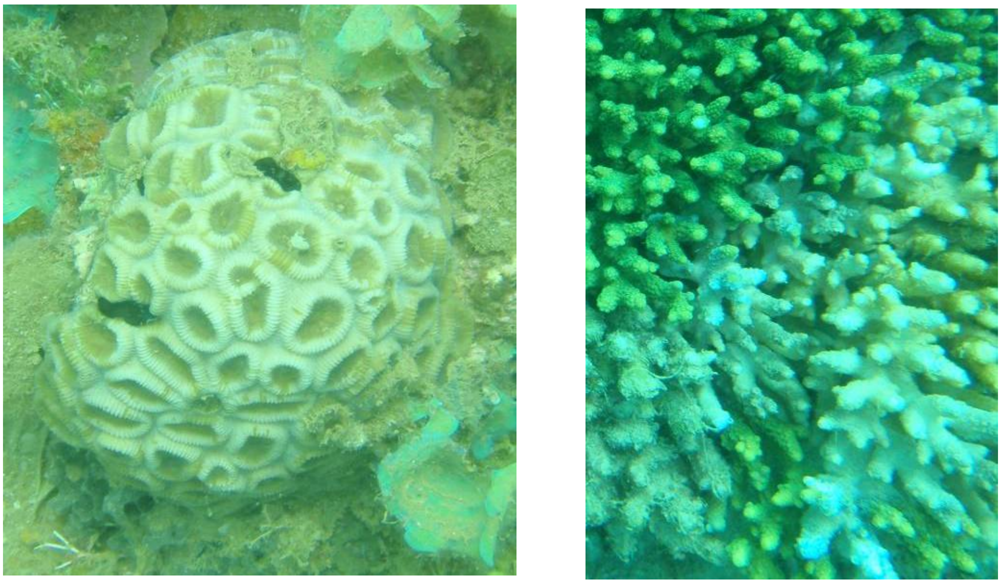
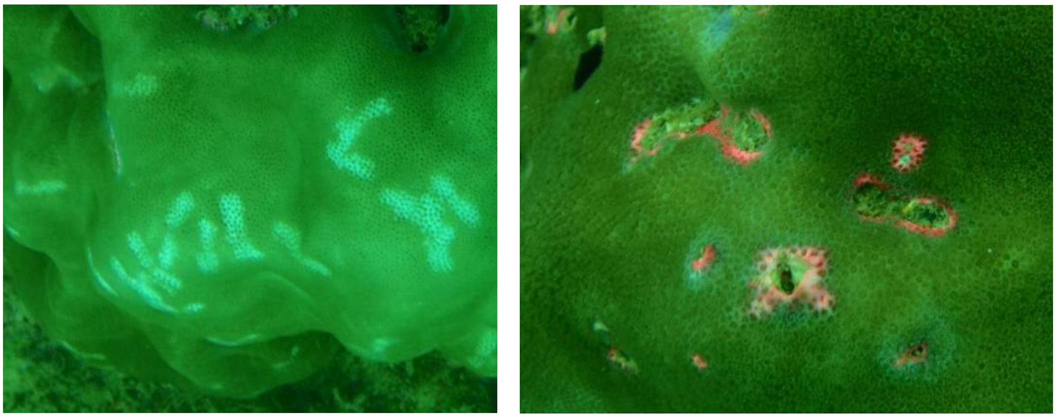


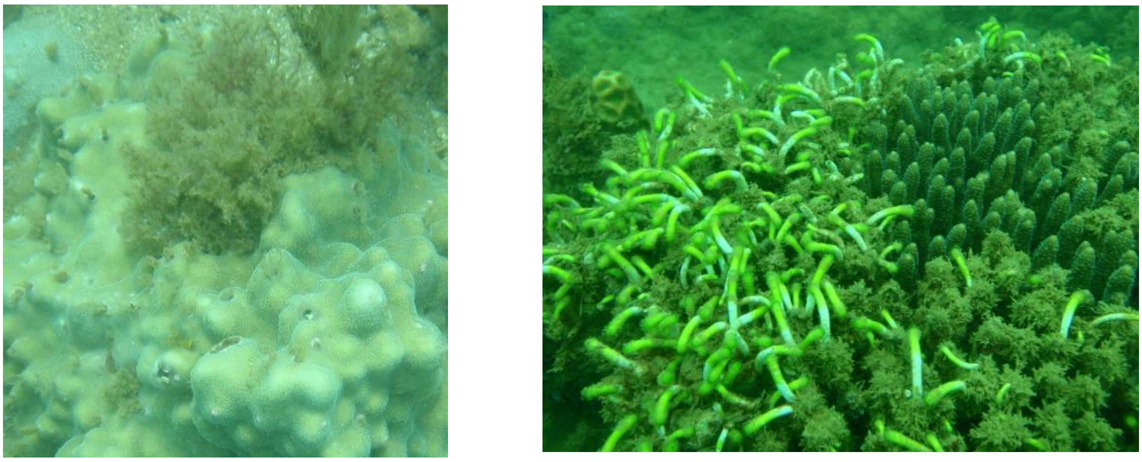
- **Figure 2.10: Examples of the major category – Bleached corals**



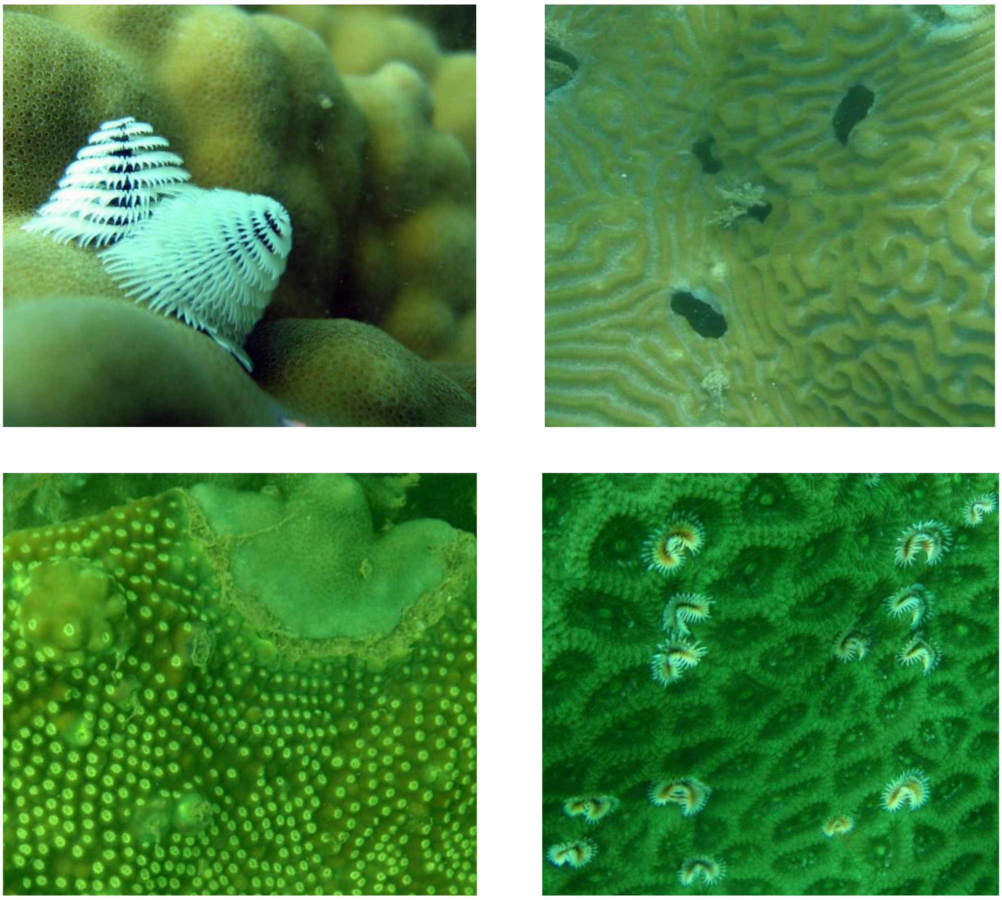
- **Figure 2.11: Examples of pigment response (fish scars)**

- **Figure 2.12: Examples of the major category – Dead coral**

- **Figure 2.13: Examples of the major category – Sediment**



- **Figure 2.14: Examples of the major category – Algae**



- **Figure 2.15: Examples of major category – Fauna**

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2.5. Statistical analyses and data presentation

2.5.1. Multivariate analyses of BPPH measures

This section of the report explains the statistical analyses used. Further insight into the techniques can be gained in Clarke and Warwick (2001) and Clarke and Gorley (2006). A separate set of analyses were done for each type of sampling (the composition of macroalgae and turf algae combined, and the composition of benthic cover) and is detailed in **Section 3 Results**. Analyses were done that enabled comparison of multiple variables, i.e. genera and their biomass (for algae) and benthic types and their percent cover (for benthic transects). These are termed multivariate data. Data were analysed firstly to compare sites (spatial analyses) for each sampling event (July and October 2008, February and May 2009) and then to compare sampling events (temporal analyses for the three or four times sampled).

Algae were analysed at the taxonomic level of genus as it was assumed that species within a genus would respond similarly to one another to any potential impact. In other studies genus level species richness has been shown to be strongly correlated to species diversity (Goldberg et al. 2006).

Multivariate analyses were done using the PRIMER 6 statistical package (Clarke and Gorley 2006). Non-metric multidimensional scaling (MDS) (Field, et al. 1982; Clarke 1993) was used to examine patterns in the composition of algae and benthic cover among sites and sampling events. MDS produces an ordination in which similar replicates or sites cluster together, based on their algal composition or benthic cover, and dissimilar replicates or sites are further apart. Compressing the ordinations to two dimensions for reporting, results in a loss of the clarity of data (i.e. sites may appear close to each other in two dimensional space but were not close in the original ordination). The stress value on each of the MDS ordinations in this report is a measure of how well the two dimensional ordination truly represents the multi dimensional ordination. Stress values greater than 0.25 indicate that the ordination does not provide a true representation of the replicates and should be treated with caution. Cluster analyses, calculated by the rank similarity matrix in PRIMER and based on the group average, were used to produce overlays on the MDS ordinations to highlight differences or similarities among sites or sampling events.

A focus of the monitoring was on potential changes in community structure not just dominant species. Therefore, data on the composition of algae were square root transformed allowing less abundant species to play a part in the analyses. No transformation was done for benthic transects as the interest was in the relative proportions of benthic cover among sites and sampling events.

Analyses of similarity (ANOSIM) (Clarke and Warwick 1994) were used to determine the significance of any clustering of replicates, within groups (sites or sampling events) in MDS ordinations. The tests were based on a Bray-Curtis rank similarity matrix. Data on the

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composition of macroalgae were zero adjusted prior to analyses in PRIMER (i.e. inserting dummy variable of 1 prior to similarity matrix) (Clarke, et al. 2006). ANOSIM produces a test statistic (R-value) that reflects the observed differences among sites or sampling events, contrasted with differences within these groups. The R-value cannot lie outside the range (-1, 1) and is usually a positive value. R = 1 if all replicates within groups are more similar to each other than to any replicates from different groups. R is approximately zero if the null hypothesis is true (i.e. similarities among and within groups are the same on average). The significance level is a percentage, and can be interpreted similar to a P-value in univariate statistics. If the value is less than 5% then differences are considered significant. However, it is important to consider both the R value and the significance level simultaneously. An R value close to zero (i.e. a weak trend) may be statistically significant because it is consistent, but not of great value in interpreting data (Clarke and Warwick 2001). Consequently, SKM chose *a priori* to interpret significant trends (i.e. significance < 5%) as: weak (R value of 0 to 0.3); moderate (R value of 0.3 to 0.6); and strong (R value of 0.6 to 1.0). One-way ANOSIM was used to make comparisons among sites and between sampling events within each site.

Similarity percentages (SIMPER) analyses were undertaken (Clarke 1993) to identify which species were driving any significant differences in the composition of marine assemblages. SIMPER produces an average dissimilarity among the groups (sites or sampling events) with higher values indicating greater dissimilarity, a ratio and a percent contribution for each of the species to the dissimilarity and the mean biomass. The consistency of each species in differentiating among groups is indicated by the ratio, which is the average dissimilarity divided by the standard deviation. A large ratio indicates that a species contributes a consistently large amount to dissimilarity among groups. If the % dissimilarity and the ratio are large, then the species not only contributes much to the dissimilarity but does so consistently, and is therefore a good discriminator (Clarke, 1993). Both ANOSIM and SIMPER produce pairwise comparisons that compare individual groups against one another. More detail on these analyses can be found in Clarke and Warwick (1994), Carr (1997) and Clarke and Warwick (2001).

A change in the marine assemblages over time, such as a shift in the dominant species would be highlighted by a change in the MDS ordinations, ANOSIM R-values and SIMPER outputs. These analyses would be applied to future data collections to assess the level of change among sites and sampling events. Bar charts were produced with the mean and standard error of algal biomass and benthic cover to provide an illustration of how these were composed at each site and sampling event.

2.5.2. Multivariate analyses of environmental data

Water quality data collected as part of the Port B development (SKM 2009b) were used to provide information on which environmental variables might influence the composition of algae or benthic

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cover. The median values of the BPPH data collections was used for each of turbidity (NTU), water temperature (°C) and sedimentation rates (mg cm^{-2} day^{-1}) for these analyses. Algae may respond to changes in environmental conditions such as temperature, turbidity or sedimentation in a period of weeks (Klumpp and McKinnon 1992; Umar, et al. 1998; Stiger and Payri 1999a; Lirman and Biber 2000; Padilla-Gamino and Carpenter 2007). Consequently, only the previous two months was used for this purpose as measures from that timeframe would most likely influence the biological measures (growth rates, recruitment, seasonality), not the full dataset which comprises of over 12 months of data. Hence the values for the environmental data quoted in this report may differ slightly from those in the water quality report (SKM 2009b) which utilise the full dataset.

MDS ordinations were produced to investigate similarities or differences in environmental variables among the sites. Bar charts were also produced to highlight trends and for comparison with the algal and benthic cover data. MDS ordinations of the algal and benthic transect data were overlain with vectors that were based on a Pearson's correlation between the environmental variables and the ordination scores to infer the degree of influence over the biological data (Clarke and Gorley 2006). These were further analysed using the BIOENV routine in PRIMER (Clarke and Ainsworth 1993; Clarke and Gorley 2006). This analysis produces a Spearman's rank correlation value and level of significance (similar to ANOSIM significance) to match environmental and biological data. This is based on a Euclidean distance resemblance measure. It also provides Spearman's correlations for each variable individually. From these it is possible to see which of the environmental variables (if any) are closely correlated to the algal or benthic cover datasets for each site.

Correlations between algal or benthic cover data and environmental variables were interpreted as proposed by Fowler and Cohen (1990) (**Table 2.4**).

- **Table 2.4: Interpretation of correlation coefficient values**

R value	Interpretation
0.00 to 0.19	A very weak correlation
0.20 to 0.39	A weak correlation
0.40 to 0.69	A modest correlation
0.70 to 0.89	A strong correlation
0.90 to 1.00	A very strong correlation

Source: Fowler and Cohen (1990)

2.5.3. Univariate analyses of coral partial mortality measures

Each coral image (i) was assigned a percentage partial mortality (PM) estimate by dividing the number of points scored as mortality (M) by the total number of points within the coral boundary (N) using the equation: PM (i) = M/N. Then, for each monitoring site, the partial mortality was

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calculated as the average partial mortality of all the corals scored at that site for that particular survey -

$PM(s,x) = \Sigma PM(i,s,x)/N$, where:

- PM = partial mortality;
- s = site name;
- x = survey number;
- i = coral images, where i goes from 1 to N corals; and
- N = number of corals scored at the particular site.

2.5.3.1. Statistical power analyses of coral partial mortality measures

One of the objectives of this coral mortality monitoring was to provide a quantitative measure of coral health which could be assessed against possible management trigger levels. The management trigger levels will be based on the data collected during these baseline surveys, however indicative trigger levels based on previous dredging programs are suggested to be within the range of 0% to 10% partial mortality. For this management approach to be successful, the monitoring program needs to be able to adequately detect changes within this range of partial mortality. This can be determined by performing power analyses on the baseline data.

A power analysis was done on data collected from each site from the first survey to determine the percent change that could be detected with sufficient confidence. The inputs used for this power analysis to calculate the effect size were: power 0.8 and α 0.05. The effect size was then multiplied by the average standard deviation for coral "mortality" to give the percent change that could be detected with 80% confidence.

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3. Results

3.1. Species richness and algal biomass

A total of 76 species of algae were recorded from the 13 sites over the four sampling events. These were from 54 genera and 30 families and included both macroalgae and turf algae. A full list of species is provided in the Appendix (**Table A.1**).

The dominant species / genera collected included: *Amphiroa* sp., *Asparagopsis taxiformis*, *Lobophora variegata*, *Stypopodium flabelliforme* and *Padina boryana*. Less common algae included *Halimeda* sp, *Hypnea* sp, *Turbinaria ornata*, *Dictyota* sp, *Galaxaura rugosa*, *Laurencia* sp, *Neomeris* sp and *Sargassum* sp. Images of some of these are presented in **Figure 3.1**.

The site with the highest biomass of algae was Samson Beach with 196 g. 0.25 m^{-2} in October 2008 (**Figure 3.2**) however biomass varied among sampling events. This was driven by large amounts of *Stypopodium flabelliforme*, *Halimeda* and *Lobophora*. Cape Lambert West also had high biomass of *Asparagopsis taxiformis* in October. Other sites generally recorded between 10 and 80 g. 0.25 m^{-2}. The site with the lowest biomass was Bezout Island. At some sites there was a general trend of less biomass of algae in February and May than in July and October (e.g. Bells Reef, Bezout Rock, Cape Lambert West, Hat Rock, Mangrove Point, Middle Reef and Power Station).

A new genus was recorded for the region *Rhodogorgon* sp. which has previously not been described in Western Australia. This was collected from Dixon Island East in May 2009. This genus was originally described from the Caribbean and has subsequently been recorded in the Indo-Pacific (Huisman pers. com.).

Results are presented as temporal analyses including all sites. These data showed high variability among sites so sites were presented individually to investigate changes over time.

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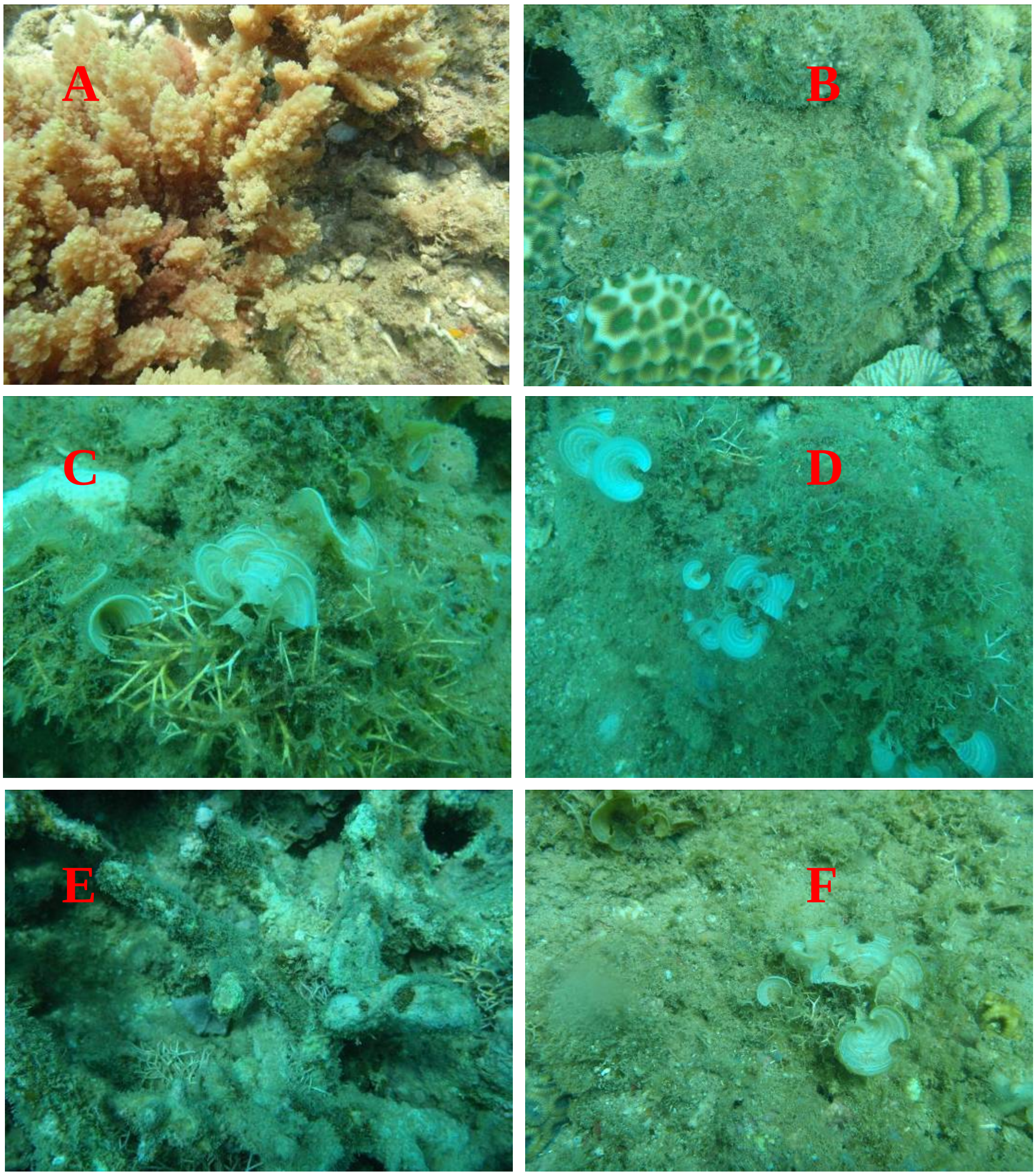

- **Figure 3.1: Close-up images of macroalgae**

A – Cape Lambert West (mainly *Asparagopsis taxiformis*);

B – Bezout Island (turf and corals);

C – Bezout Rock (*Padina boryana* and *Amphiroa sp*.);

D – Boat Rock (*Padina boryana*, *Amphiroa sp*. and turf);

E – Delambre Island (mainly turf); and

F – Dixon Island East (*Padina boryana* and turf).

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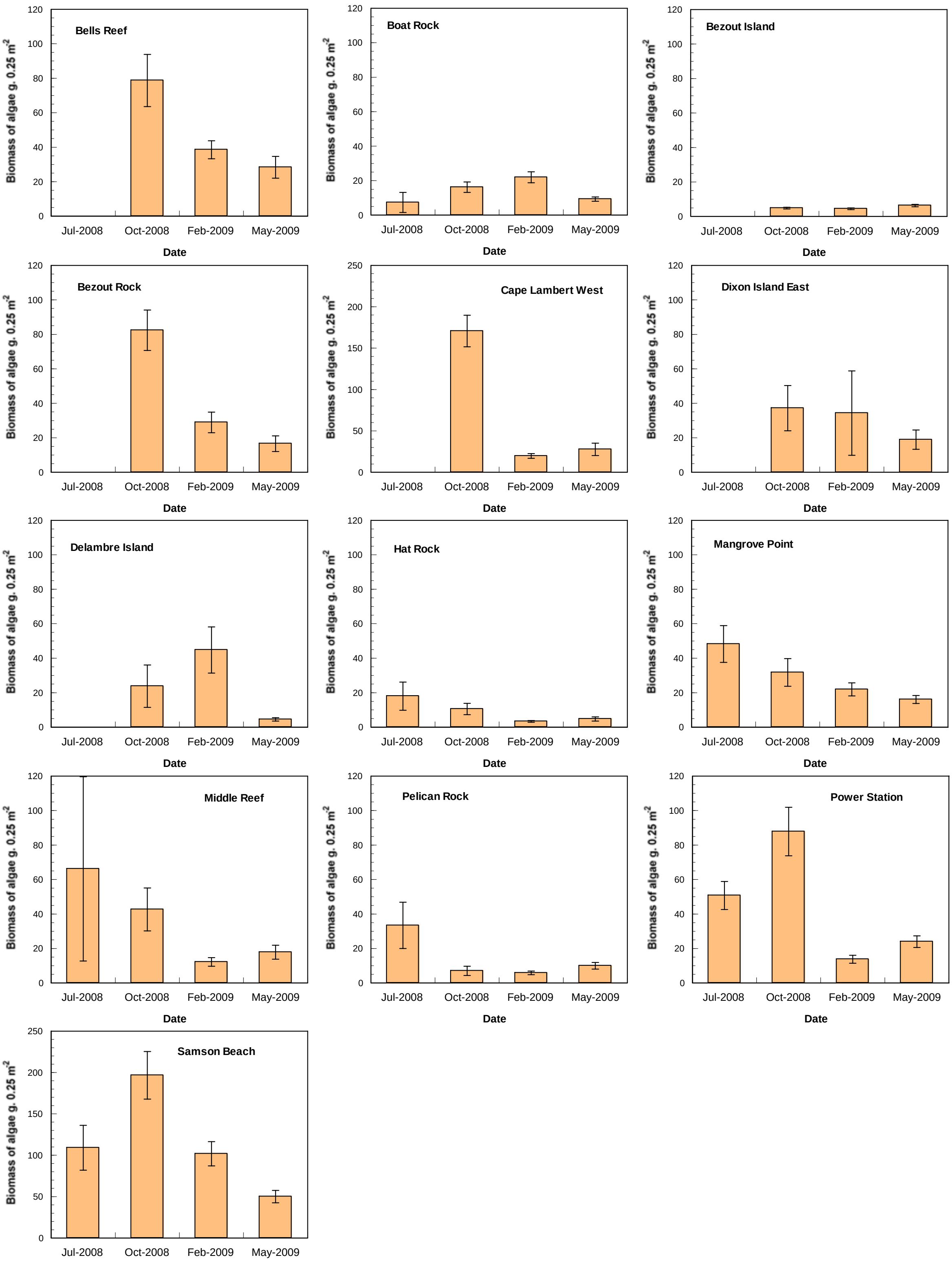

- **Figure 3.2: Mean biomass (± S.E.) of algae per quadrat (0.25 m^{-2}) for each site and sampling event.**

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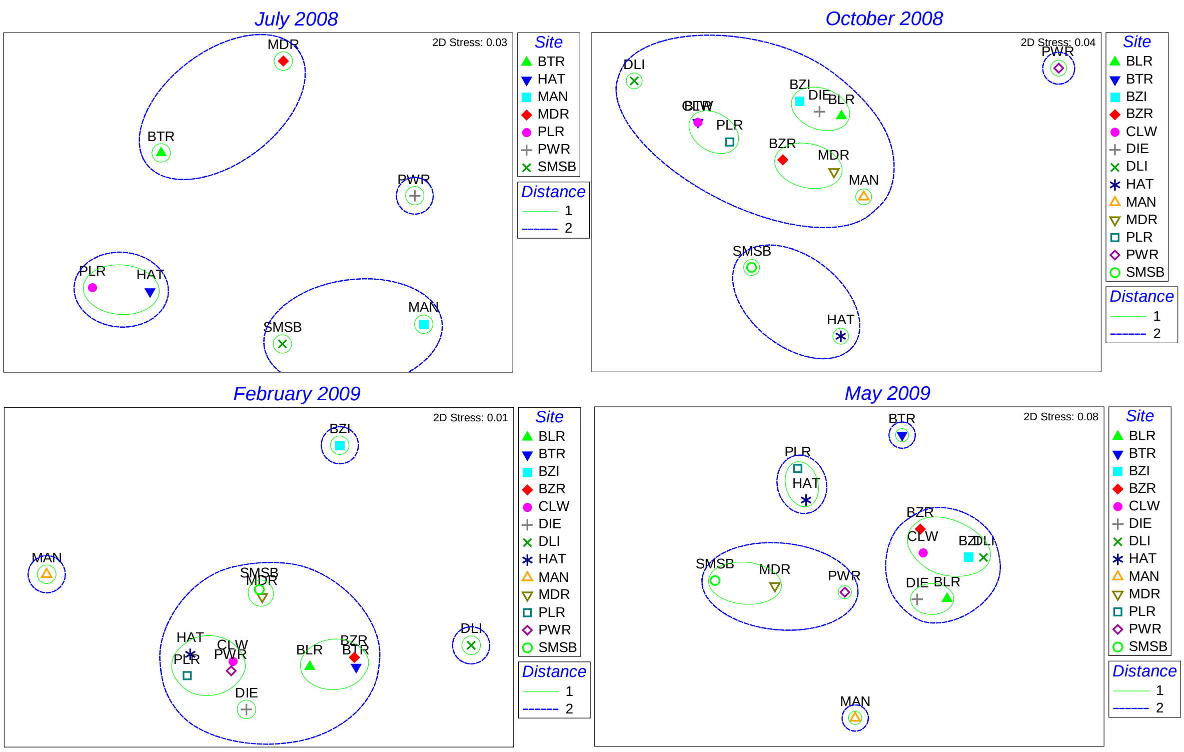
3.2. Differences in environmental variables

There were no consistent patterns in MDS ordinations of physical variables (turbidity, water temperature and sedimentation) among sites within each sampling event (**Figure 3.3**). Cluster analysis overlays showed similarity among sites but this was different for each sampling event. Dixon Island East, Bells Reef and Bezout Rock (all to the east of Cape Lambert) were similar in October, February and May. Samson Beach and Middle Reef (immediately to the east of Cape Lambert) were similar for both February and May. Mangrove Point was not similar to any other sites in February and May, nor was Power Station similar to any other site in July and October. Pelican Rock and Hat Rock (further east of Cape Lambert) were similar in July, February and May but not October. These trends will be described further with the algal and benthic cover data (**Section 3.3** and **Section 3.4)**.



- **Figure 3.3: MDS ordinations of environmental variables (medians of NTU, temperature and sedimentation) for 2 months preceding algal and benthic cover data collections for each sampling event.**

Notes:

Circles represent similarity among sites based on group average cluster analysis.

Only seven sites sampled in July 2008.

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3.3. Composition of macroalgae and turf algae

MDS ordinations generally showed clustering of replicates for each site for each sampling occasion and differentiation among some sites (**Figure 3.4**). Group average cluster analyses also showed similarity among some sites and in some cases these relationships were consistent with the physical data (**Figure 3.3** and **Figure 3.4**). Particular examples of similarities in both biological and environmental data were: Hat Rock and Pelican Rock in July and February; Bezout Rock, Bells Reef and Boat Rock in February; and Cape Lambert West and Power Station in February. ANOSIM global R values and pairwise comparisons showed differences between many sites within each time and analyses could not be grouped by sites. Consequently, it was necessary to conduct further analyses site by site.

Trends or patterns in the composition of algae are described in the following sections. Results from selected sites that show the different trends over time have been described. Examples of these are where one sampling event is different to the other sampling events in MDS and ANOSIM (e.g. Bells Reef), where all sampling events are separate in MDS and ANOSIM (e.g. Boat Rock) and where there are no clear trends or differences among sampling events (e.g. Dixon Island East).

3.3.1. BLR – Bells Reef

At Bells Reef the MDS ordination showed a clear separation between the October data, and the combined February and May data, and clear groupings in the cluster analysis overlay (**Figure 3.5**). These differences were supported by very strong ANOSIM R values particularly between Oct and Feb (ANOSIM R = 0.998) (**Table 3.1**). The vector overlay indicated that all physical variables were correlated (Pearson's R) with the algal composition data. BIOENV showed a strong overall relationship (Spearman's R correlation) between the biological and environmental variables. On an individual basis, NTU and temperature had the highest correlations (0.748 and 0.709 respectively) indicating that these may have had a greater influence than sedimentation over the algal composition at this site. Differences in the algal composition over time were driven by *Stypopodium* which was prevalent in October but not recorded in other months, and by differences in *Amphiroa* and *Lobophora* (**Table 3.1**).

The water temperature was lower in October than in February and May (24.6°C, 30.1°C and 28.7°C respectively) (**Figure 3.5**). There was more sedimentation in February (11.2 mg cm^{-2} day^{-1}) than in October and May. Turbidity was low throughout ranging from 0.96 to 1.35 NTU.

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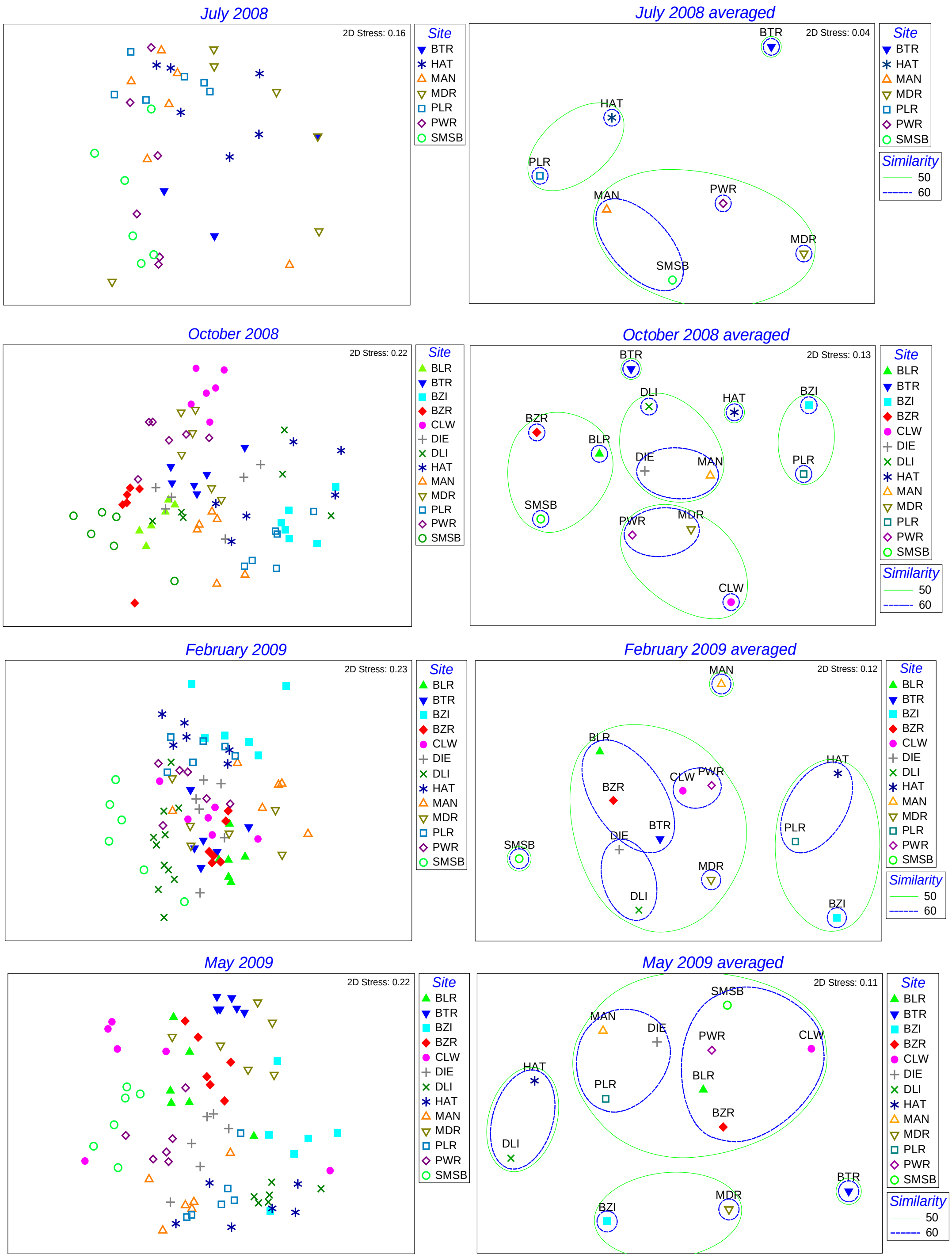

- **Figure 3.4: MDS ordinations to compare the composition of algae (biomass g. 0.25 m^{-2}) among sites for each sampling event.**

Notes:

Charts on the left illustrate each individual replicate while charts on the right represent averaging of replicates at each site and sampling event.

Circles denote level of similarity (50% and 60% using group average cluster analyses) among sites.

3.3.2. BTR – Boat Rock

The MDS at Boat Rock showed a clear separation among all three sampling occasions with groupings at the 50% similarity level, based on the cluster analysis (**Figure 3.5**). This was supported by strong ANOSIM R values (**Table 3.1**), particularly between October and May (ANOSIM R = 0.983). Temperature, NTU and sedimentation were all correlated with the differences in algal composition as indicated by the vector overlay.

Trends in the environmental data were very similar to Bells Reef with higher water temperatures in February and May (approximately 30°C), a peak in sedimentation in February and low turbidity. BIOENV showed a modest correlation for the combined environmental variables and for each of the variables individually. Differences in the composition of algae were driven by more *Amphiroa* in February and more *Padina* in October.

3.3.3. DIE – Dixon Island East

At Dixon Island East there was no clear pattern in the MDS ordination or groupings based on cluster analysis (**Figure 3.5**). The vector overlay also showed much smaller vector trajectories indicating that NTU, temperature and sedimentation played a lesser influence than at other sites. Pairwise ANOSIM R values were weak between most sampling events with the exception of October and May which showed a moderate difference (0.369). BIOENV showed weak or very weak correlations. Unlike most other sites, sedimentation did not show a peak in February and remained low (1.2 to 2.4 mg cm^{-2} day^{-1}), along with turbidity.

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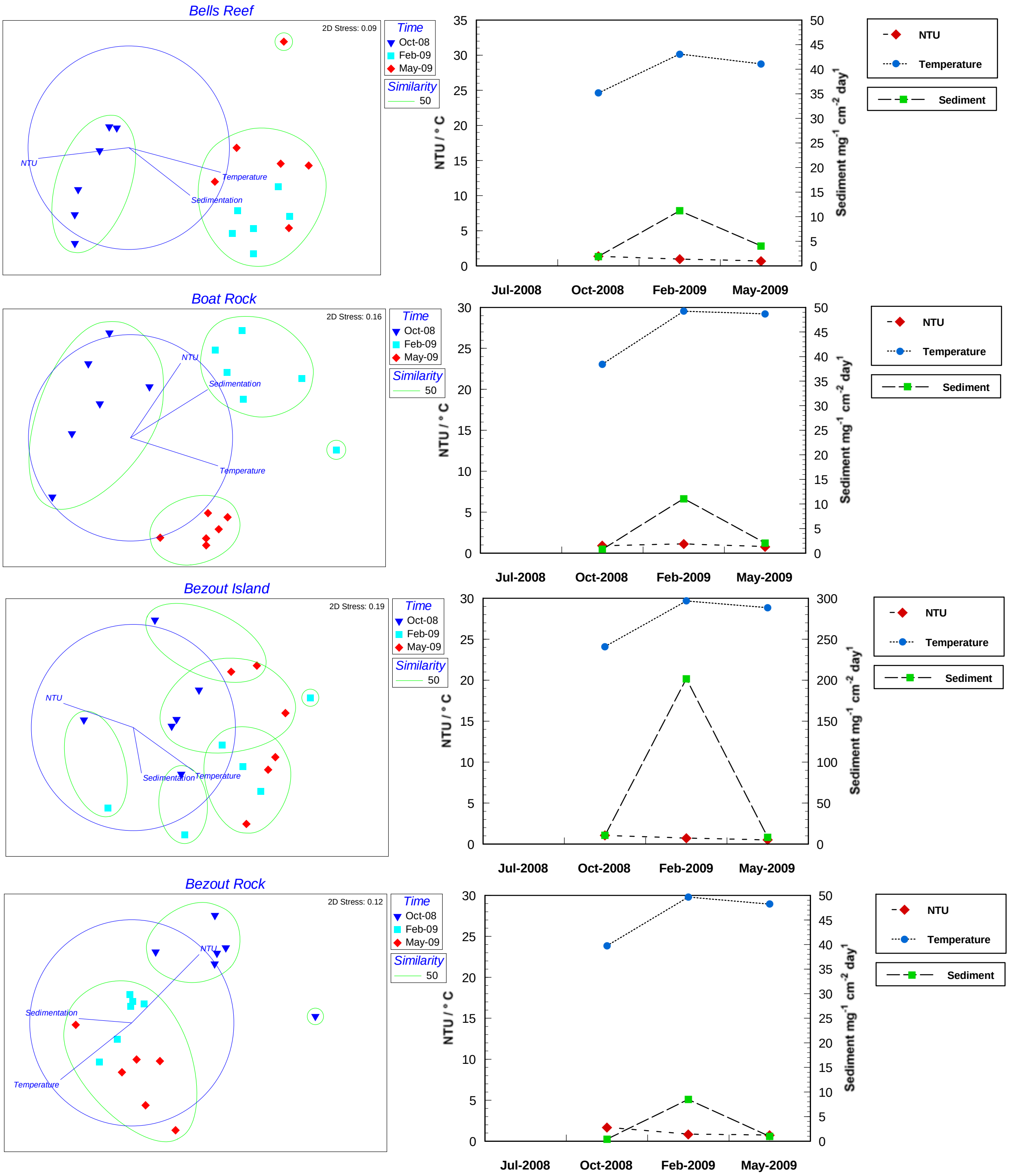

- **Figure 3.5: MDS ordinations to compare the composition of algae among sampling events at each site; and line chart of physical variables (median) for two months preceding data collections**

Note: figure continues on following three pages.

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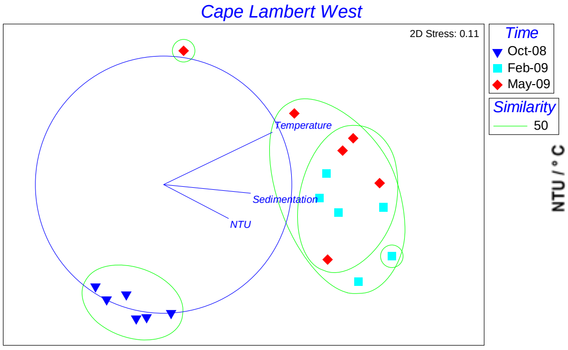
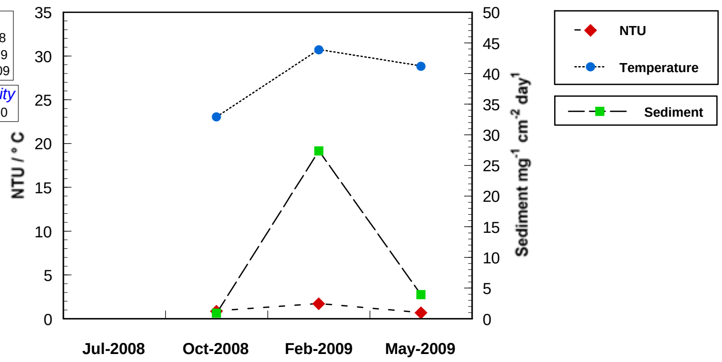
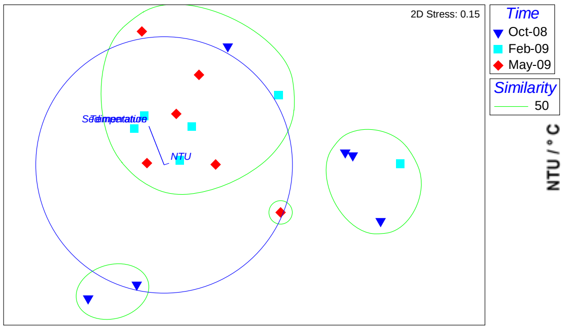
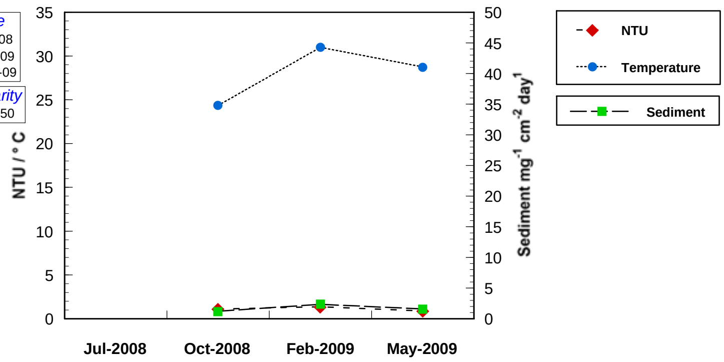
Cape Lambert West



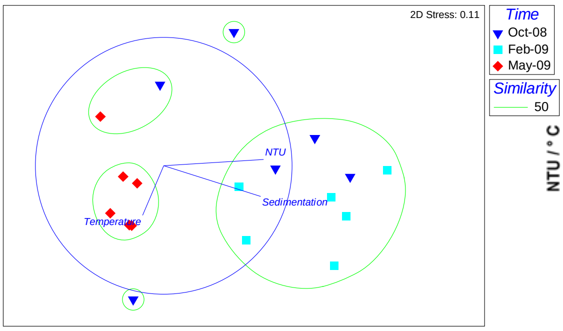


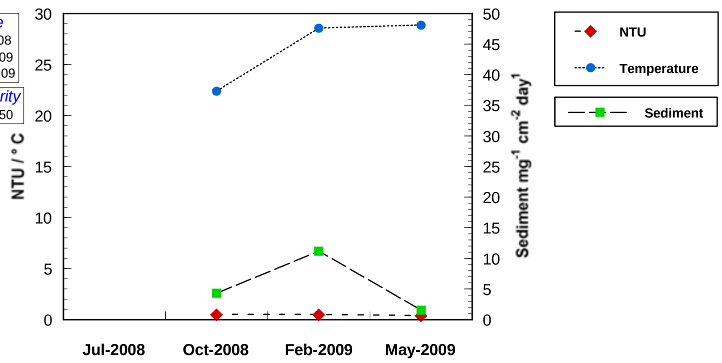
Dixon Island East



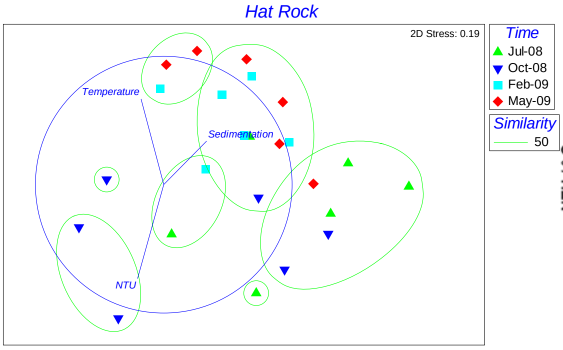


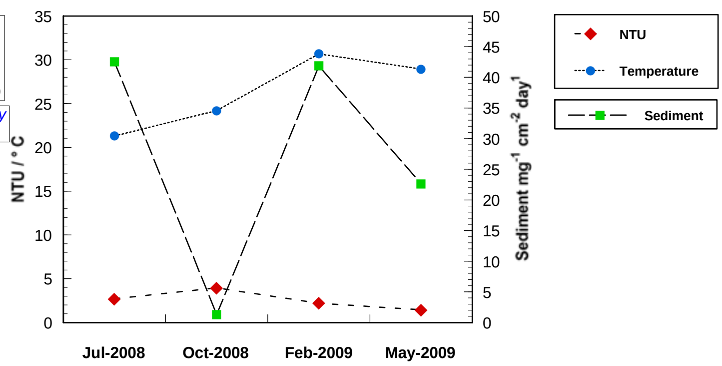
Delambre Island





Hat Rock





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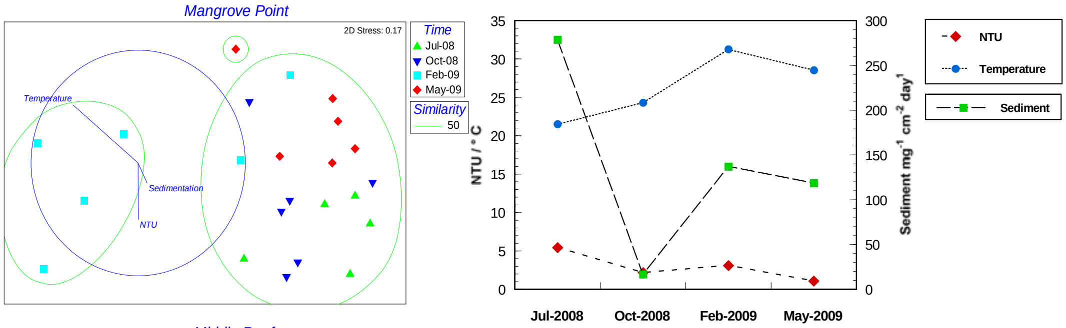
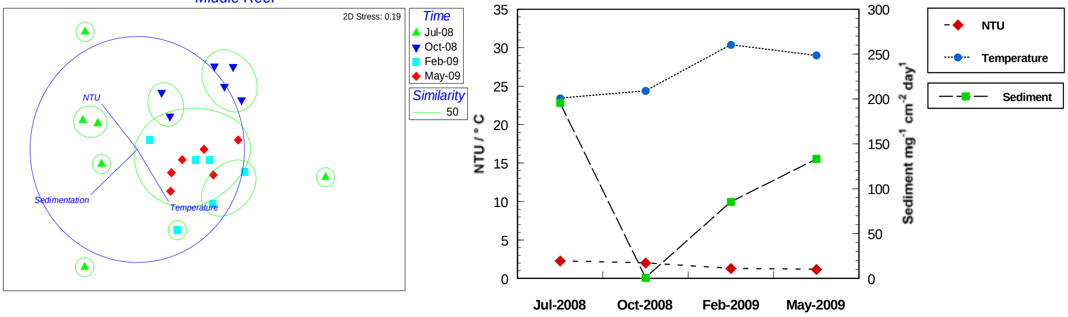
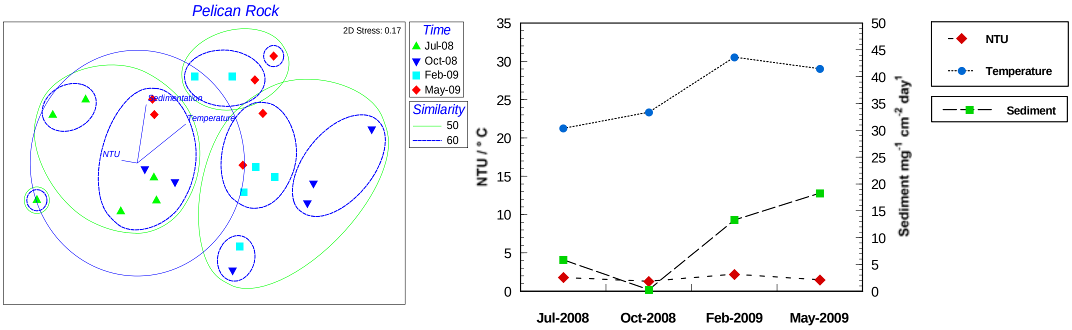
Mangrove Point



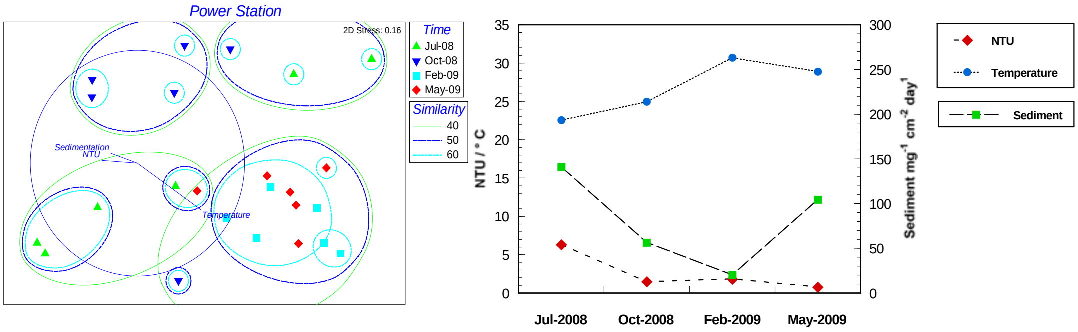
Middle Reef



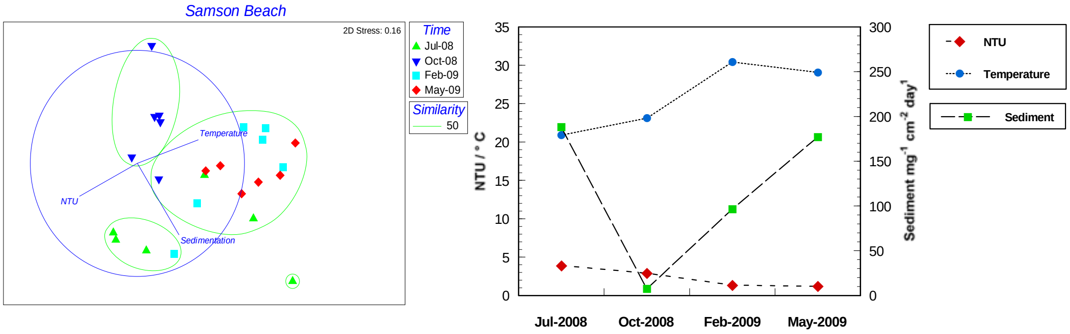
Pelican Rock



Power Station



Samson Beach



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- **Table 3.1: ANOSIM - R values, significance and pairwise comparisons of algal composition among sampling events; BIOENV correlations (Spearman's Rho and significance) for physical variables; and SIMPER output (mean g. 0.25 m-2) on species driving any significant differences**

SITE	ANOSIM R and sig %		BIOENV - Rho value and sig %		ANOSIM R and sig %		BIOENV - Rho value and sig %
BELLS REEF	0.692 – 0.1		0.748 – 1.0	CAPE LAMBERT WEST	0.804 – 0.1		0.753 – 0.1
Oct-08, Feb-09	0.998 – 0.2	NTU	0.748	Oct-08, Feb-09	1.000 – 0.2	NTU	0.250
Oct-08, May-09	0.896 – 0.2	Temp	0.709	Oct-08, May-09	0.900 – 0.2	Temp	0.753
Feb-09, May-09	0.246 – 3.0	Sediment	0.407	Feb-09, May-09	0.363 - 0.2	Sediment	0.485
SIMPER	Oct-08	Feb-09	May-09	SIMPER	Oct-08	Feb-09	May-09
Amphiroa	41.3	11.3	4.8	*Asparagopsis*	160.93	0.0	0.10
Stypopodium	16.9	0.0	0.0	*Halimeda*	0.33	8.22	11.42
Lobophora	14.1	4.8	8.6	*Laurencia*	0.0	1.05	10.63
BOAT ROCK	0.829 – 0.1		0.544 – 0.1	DIXON ISLAND EAST	0.268 - 1.3		0.388 – 3.0
Oct-08, Feb-09	0.678 – 0.2	NTU	0.494	Oct-08, Feb-09	0.252 – 5.4	NTU	0.003
Oct-08, May-09	0.983 – 0.2	Temp	0.544	Oct-08, May-09	0.369 – 1.5	Temp	0.388
Feb-09, May-09	0.806 – 0.2	Sediment	0.504	Feb-09, May-09	0.120 – 9.7	Sediment	0.168
SIMPER	Oct-08	Feb-09	May-09	SIMPER	Oct-08	Feb-09	May-09
Amphiroa	4.58	10.97	4.08	*Amphiroa*	4.0	3.4	2.0
Padina	5.87	0	0	*Padina*	1.1	0.0	0.0
Hypnea	1.92	3.12	0	*Lobophora*	2.1	1.9	2.5
BEZOUT ISLAND	0.222 – 0.6		0.235 – 1.5	DELAMBRE ISLAND	0.535- 0.1		0.515 – 0.1
Oct-08, Feb-09	0.277 – 1.3	NTU	0.235	Oct-08, Feb-09	0.128 – 8.7	NTU	0.515
Oct-08, May-09	0.352 – 0.4	Temp	0.219	Oct-08, May-09	0.439 – 0.9	Temp	0.253
Feb-09, May-09	0.045 – 28.8	Sediment	0.051	Feb-09, May-09	0.896 – 0.2	Sediment	0.436
SIMPER	Oct-08	Feb-09	May-09	SIMPER	Oct-08	Feb-09	May-09
Peyssonnelia	1.00	0.17	0.00	*Amphiroa*	21.2	52.5	0.0
Pterocladiella	0.00	0.67	0.67	*Parvocaulis*	0.3	0.8	0.0
Gelidiella	0.17	0.00	0.67	*Lobophora*	0.5	0.8	0.8
BEZOUT ROCK	0.710 – 0.1		0.734 – 1.0				
Oct-08, Feb-09	0.770 – 0.2	NTU	0.734				
Oct-08, May-09	0.885 – 0.2	Temp	0.620				
Feb-09, May-09	0.507 – 0.2	Sediment	0.343				
SIMPER	Oct-08	Feb-09	May-09				
Amphiroa	5.3	3.5	2.0				
Stypopodium	3.3	0.0	0.0				
Padina	3.0	0.2	0.0				

Note: table continues on following page.

ANOSIM and BIOENV values in the same row as the site name are the overall value, subsequent ANOSIM values are the results of pairwise comparisons between sampling events, subsequent BIOENV values are for each individual environmental parameter. Blue shaded cells indicate moderate or strong ANOSIM R and modest to very strong BIOENV correlation (see methods). SIMPER values are the mean biomass for the respective algal species and sampling event.

SITE	ANOSIM R and sig %		BIOENV - Rho value and sig %			ANOSIM R and sig %		BIOENV - Rho value and sig %	
HAT ROCK	0.297 – 0.1		0.412 – 0.1		PELICAN ROCK	0.312 – 0.2		0.310 – 0.1	
Jul-08, Oct-08	0.144 – 12.6	NTU	0.355		Jul-08, Oct-08	0.298 – 3.2	NTU	0.028	
Jul-08, Feb-09	0.372 – 1.1	Temp	0.259		Jul-08, Feb-09	0.669 – 0.2	Temp	0.310	
Jul-08, May-09	0.224 – 5.4	Sediment	0.324		Jul-08, May-09	0.522 – 0.2	Sediment	0.188	
Oct-08, Feb-09	0.587 – 0.2				Oct-08, Feb-09	0.100 – 21.2			
Oct-08, May-09	0.444 – 0.6				Oct-08, May-09	0.298 – 3.2			
Feb-09, May-09	0.063 – 28.8				Feb-09, May-09	0.050 – 30.5			
SIMPER	Jul-08	Oct-08	Feb-09	May-09	SIMPER	Jul-08	Oct-08	Feb-09	May-09
Lobophora	16.0	3.5	1.0	2.4	*Lobophora*	27.6	5.0	2.6	5.9
Padina	0.0	1.4	0.0	0.0	*Sargassum*	3.6	0.0	0.0	0.0
Amphiroa	0.3	1.0	0.1	0.1	*Peyssonnelia*	0.0	0.7	0.5	0.2
MANGROVE POINT	0.409-0.1		0.287 – 2.0		POWER STATION	0.548 – 0.1		0.528 – 1.0	
Jul-08, Oct-08	0.016 – 39.8	NTU	0.017		Jul-08, Oct-08	0.470 – 0.9	NTU	0.322	
Jul-08, Feb-09	0.635 – 0.9	Temp	0.287		Jul-08, Feb-09	0.570 – 0.2	Temp	0.517	
Jul-08, May-09	0.264 - 3.0	Sediment	0.016		Jul-08, May-09	0.524 – 0.6	Sediment	0.254	
Oct-08, Feb-09	0.589 – 0.6				Oct-08, Feb-09	0.865 – 0.2			
Oct-08, May-09	0.344 – 0.6				Oct-08, May-09	0.789 – 0.2			
Feb-09, May-09	0.552 – 0.9				Feb-09, May-09	0.128 – 10.8			
SIMPER	Jul-08	Oct-08	Feb-09	May-09	SIMPER	Jul-08	Oct-08	Feb-09	May-09
Lobophora	38.0	4.2	4.2	12.1	*Asparagopsis*	0.2	41.9	0.0	0.0
Amphiroa	4.2	5.6	1.9	0.4	*Amphiroa*	32.7	17.4	2.6	3.2
Caulerpa	1.0	0.9	2.5	0.2	*Lobophora*	15.1	6.8	3.0	7.2
MIDDLE REEF	0.458 – 0.1		0.538 – 0.1		SAMSON BEACH	0.460 – 0.1		0.413 – 0.1	
Jul-08, Oct-08	0.409 – 1.1	NTU	0.458		Jul-08, Oct-08	0.509 – 0.2	NTU	0.364	
Jul-08, Feb-09	0.381 – 0.6	Temp	0.297		Jul-08, Feb-09	0.257 – 5.0	Temp	0.366	
Jul-08, May-09	0.415 – 0.4	Sediment	0.435		Jul-08, May-09	0.457 – 0.4	Sediment	0.370	
Oct-08, Feb-09	0.583 – 0.2				Oct-08, Feb-09	0.678 – 0.2			
Oct-08, May-09	0.850 – 0.2				Oct-08, May-09	0.847 – 0.2			
Feb-09, May-09	0.220 – 0.8				Feb-09, May-09	0.102 – 19.7			
SIMPER	Jul-08	Oct-08	Feb-09	May-09	SIMPER	Jul-08	Oct-08	Feb-09	May-09
Asparagopsis	0.3	28.4	0.0	0.0	*Stypopodium*	0.0	117.1	0.0	0.0
Amphiroa	55.4	8.2	6.5	8.8	*Lobophora*	28.2	3.2	6.2	10.3
Hypnea	5.1	0.2	0.4	1.3	*Halimeda*	21.4	21.2	53.0	22.8

3.4. Composition of benthic cover

Turf algal cover was generally higher than any other benthic category and ranged from 6% at Samson Beach in October to 64% at Boat Rock in Feb 2009 (**Figure 3.6**). Many sites had consistently high cover of approximately 40% or more for all four sampling events including Boat Rock, Bezout Island, Bezout Rock, Cape Lambert West, Dixon Island East, Mangrove Point and Middle Reef.

Sand was the next most dominant cover category. Cover of sand ranged greatly at some sites particularly Samson Beach with approximately 26% cover in July and May and up to 48% in October and February. Live hard coral cover also ranged over sampling events at some sites. The sites with the most cover of live hard coral were Bezout Island and Delambre Island (approximately 50% and 55% respectively). Macroalgal cover ranged from 0 to 30% generally being the greatest at Samson Beach.

As for algal composition, MDS ordinations generally showed clustering of replicates for sites for each sampling event and differentiation among some sites. Bells Reef, Power Station and Mangrove Point were 80% similar to one another in terms of the cluster analysis overlays for both February and May (**Figure 3.7**). Middle Reef and Cape Lambert West were both 80% similar to one another in February and May.

As for the algal composition data the high level of among site variability necessitated analyses to be done site by site. Trends in the composition of benthic cover are described below for a selection of sites that show the range of different trends over time. Examples of these are: where one sampling event differs from the other sampling events combined in MDS and ANOSIM (e.g. Bells Reef), where all sampling events are different in MDS and ANOSIM (e.g. Delambre Island); and where there are no clear or significant differences among sampling events (e.g. Bezout Island).

3.4.1. BLR – Bells Reef

At Bells Reef the MDS ordination showed a separation of the October data from the other sampling events and a clear grouping of the October samples in the cluster analysis overlay (**Figure 3.8**). This was similar to the trend in algal composition at Bells Reef (**Figure 3.5**). The differences were supported by strong ANOSIM R values between October and other sampling events but non–significant values between February and May (**Table 3.2**). BIOENV showed a modest and significant correlation between the environmental variables and benthic cover (**Table 3.2**). NTU and temperature were the variables most closely correlated to the benthic cover.

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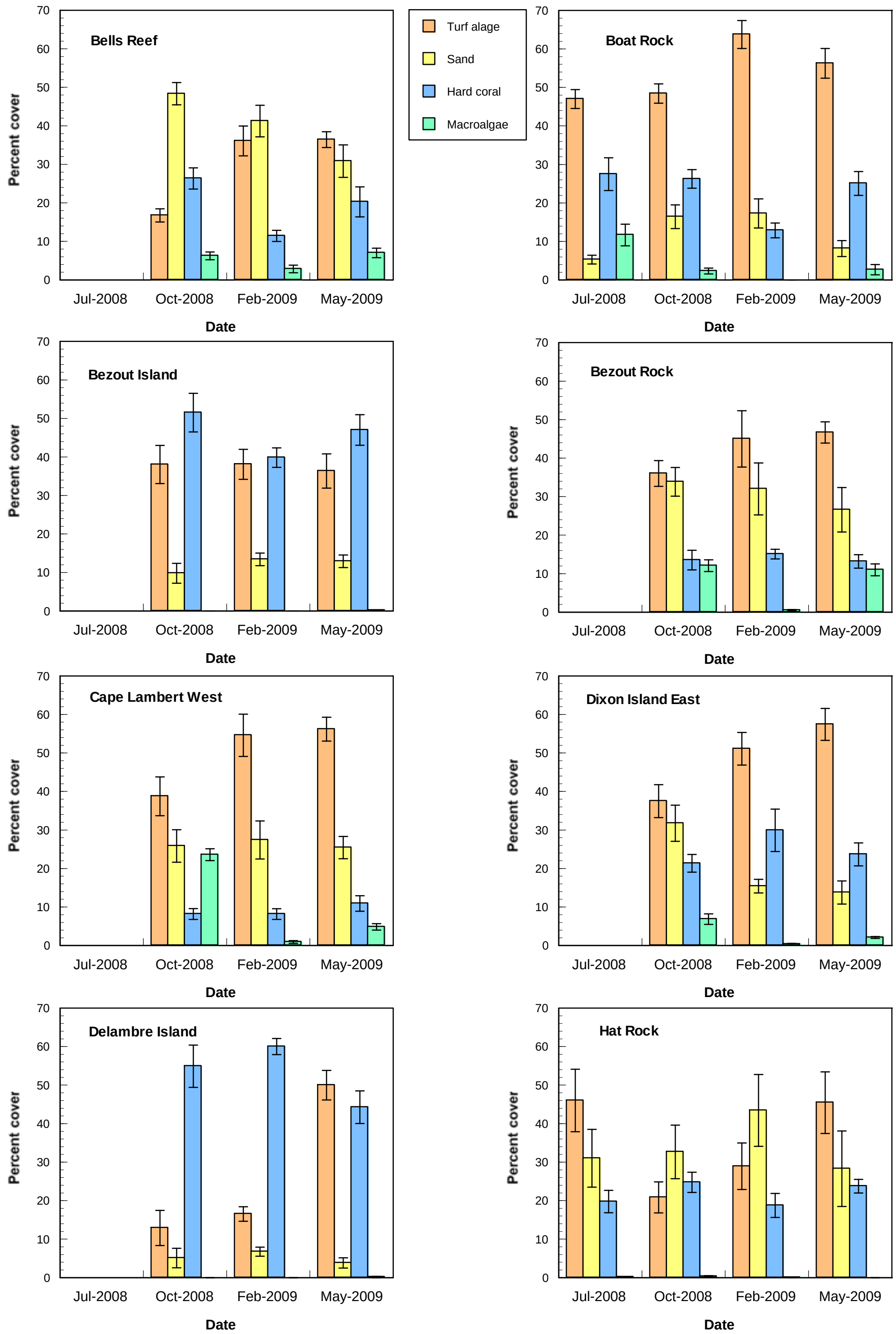
3.4.2. DLI – Delambre Island

At Delambre Island there was a clear pattern of a separation among the three sampling events and of groupings in the cluster analysis overlay (**Figure 3.8**). This was supported by strong ANOSIM R values between sampling events and particularly between May and the other sampling events (**Table 3.2**). BIOENV produced a strong overall correlation between the environmental variables and the benthic cover data. On an individual basis the variables most correlated to the benthic cover data were temperature and sediment (**Table 3.2**). Turf algal cover was less in October and February than May (12, 16 and 50% respectively) (**Figure 3.6**). Coral cover ranged from 44 to 60%.

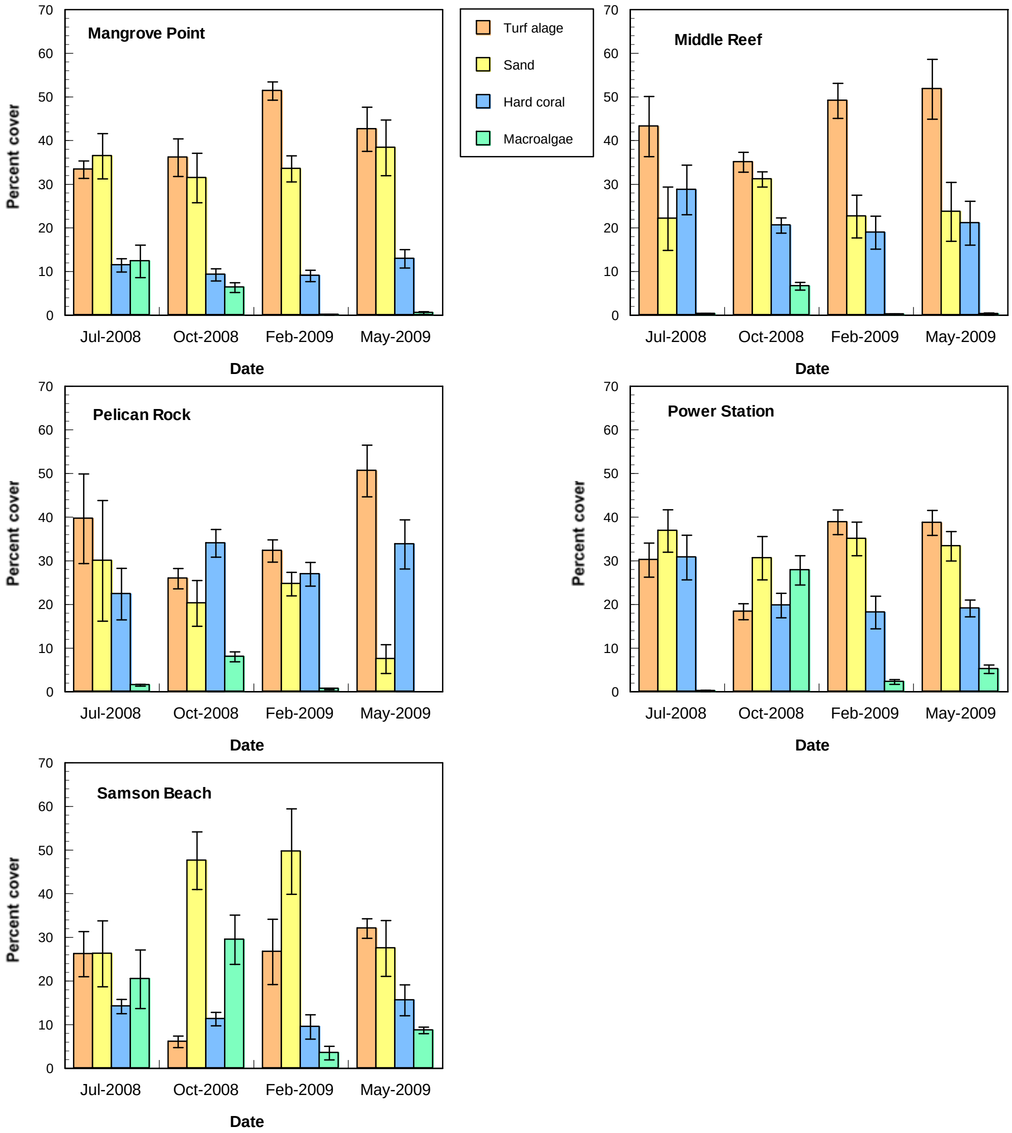
3.4.3. BZI - Bezout Island

There was no clear pattern in the MDS ordination for benthic cover at Bezout Rock or the cluster analysis overlays (**Figure 3.8**) indicating that the benthic cover did not change significantly over time. This was confirmed by the low and non-significant ANOSIM R value (0.097 and 12.8%) (**Table 3.2**). The similarity among sampling events is evident in **Figure 3.6** which shows the relative composition of benthic cover for the three times sampled. Turf algae ranged between 36 and 38%, sand between 9 and 12% and hard coral cover between 40 and 51%.



- **Figure 3.6: Percent cover of dominant benthic types (mean ± S.E.) from benthic transects for each site and sampling event**

Note: figure continues on following page.


Mangrove Point
Turf alage
Sand
Hard coral
Macroalgae
Middle Reef
Pelican Rock
Power Station
Samson Beach
Percent cover
Date
Jul-2008
Oct-2008
Feb-2009
May-2009
0
10
20
30
40
50
60
70

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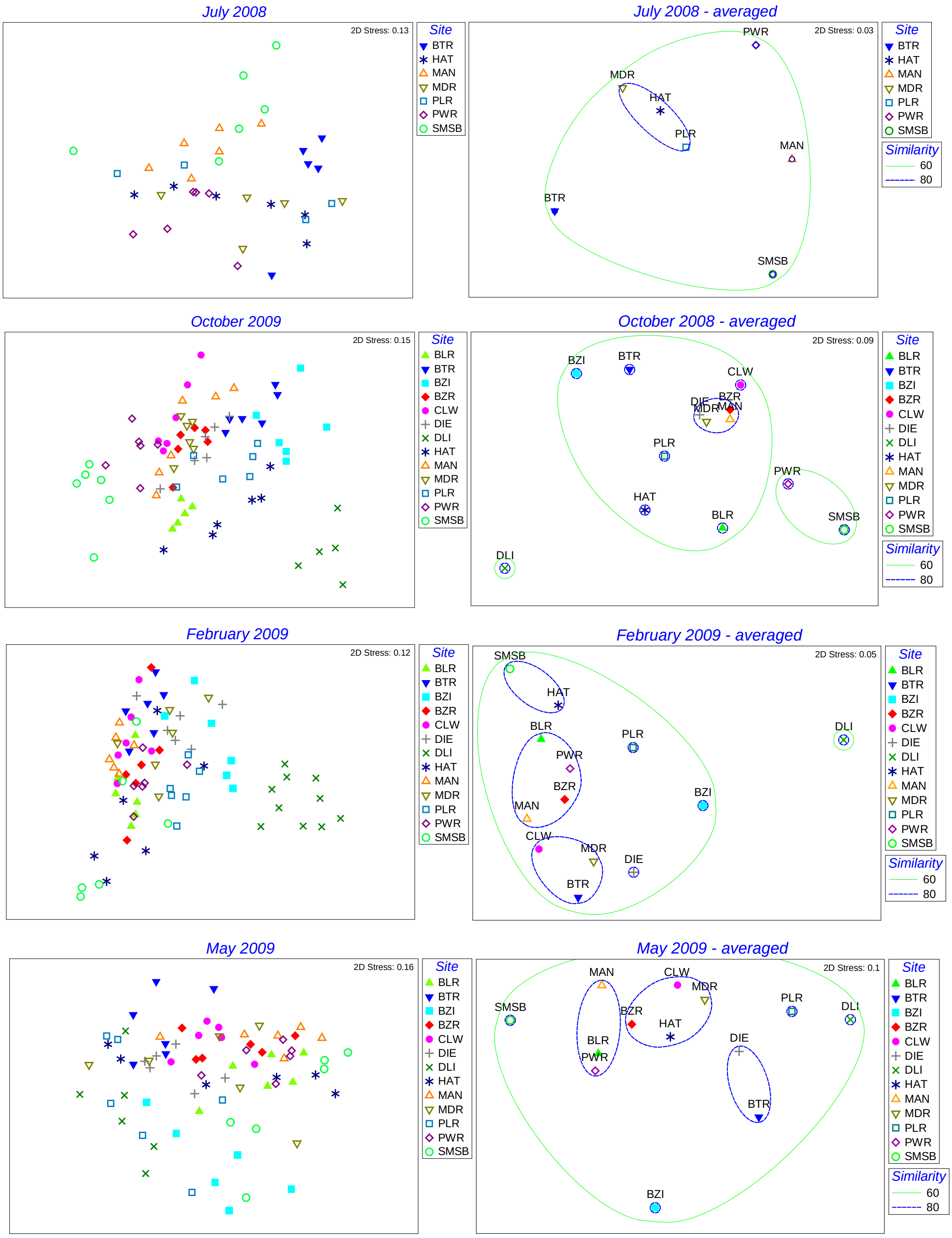

- **Figure 3.7: MDS ordinations to compare the composition of benthic cover among sites for each sampling event**

Charts on the left illustrate each individual replicates while charts on the right represent averaging of replicates at each site and sampling event.

Circles denote level of similarity (60 and 80% using group average cluster analyses) among sites.

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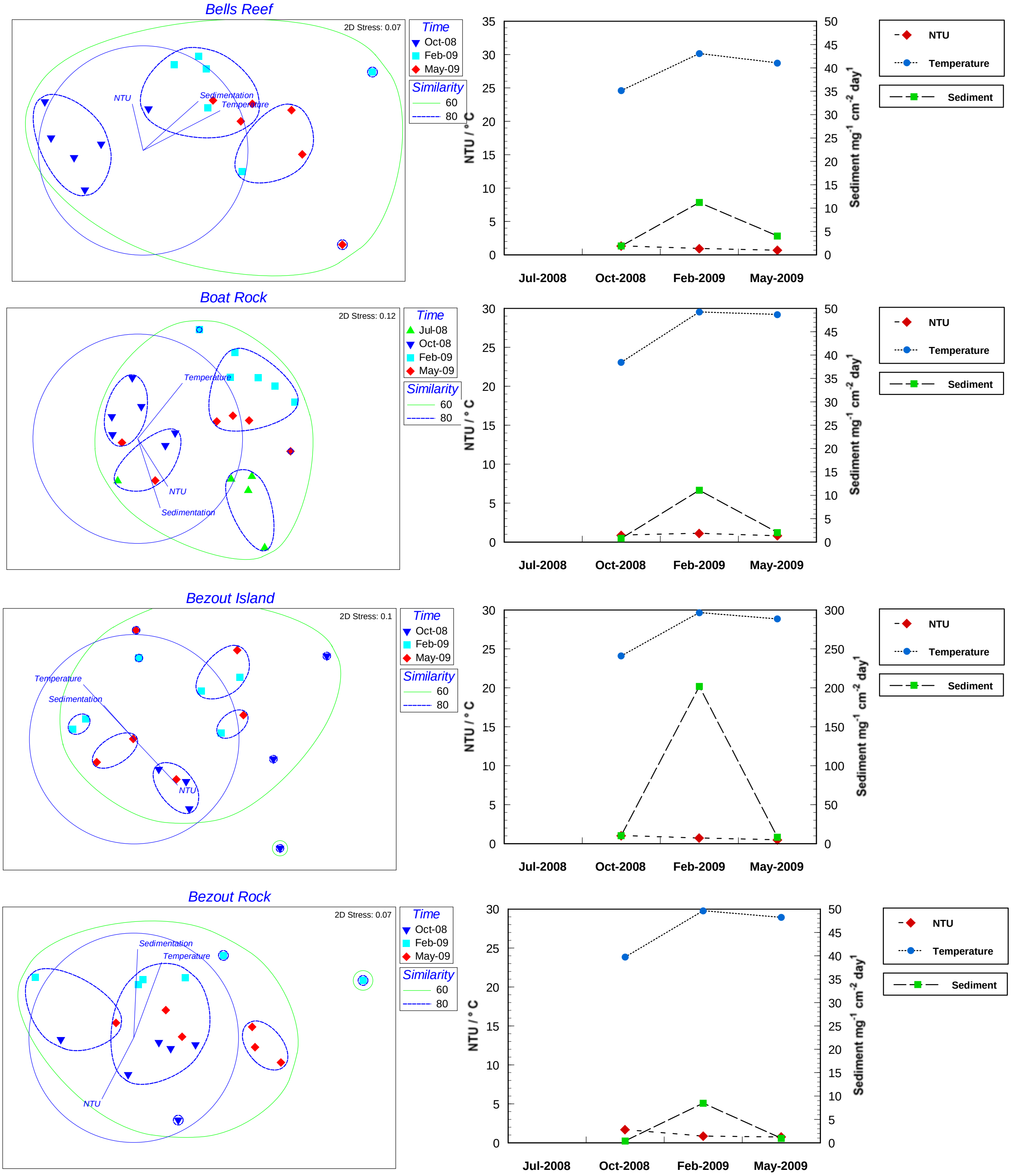

- **Figure 3.8: MDS ordinations to compare the composition of benthic cover among sampling events at each site; and line chart of physical variables (median) for two months preceding data collections**

Note: figure continues on following three pages.

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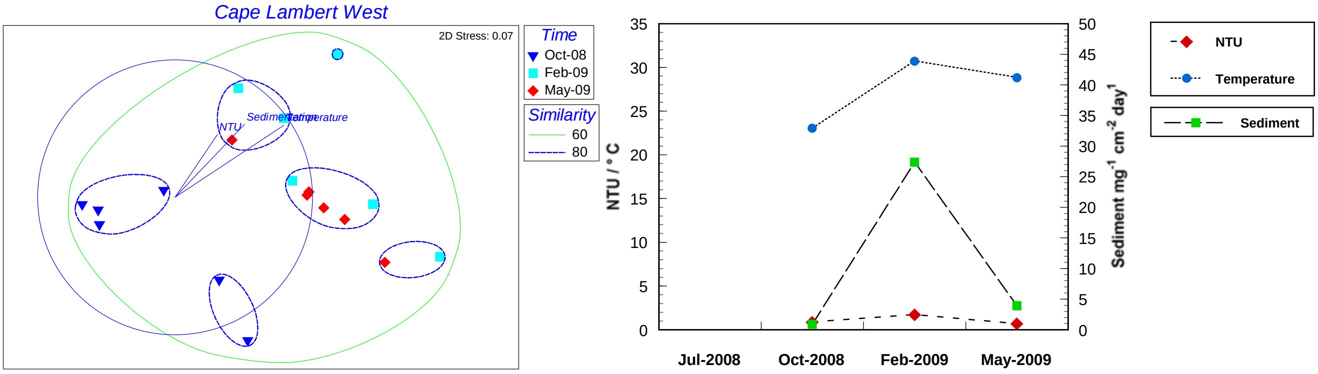
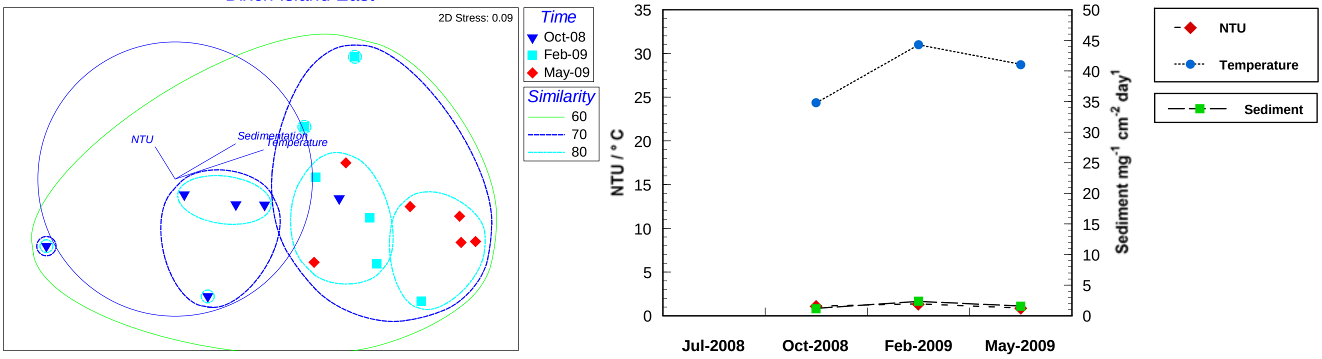
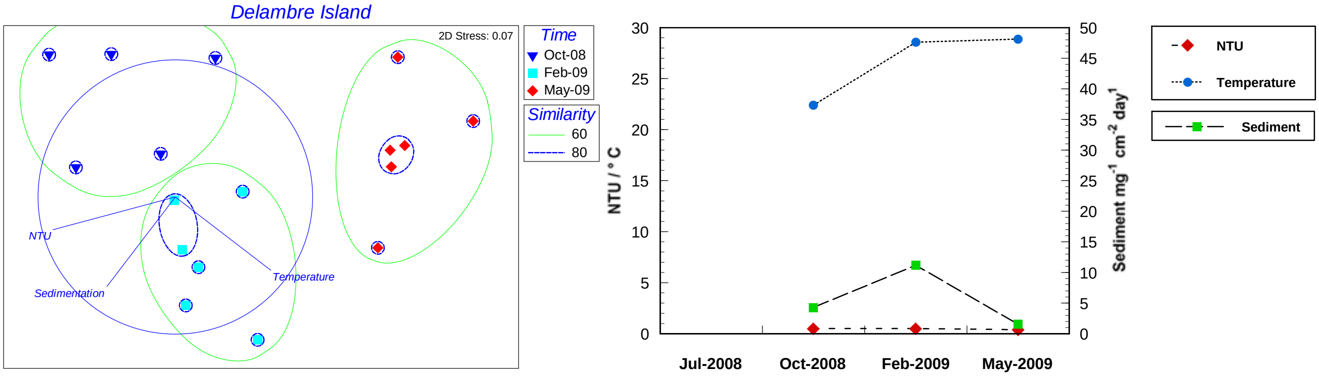
Cape Lambert West



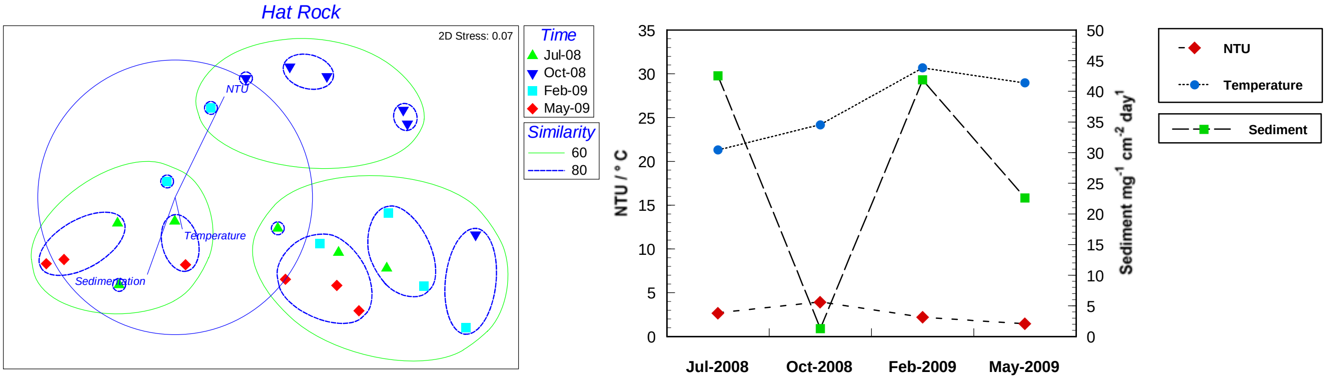
Dixon Island East



Delambre Island



Hat Rock



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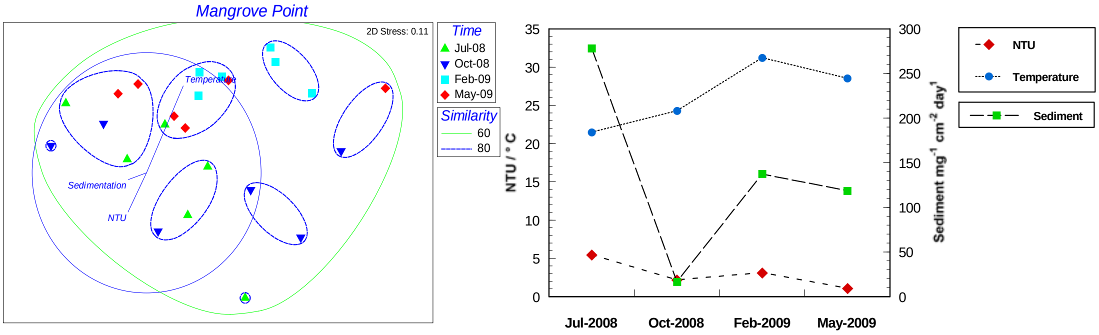
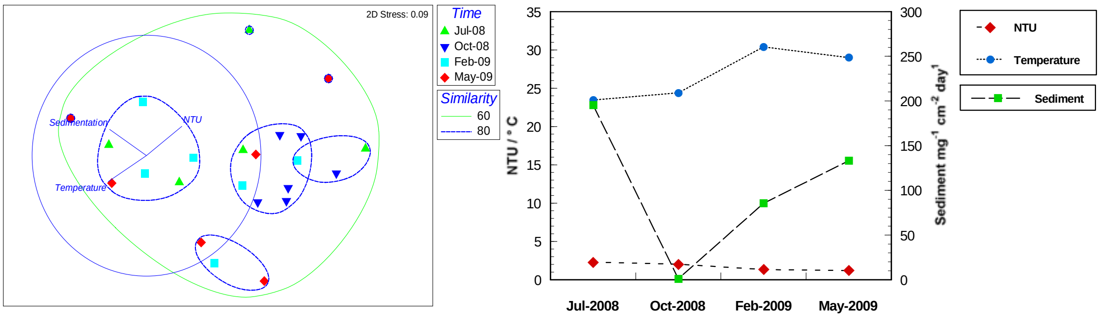
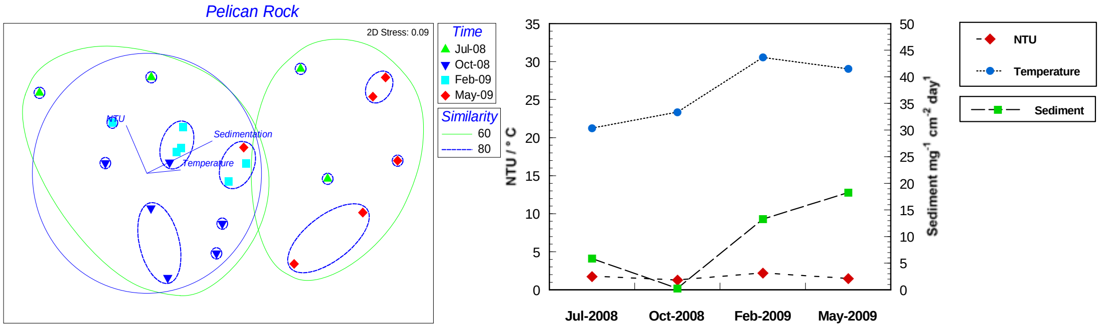
Mangrove Point



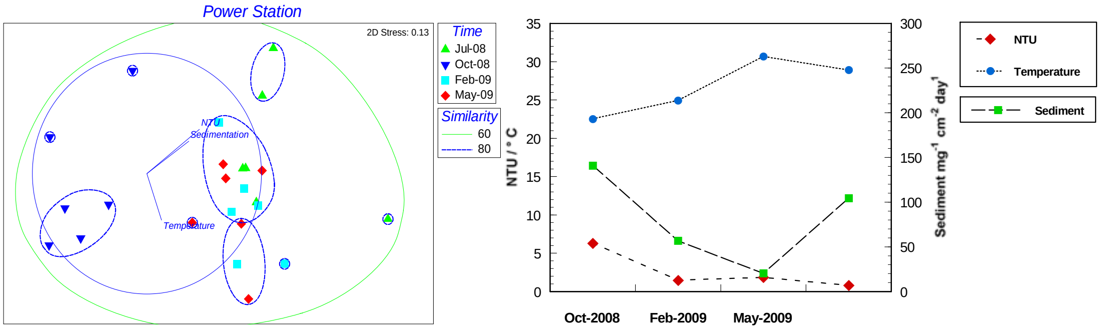
Middle Reef



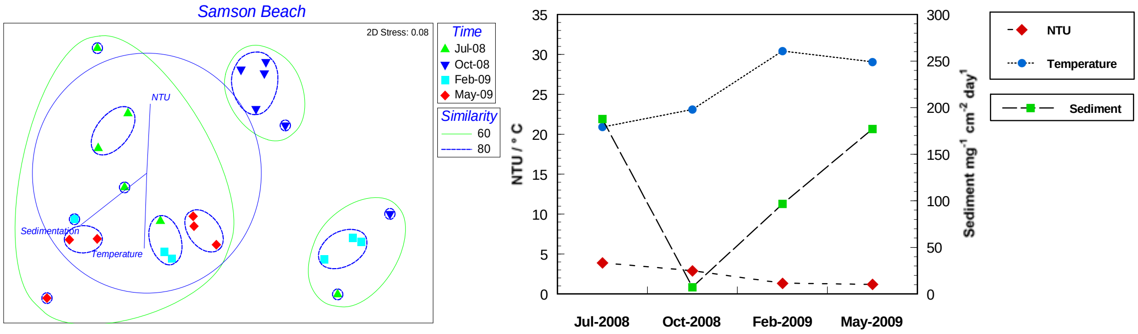
Pelican Rock



Power Station



Samson Beach



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- **Table 3.2: ANOSIM R values, significance and pairwise comparisons of benthic cover among sampling events; and BIOENV correlations (Spearman's Rho and significance) for physical variables**

SITE	ANOSIM R and sig %		BIOENV - Rho value and sig %	SITE	ANOSIM R and sig %		BIOENV - Rho value and sig %
BELLS REEF	0.619 – 0.1		0.637 – 1.0	MANGROVE POINT	0.266 – 0.3		0.230 – 2.0
Oct-08, Feb-09	0.739 – 0.2	NTU	0.637	Jul-08, Oct-08	0.045 – 27.7	NTU	0.044
Oct-08, May-09	0.877 – 0.2	Temp	0.547	Jul-08, Feb-09	0.590 – 0.2	Temp	0.230
Feb-09, May-09	0.177 – 5.0	Sediment	0.309	Jul-08, May-09	0.123 – 10.6	Sediment	0.171
BOAT ROCK	0.581 – 0.1		0.417 – 0.1	Oct-08, Feb-09	0.484 – 0.2		
Jul-08, Oct-08	0.669 – 0.9	NTU	0.339	Oct-08, May-09	0.181 – 8.2		
Jul-08, Feb-09	0.767 – 0.2	Temp	0.410	Feb-09, May-09	0.194 – 7.1		
Jul-08, May-09	0.245 – 8.4	Sediment	0.417	MIDDLE REEF	0.216 – 0.6		0.143 – 5.0
Oct-08, Feb-09	0.943 – 0.2			Jul-08, Oct-08	0.423 – 0.2	NTU	0.143
Oct-08, May-09	0.368 – 2.6			Jul-08, Feb-09	0.013 – 38.7	Temp	0.073
Feb-09, May-09	0.372 – 0.2			Jul-08, May-09	-0.051 – 57.4	Sediment	0.108
BEZOUT ISLAND	0.097 – 12.8		0.207 – 5.0	Oct-08, Feb-09	0.477 – 0.4		
Oct-08, Feb-09	0.278 – 2.4	NTU	0.174	Oct-08, May-09	0.356 – 0.4		
Oct-08, May-09	0.165 – 9.7	Temp	0.207	Feb-09, May-09	0.060 – 28.6		
Feb-09, May-09	-0.176 – 95.5	Sediment	-0.049	PELICAN ROCK	0.485 – 0.1		0.351 – 0.2
BEZOUT REEF	0.246 – 0.3		0.274 – 2.0	Jul-08, Oct-08	0.494 – 1.4	NTU	0.011
Oct-08, Feb-09	0.313 – 0.2	NTU	0.065	Jul-08, Feb-09	0.480 – 1.4	Temp	0.148
Oct-08, May-09	0.206 – 7.4	Temp	0.181	Jul-08, May-09	0.278 – 8.1	Sediment	0.250
Feb-09, May-09	0.209 – 5.6	Sediment	0.274	Oct-08, Feb-09	0.345 – 0.4		
CAPE LAMBERT WEST	0.522 – 0.1		0.615 – 1.0	Oct-08, May-09	0.781 – 0.2		
Oct-08, Feb-09	0.719 – 0.2	NTU	0.121	Feb-09, May-09	0.596 – 0.4		
Oct-08, May-09	0.802 – 0.2	Temp	0.615	POWER STATION	0.495 – 0.1		0.244 – 0.2
Feb-09, May-09	0.078 – 17.7	Sediment	0.400	Jul-08, Oct-08	0.878 – 0.2	NTU	0.113
DIXON ISLAND EAST	0.348 – 0.2		0.350 – 1.0	Jul-08, Feb-09	0.167 – 7.4	Temp	0.214
Oct-08, Feb-09	0.349 – 1.1	NTU	0.058	Jul-08, May-09	0.201 – 3.7	Sediment	0.154
Oct-08, May-09	0.556 – 0.4	Temp	0.350	Oct-08, Feb-09	0.927 – 0.2		
Feb-09, May-09	0.119 – 16.5	Sediment	0.184	Oct-08, May-09	0.852 – 0.2		
DELAMBRE ISLAND	0.889 – 0.1		0.774 – 0.1	Feb-09, May-09	0.076 – 24.5		
Oct-08, Feb-09	0.691 – 0.2	NTU	0.662	SAMSON BEACH	0.431 – 0.1		0.379 – 0.1
Oct-08, May-09	0.973 – 02	Temp	0.666	Jul-08, Oct-08	0.474 – 0.6	NTU	0.216
Feb-09, May-09	0.969 – 0.2	Sediment	0.479	Jul-08, Feb-09	0.244 – 7.4	Temp	0.236
HAT ROCK	0.233 – 0.5		0.265 – 0.1	Jul-08, May-09	0.306 – 0.9	Sediment	0.364
Jul-08, Oct-08	0.454 – 0.4	NTU	0.265	Oct-08, Feb-09	0.518 – 0.2		
Jul-08, Feb-09	0.016 – 30.5	Temp	-0.002	Oct-08, May-09	0.820 – 0.2		
Jul-08, May-09	-0.027 – 48.3	Sediment	0.232	Feb-09, May-09	0.209 – 10.2		
Oct-08, Feb-09	0.195 – 8.7						
Oct-08, May-09	0.639 – 0.2						
Feb-09, May-09	0.070 – 22.1						

Note: ANOSIM and BIOENV values in the same row as the site name are the overall value, subsequent ANOSIM values are the results of pairwise comparisons between sampling events, subsequent BIOENV values are for each individual environmental parameter. Blue shaded cells indicate moderate or strong ANOSIM R and modest to very strong BIOENV correlation (see methods).

3.5. Coral mortality measures

The partial coral mortality ranged from 2 to 8.9 % among the sites and sampling events (**Figure 3.9**). Partial mortality was variable within each site, with some sites increasing in mortality over time (Bezout Island, Cape Lambert West, Delambre Island and Middle Reef), one site decreasing (Power Station) and some sites with little change (Boat Rock, Bezout Rock, Dixon Island East and Pelican Rock). The lowest level of partial mortality was at Pelican Rock (< 4%). Average partial mortality across all sites and sampling events was 4.9%.

Both Mangrove Point and Bells Reef showed a decrease in mortality between survey 1 and 2 and then showed an increase in mortality between surveys 2 and 3. The opposite occurred at Samson Beach where the mortality increased between surveys 1 and 2 and then decreased between surveys 2 and 3.

3.6. Coral bleaching

The highest level of partial coral bleaching was recorded at Cape Lambert West (10.9%) in February which coincided with the highest water temperature 30.7°C (**Figure 3.9**). However, there was no bleaching recorded at this site in October or May. There were also peaks in partial bleaching in February at another eight of the 13 sampling sites which coincided with the highest water temperatures. These included Bezout Island, Dixon Island East, Hat Rock, Mangrove Point, Middle Reef, Pelican Rock, Power Station and Samson Beach.

3.6.1. Statistical power

The results of the power analysis on the sites during the first survey indicate that the sampling size used in this monitoring program is sufficient to detect a 3% change in partial mortality (**Table 3.3**).

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- **Table 3.3: Power analysis to determine the percent change in coral mortality that can be detected with 80% confidence**

Power analysis				
Site	**STD. DEV.**	**sample size**	**Effect size**	**% change**
BLR	6.57	60	0.3247	2.13
BTR	5.13	60	0.3247	1.67
BZI	6.68	60	0.3247	2.17
BZR	5.30	60	0.3247	1.72
CLW	4.8	58	0.3304	1.59
DIE	4.35	60	0.3247	1.41
DLI	5.31	60	0.3247	1.73
HAT	5.52	58	0.3304	1.83
MAN	8.38	60	0.3247	2.72
MDR	4.75	60	0.3247	1.55
PLR	3.34	58	0.3304	1.11
PWR	6.67	60	0.3247	2.17
SMSB	6.18	60	0.3247	2.01

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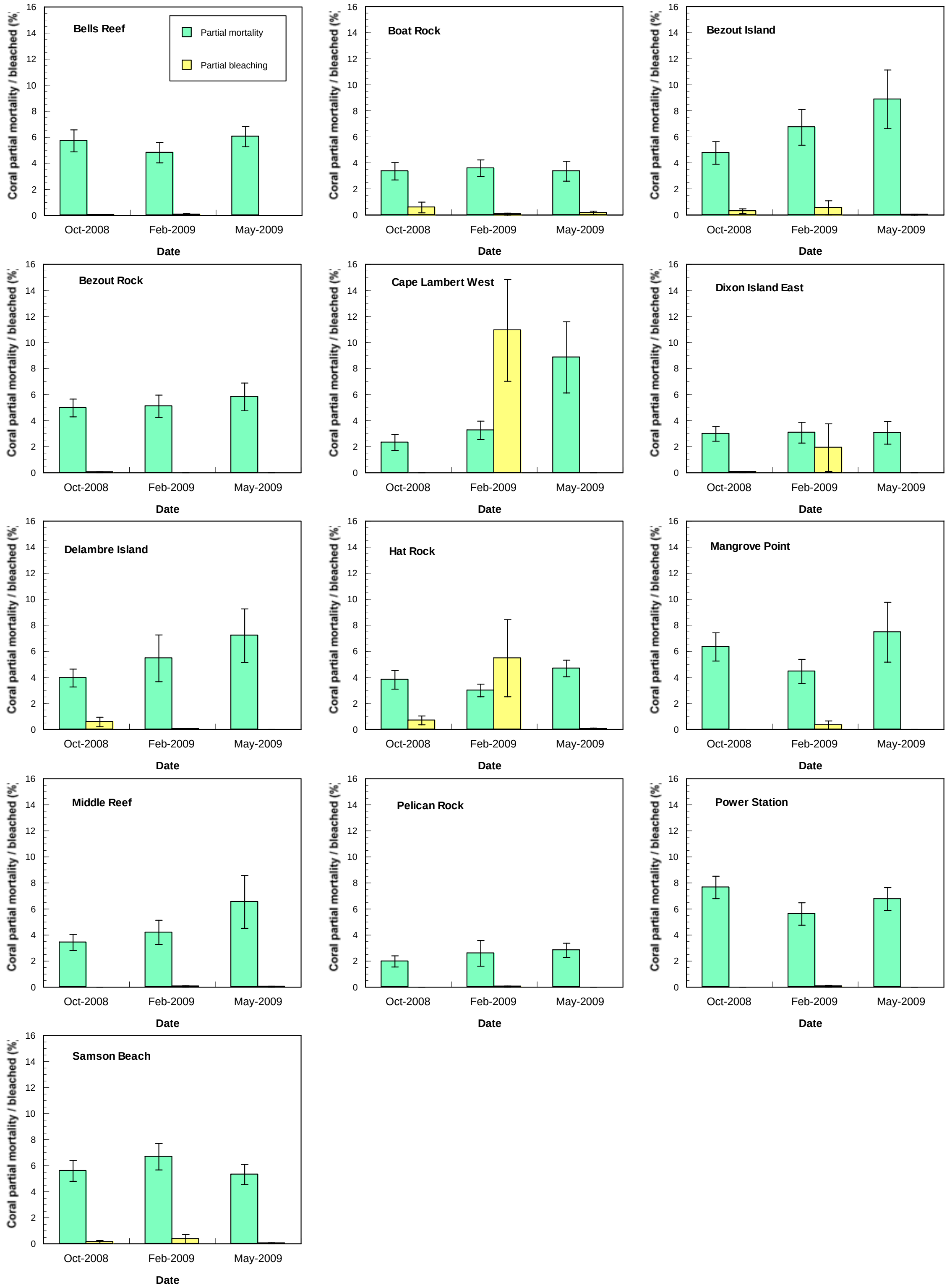

- **Figure 3.9: Mean percent coral partial mortality and partial bleaching (± S.E.) of the tagged coral colonies for each site and sampling event**

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4. Discussion

This study has generated a comprehensive baseline monitoring dataset that encompasses the natural (spatial and temporal) variability in BPPH (algae and coral cover) and coral health in the Cape Lambert region over a one-year period. The environmental data collected (turbidity, water temperature and sedimentation) have also enabled investigations into the relationships between these potential drivers of change and the benthic communities. These baseline data are essential to improve the knowledge of natural changes in BPPH in the Cape Lambert region and for the management of dredging activities associated with the Port B development.

A total of 76 species of algae were recorded from the 13 sites. Many of these species are common to other tropical areas (Huisman and Borowitzka 2003).

There was significant variability among sites and sampling events in terms of the biomass of algae and benthic cover. In some cases the observed differences were moderately or strongly correlated to the environmental variables (water temperature, sedimentation and turbidity). However, in other cases relationships between these were less clear. These are discussed below.

4.1. Variability in algae and relationships with environmental measures

There was a peak in the biomass of algae in October at Bells Reef, Bezout Rock, Cape Lambert West, Power Station and Dixon Island East. These sites are all to the west of Cape Lambert and may consequently experience similar oceanographic conditions influencing algal growth. October was a time of low sedimentation and low water temperature. Airoldi (1998) showed that stress on algae due to sediment deposition significantly influenced macroalgae that persist by sexual reproduction, however it did not affect spatial dominance by the turf algae. The turf regained space very quickly after a stress induced impact. The findings of Airoldi (1998) may explain the relationship between greater macroalgal biomass in October at these sites and the lower amount of sedimentation recorded in the water quality surveys (SKM 2009b). In terms of the larger spatial scale of benthic cover, there was a dominance of algal turfs over macroalgae at all 13 sites sampled in the Cape Lambert region. This is consistent with the aforementioned influence of sedimentation in the region i.e. that turf algae can regain space very quickly after a stress induced impact from sediment. Despite the dominant turf algal cover, when sedimentation decreased, macroalgae were potentially able to respond with increased growth. Algal turfs have been shown in other studies to dominate hard substrates without being influenced by environmental water quality gradients (Fabricius and McCorry 2006).

The algal and coral communities in the Cape Lambert region cope with high levels of sedimentation compared to some other Western Australian coral reefs. For example, sedimentation at reference sites on coral reefs at Ningaloo has been recorded at between 1 and 1.6 mg cm^{-2} day^{-1}

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(Babcock and Smith 2000). At Scott Reef mean sedimentation ranges from 0.45 to 1.25 mg cm^{-2} day^{-1} (Gilmour, et al. 2008). However, mean sedimentation among sites at Cape Lambert was an order of magnitude higher at 44.7 mg cm^{-2} day^{-1} (SKM 2009b) with a maxima of over 250 mg cm^{-2} day^{-1}. This sediment is likely to be regularly resuspended by tides and winds but may also be shifted offshore by the tides. The February peak in sedimentation and NTU recorded at a number of sites coincides with the cyclone season in the north west.

The Mangrove Point monitoring site (**Figure 2.1**) is near a creek that discharges turbid waters with each tidal cycle and following periods of high rainfall. Not surprisingly, this site also experienced the highest mean turbidity (2.97 NTU) and the highest mean sedimentation (137.8 mg cm^{-2} day^{-1}) of all sites. However, there was no clear relationship between these variables and the biomass or composition of algae. High algal biomass in July corresponded with a peak in sedimentation.

The environmental data showed some general trends in terms of an increase in water temperature in summer (**Figure 3.5**). There was also a general increase in sedimentation in February, possibly associated with increased winds. Median turbidity was generally less than 5 NTU for most sites and sampling events (SKM 2009b).

On a site by site basis, there was variability among sampling events with some sites showing distinct differences in the composition of algae and benthic cover (e.g. Bells Reef, Boat Rock and Cape Lambert West). However, other sites were quite similar among sampling events (e.g. Bezout Island, Dixon Island East and Hat Rock).

Temporal variability in terms of the composition of algae was driven by peaks in the biomass of Asparagopsis *taxiformis* in October (at Cape Lambert West, Middle Reef and Power Station) and *Stypopodium flabelliforme* in October (at Bells Reef, Bezout Rock, and Samson Beach). There was generally less biomass of *Amphiroa* in May than other sampling events (at Bells Reef, Boat Rock, Dixon Island East, Delambre Island, Bezout Rock, Mangrove Point). *Sargassum* spp. and *Turbinaria ornata* were recorded in the survey in low biomass compared with other species. These species are also known to be seasonally abundant in the Dampier and Ningaloo regions (Ayling and Ayling 1987; Westera 2003) and may increase in cover at some stage. Seasonal changes in these species were not recorded in the monitoring at Cape Lambert.

There were differences in benthic cover among sampling events at some sites that may have been due to shifting sand sheets. The cover of sand at Samson Beach increased between July and October from 26% to 48%. This site is located approximately 300 m offshore and close to an intertidal survey location where similar observations (shifting sand sheets) have been made (SKM 2009b). Such sand movement may strongly influence subtidal algal communities as the amount of substrate available for attachment and growth would be reduced when inundated by sand. The sand movement may have been due to winds or storms.

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4.2. Coral mortality measures

The results of the coral health baseline surveys indicate that partial mortality varies both between and within sites. An increase in mortality was not always observed at the sites, indicating some levels of recovery. Mortality increased at some sites over the monitoring period while other sites remained constant or decreased. A lack of accumulating mortality over time was also observed at during the coral health surveys during the previous port upgrade at Cape Lambert (MScience 2007).

The partial mortality observed may have been caused by a number of physical and biological factors including temperature, turbidity, sedimentation, borers, algae, physical damage or competition from other corals as has been shown in other studies (Cumming 1999; Yarden et al. 2007; Cooper et al. 2008; Fernandez and Perez 2008; Jones 2008). In some cases partial mortality progressed to the complete death of the coral, while in other cases the corals recovered. Partial mortality remained below 10% for all the monitoring sites. The largest change in mortality occurred at Cape Lambert West (**Figure 3.9**) where mortality increased from 2.32% in October 2008 to 8.85% in May 2009.

Cooper et al (2008) suggest that long-term turbidity > 3 NTU may lead to sublethal stress of corals at shallow depths, and that long-term turbidity > 5 NTU corresponds to severe stress effects on corals. The highest turbidity measures recorded at Cape Lambert (up to 6.3 NTU) were recorded in July 2008, prior to the collection of data on coral partial mortality. Mean turbidity was less than 2 NTU at all sites with the exception of Hat Rock, Mangrove, Power Station and Samson Beach which all averaged between 2 and 3 NTU.

This monitoring program is capable of detecting a change in coral mortality of 3% or more. A power analysis was performed on the data from the October 2008 survey which found that a change in coral mortality of 3% can be detected with a 0.8 level of power. This is a high level of statistical power corresponding to a high level of confidence in the data.

Low levels of coral bleaching were identified from all the monitoring sites at some stage during the baseline data collection. There was a notable increase in coral bleaching at Hat Rock, Dixon Island East and Cape Lambert West during February 2009 which coincided with a peak in water temperature of approximately 31°C among sites (SKM 2009b).

This was similar to the previous Cape Lambert port upgrade during which coral bleaching resulted from elevated water temperatures causing high coral mortality within the locality of Cape Lambert (SKM 2008d). Routine summer water temperature maxima around Cape Lambert have a median value of 31.5°C (SKM 2008e). SKM recorded a maximum water temperature of 33.5°C during February 2008 at three sites in close proximity to Cape Lambert. Research has shown that an

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increase in the water temperature of at least 1°C above the normal summer maxima sustained for at least 2-3 days can lead to coral bleaching (Reaser et al. 2000; Veron 2000).

The bleaching at the three sites in the current study had recovered to prior levels by the third survey in May 2009 when water temperatures were decreasing (SKM 2009b).

The bleached corals recorded during the previous port upgrade were consistently of a bright white colouration and contained no algal or epiphytic over-growth indicating that the bleaching had occurred within the previous few weeks rather than within the time scale of the dredging program. Additionally, SKM had used Pulse Amplitude Modulated fluorometry (PAM) monitoring throughout the dredging program and recorded no sub-lethal effects from dredging or any bleaching at any sites.

Coral bleaching can provide a useful indicator during a dredging program of any potential subsequent mortality. However, notably corals have been shown to bleach independently of any dredging activity. Reef corals have been shown elsewhere to bleach in response to temporary stress which allows them to adapt and to survive environmental changes (Obura 2005; Rodrigues and Grottoli 2007; Obura 2009). These surveys have also shown the ability of the corals to recover from bleaching.

4.3. Why monitor algae in addition to corals?

Macroalgae and turf algae were recorded as widespread in the Cape Lambert region based on surveys in early 2008 (SKM, 2008a) and may contribute more to primary production than hard corals. In the Great Barrier Reef, algae have been shown to be responsible for one-third of the gross production and most of the net production on some reefs (Klumpp and McKinnon, 1989). Furthermore, Larkum (1983) noted that turf and macroalge combined contributed between 1.1 and 10 g. C. m^{-2} day^{-1} compared with coral (0.6 g. C. m^{-2} day^{-1}) and seagrass (1 to 7 g. C. m^{-2} day^{-1}). Macroalgae and turf algae are also specifically listed as Benthic Primary Producers (BPP) in the Environmental Protection Authority Guidance Statement on BPPH Protection (Environmental Protection Authority 2004) and may therefore may be assessed under this Guidance Statement.

Thus, there is a need to understand natural variability in algal assemblages among sites and over time to enable detection of any impacts that may be due to dredging or other causes. The algal monitoring undertaken for this report provides a one-year baseline dataset, documenting the natural variability in algal assemblages on reefs in the Cape Lambert region against which potential impacts could be measured. However, to detect such impacts their magnitude would have to be larger than the natural variability recorded from the baseline surveys.

Understanding the composition of macroalgae is important as there can be large functional and ecological differences among different types of algae. Harvesting macroalgae provides the

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necessary detail about the species composition and structure of an algal community at scales of < 1 m^2 that cannot be extracted from benthic video transects as species identification often requires examination of algal samples. Some larger genera of macroalgae such as *Sargassum* have been described as nursery habitats for juvenile fishes (Ayling and Ayling 1987). Other smaller species are an important food source for fishes (Polunin and Klumpp 1992; Choat et al. 2002) and invertebrates (de Loma et al. 2002; Wernberg et al. 2008) or provide habitat for cryptofauna (Ferreira et al. 1998). Knowledge of the species that compose the macroalgae is necessary to understand the ecological role of algae and is generally part of any rigorous baseline study (McField et al. 2001; Barrett et al. 2002; Keesing and Heine 2005).

Benthic transects provide less detail about the individual algal species but are necessary to understand the broader characteristics of a site at larger spatial scales i.e. tens of metres. They also provide information about the distribution of different benthic types within each site. For example, changes in sand (and thus recruitable habitat for algae) could not be detected without the benthic transect data. They also provide information about the amount of live coral cover within a site.

The datasets generated from this study can be used to provide power analyses to assess the differences that can be detected (e.g. the percentage change in the cover of macroalgae, turf algae or corals). Greater replication will generally provide a greater level of statistical power to detect change. Based on the current methodology and other work (Houk and Van Woesik 2006) it is anticipated that a 30% change in algal or coral cover with 80% power will be detected by the monitoring technique.

Tradition statistical power analyses cannot be applied to multivariate datasets in the same manner as univariate datasets. However, the ability of multivariate data to detect change can be inferred from the level of replication and species area curves. Tests conducted in this study showed that the multivariate datasets were sufficient to capture approximately 95% of the benthic cover categories and algal species. Similarly, the level of replication (n = 6 at each site) allowed sufficient permutations (462) for valid ANOSIM analyses.

4.4. Conclusions

Dredging has the potential to impact macroalgal, turf algal and coral communities by limiting light to the seafloor and reducing the available light for photosynthesis (Airoldi 1998), and by burial from sediment that settles out of the water column (Lirman and Manzello 2009). Increased amounts of sediment on the seafloor may also reduce the hard surfaces available for settlement and recruitment of algae and corals. The magnitude of any impact would likely be influenced by the frequency and duration of any events that resulted in suspended sediment plumes. Impacts may also be influenced by the large tidal range in Cape Lambert region that may transport sediment.

This report details the results a baseline monitoring program that has been developed and implemented to build an understanding of the spatial and temporal variability in macroalgal, turf algal and coral communities in the Cape Lambert region. Together these datasets and the analyses performed provide a rigorous (one-year) baseline that describes the natural spatial and temporal variability in the composition of benthic cover and algal assemblages, and the partial mortality of corals. This program has also provided quantitative measures of coral health which can be assessed against management trigger levels.

The following key conclusions can be drawn from the monitoring to date.

- There were similarities in the environmental variables at some of the sites located to the west of Cape Lambert (Bells Reef, Bezout Rock and Boat Rock), immediately east of Cape Lambert (Samson Beach and Middle Reef) and some distance east of Cape Lambert (Pelican Rock and Hat Rock).
- There was significant spatial variability among some sites in terms of the composition of algae and benthic cover; however, some sites were similar, particularly those in geographically similar locations.
- In terms of the composition of algae, Hat Rock and Pelican Rock were similar in July 2008 and February 2009 which was consistent with that shown in the environmental data. Bells Reef, Bezout Rock, and Boat Rock were also similar in February 2009 which was consistent with that shown in the environmental data. Cape Lambert West and Power Station were similar in February 2009 which was consistent with that shown in the environmental data.
- Sampling benthic cover and algal composition is necessary to understand the different spatial scales (metres versus tens of metres) at each site and the complexity of macroalgal and turf algal assemblages (and coral cover) at Cape Lambert.
- Coral partial mortality varied within and between sites with baseline levels below 10%.
- The statistical power of the coral mortality monitoring is sufficient to detect a 3% change in coral mortality.
- Coral bleaching occurred at a number of sites in February 2009 when water temperatures were the highest.
- Coral bleaching can provide a useful early warning indicator to potential coral mortality. These surveys have shown that if the stressor causing coral bleaching is removed in time the corals can recover.
- A suite of methods must be agreed upon that can deliver the data required but are also measurable and achievable bearing in mind the level of variability measured in this study.

The final objective of this study was to 'conduct analysis of data and reporting, as well as preparation of inputs to Dredging and spoil Disposal Management Plan (DSDMP) and future monitoring programs where appropriate'. In addressing this objective the following recommendation is made:

- That the methods developed in this program have provided the necessary information to understand variability in BPPH at the sites monitored in the Cape Lambert region. Inclusion of these methods into the DSDMP would allow additional information to be collected both during and after a dredging program. These data can be analysed with water quality data to investigate any potential links between dredging and changes in BPPH.
- Including the use of benthic transects allows us to characterise the broader habitat types at each site and assess changes in percent cover of benthic types (corals and algae). The use of quadrats to sample macro algae enables us to assess changes in algal composition. These methods provide additional and larger scale information than just using coral mortality measures.
- The DSDMP proposes the use of coral triggers for management. The collection of this data will assist in reporting and long term impacts from dredging on all BPPH not just corals.

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Appendix - Algal species recorded in surveys

- **Table A.1: Algal species recorded in surveys in the Cape Lambert region**

Species	Class	Order	Family	Genus
Amphiroa foliacea	Florideophyceae	Corallinales	Corallinaceae	Amphiroa
Amphiroa fragilissima	Florideophyceae	Corallinales	Corallinaceae	Amphiroa
Anadyomene plicata	Ulvophyceae	Cladophorales	Anadyomenaceae	Anadyomene
Anotrichium tenue	Florideophyceae	Ceramiales	Wrangeliaceae	Anotrichium
Asparagopsis taxiformis	Florideophyceae	Bonnemaisoniales	Bonnemaisoniaceae	Asparagopsis
Asteromenia exanimans	Florideophyceae	Rhodymeniales	Hymenocladiaceae	Asteromenia
Betaphycus speciosum	Florideophyceae	Gigartinales	Areschougiaceae	Betaphycus
Boodleopsis sp.	Bryopsidophyceae	Bryopsidales	Udoteaceae	Boodleopsis
Bornetella oligospora	Ulvophyceae	Dasycladales	Dasycladaceae	Bornetella
Bryopsis sp.	Bryopsidophyceae	Bryopsidales	Bryopsidaceae	Bryopsis
Caulerpa serrulata	Bryopsidophyceae	Bryopsidales	Caulerpaceae	Caulerpa
Caulerpa sertularioides	Bryopsidophyceae	Bryopsidales	Caulerpaceae	Caulerpa
Centroceras clavulatum	Florideophyceae	Ceramiales	Ceramiaceae	Centroceras
Ceramium sp.	Florideophyceae	Ceramiales	Ceramiaceae	Ceramium
Champia compressa	Florideophyceae	Rhodymeniales	Champiaceae	Champia
Champia parvula	Florideophyceae	Rhodymeniales	Champiaceae	Champia
Chondria armata	Florideophyceae	Ceramiales	Rhodomelaceae	Chondria
Chondria dangeardii	Florideophyceae	Ceramiales	Rhodomelaceae	Chondria
Chondria sp.	Florideophyceae	Ceramiales	Rhodomelaceae	Chondria
Chondrophycus sp.	Florideophyceae	Ceramiales	Rhodomelaceae	Chondrophycus
Cladophora catenata	Ulvophyceae	Cladophorales	Cladophoraceae	Cladophora
Cladophora herpestica	Ulvophyceae	Cladophorales	Cladophoraceae	Cladophora
Cladophora sp.	Ulvophyceae	Cladophorales	Cladophoraceae	Cladophora
Cladophora vagabunda	Ulvophyceae	Cladophorales	Cladophoraceae	Cladophora
Coelothrix irregularis	Florideophyceae	Rhodymeniales	Rhodymeniaceae	Coelothrix
Corallophila apiculata	Florideophyceae	Ceramiales	Ceramiaceae	Corallophila
Crustose coralline (growth form)	Florideophyceae	Corallinales	Corallinaceae	Crustose
Cyanobacteria	Cyanophyceae	Unknown	Unknown	Cyanobacteria
Dictyopteris australis	Phaeophyceae	Dictyotales	Dictyotaceae	Dictyopteris
Dictyota friabilis	Phaeophyceae	Dictyotales	Dictyotaceae	Dictyota
Dictyota furcellata	Phaeophyceae	Dictyotales	Dictyotaceae	Dictyota
Galaxaura rugosa	Florideophyceae	Nemaliales	Galaxauraceae	Galaxaura
Gayliella flaccida	Florideophyceae	Ceramiales	Ceramiaceae	Gayliella
Gelidiella acerosa	Florideophyceae	Gelidiales	Gelidiellaceae	Gelidiella
Gelidiella sp.	Florideophyceae	Gelidiales	Gelidiellaceae	Gelidiella
Gelidiopsis intricata	Florideophyceae	Rhodymeniales	Lomentariaceae	Gelidiopsis
Gracilaria canaliculata	Florideophyceae	Gracilariales	Gracilariaceae	Gracilaria
Halimeda cylindracea	Bryopsidophyceae	Bryopsidales	Halimedaceae	Halimeda
Halimeda lacunalis	Bryopsidophyceae	Bryopsidales	Halimedaceae	Halimeda
Halimeda minima	Bryopsidophyceae	Bryopsidales	Halimedaceae	Halimeda
Halimeda sp.	Bryopsidophyceae	Bryopsidales	Halimedaceae	Halimeda
Herposiphonia secunda	Florideophyceae	Ceramiales	Rhodomelaceae	Herposiphonia
Herposiphonia sp.	Florideophyceae	Ceramiales	Rhodomelaceae	Herposiphonia
Heterosiphonia crispella	Florideophyceae	Ceramiales	Dasyaceae	Heterosiphonia
Hydrolithon farinosum	Florideophyceae	Corallinales	Corallinaceae	Hydrolithon
Hypnea spinella	Florideophyceae	Gigartinales	Hypneaceae	Hypnea
Hypena sp.	Florideophyceae	Gigartinales	Hypneaceae	Hypnea
Jania sp.	Florideophyceae	Corallinales	Corallinaceae	Jania

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Species	Class	Order	Family	Genus
Laurencia sp.	Florideophyceae	Ceramiales	Rhodomelaceae	Laurencia
Laurencia sp. 2	Florideophyceae	Ceramiales	Rhodomelaceae	Laurencia
Lobophora variegata	Phaeophyceae	Dictyotales	Dictyotaceae	Lobophora
Lomentaria sp.	Florideophyceae	Rhodymeniales	Lomentariaceae	Lomentaria
Nemoeris vanbosseae	Ulvophyceae	Dasycladales	Dasycladaceae	Neomeris
Padina boryana	Phaeophyceae	Dictyotales	Dictyotaceae	Padina
Padina sp.	Phaeophyceae	Dictyotales	Dictyotaceae	Padina
Parvocaulis clavatus	Ulvophyceae	Dasycladales	Polyphysaceae	Parvocaulis
Parvocaulis parvulus	Ulvophyceae	Dasycladales	Polyphysaceae	Parvocaulis
Parvocaulis sp.	Ulvophyceae	Dasycladales	Polyphysaceae	Parvocaulis
Peyssonnelia sp.	Florideophyceae	Gigartinales	Peyssonneliaceae	Peyssonnelia
Polysiphonia sp.	Florideophyceae	Ceramiales	Rhodomelaceae	Polysiphonia
Portieria hornemannii	Florideophyceae	Gigartinales	Rhizophyllidaceae	Portieria
Pterocladiella caerulescens	Florideophyceae	Gelidiales	Gelidiaceae	Pterocladiella
Pterocladiella sp.	Florideophyceae	Gelidiales	Gelidiaceae	Pterocladiella
Rhipidosiphon javensis	Bryopsidophyceae	Bryopsidales	Udoteaceae	Rhipidosiphon
Rhodogorgon sp.	Florideophyceae	Rhodogorgonales	Rhodogorgonaceae	Rhodogorgon
Sargassum sp.	Phaeophyceae	Fucales	Sargassaceae	Sargassum
Sphacelaria rigidula	Phaeophyceae	Sphacelariales	Sphacelariaceae	Sphacelaria
Sphacelaria sp.	Phaeophyceae	Sphacelariales	Sphacelariaceae	Sphacelaria
Spongocladia vaucheriaeformis	Ulvophyceae	Siphonocladales	Boodleaceae	Spongocladia
Spyridia filamentosa	Florideophyceae	Ceramiales	Ceramiaceae	Spyridia
Stoechospermum polypodioides	Phaeophyceae	Dictyotales	Dictyotaceae	Stoechospermum
Stypopodium flabelliforme	Phaeophyceae	Dictyotales	Dictyotaceae	Stypopodium
Tolypiocladia glomerulata	Florideophyceae	Ceramiales	Rhodomelaceae	Tolypiocladia
Tricleocarpa cylindrica	Florideophyceae	Nemaliales	Galaxauraceae	Tricleocarpa
Turbinaria ornata	Phaeophyceae	Fucales	Sargassaceae	Turbinaria
Udotea argentea	Bryopsidophyceae	Bryopsidales	Udoteaceae	Udotea