Port Hedland Outer Harbour Development

BASELINE CORAL HEALTH MONITORING REPORT PERIODS 1-13

- WV03716-MV-RP-0038
- Revision 0
- 13 August 2009

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Executive Summary

Background

A key component in the environmental approval process for the BHP Billiton Iron Ore Outer Harbour Development is demonstration to regulatory authorities that potential impacts on the marine environment have been adequately investigated. A key potential impact to the marine environment resulting from the Outer Harbour Development is the reduction in light available to benthic primary producers (BPPs), such as hard coral, due to the increase in total suspended solids (TSS) released into the water column during dredging and spoil disposal activities.

The extent of seabed that BPPs inhabit, or could reasonably be expected to inhabit, is referred to as benthic primary producer habitat (BPPH) in Environmental Protection Authority (EPA) Guidance Statement No. 29 (EPA 2004). The aim of baseline monitoring in subtidal BPPH is to examine and document natural levels of change in BPPs through time, as well as to correlate any changes in BPPs with environmental conditions. Data collected will provide an understanding of the temporal dynamics of BPPs and assist in distinguishing naturally occurring impacts from any potential dredge and spoil disposal impacts.

Purpose

SKM was engaged by BHP Billiton Iron Ore to undertake a Baseline Coral Monitoring Program to:

- provide necessary data on the partial mortality of tagged coral colonies to develop coral mortality trigger values for management of impacts from dredging activities;
- compare the health of the BPPs (in particular coral) to the data collected by the water quality (WQ) monitoring component. This will aid in developing tolerance thresholds by comparing the intensity, duration, and frequency (IDF) of WQ events (e.g. increased turbidity and reduced light) with the results of the coral health assessments; and
- allow for comparisons of BPPs and WQ conditions within the Port Hedland region and other locations where similar data have been collected.

This report details the methods and results of the Baseline Coral Monitoring Program between 1 June 2008 and 31 May 2009.

Methods

- Three distinct marine environments (inshore, mid-shore and offshore) were identified during water quality baseline surveys in the Port Hedland region. The characterisation of these three water quality environments was based on a range of characteristic water quality parameters and bathymetry profiles. This enables accurate, environment specific, water quality thresholds to be developed and potential areas of impact and influence to be mapped by modellers.

- The methods used to monitor coral mortality through time appear powerful, with power analysis revealing that a 3% change in partial coral mortality is detectable at each site, between survey periods with a very high level of power (0.80) and high level of confidence (95%).

Summary of Results

- During the summer months, elevated sea temperatures in the inshore and mid-shore environments precipitated a mild bleaching event. There was a subsequent increase in partial mortality following the bleaching event and the total mortality of one tagged coral colony at Weerdee Reef.
- Partial mortality at all sites increased progressively from the start of the baseline surveys in June 2008 to the end of the surveys in June 2009. There were different rates of partial mortality at each site. The lowest rate of partial mortality was at Cape Thouin and the highest rate at Cornelisse Shoal.
- Additional coral stressors were identified and included: (i) grazing on live tissue by the corallivore, *Drupella* spp., and (ii) coral disease (Black Band Disease). These additional stressors were rare and only affected two *Turbinaria* colonies out of the 360 tagged colonies, but eventually resulted in the 70% and 100% mortality of these two colonies.
- Coral health or sub-lethal stress monitoring using the Coral Colour Chart (Siebeck et al. 2006) was effective in detecting changes in colony colour and tracking the bleaching event during summer where the bleaching was moderate to severe.
- The data collected using the Coral Colour Chart was however very inconsistent and provided no more information on sub lethal coral stress that wasn't already provided by the CPCe analysis.

Based on the low species richness and abundance of hard corals and dominance of *Turbinaria*, hard coral communities that inhabit sub tidal habitats in the Port Hedland region can be described as predominately high turbidity/sedimentation (low light) adapted communities.

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List of Acronyms

AIMS	Australian Institute of Marine Science
AVTAS	AIMS Video Transect Analysis System
BBD	Black Band Disease
BPP	Benthic Primary Producer
BPPH	Benthic Primary Producer Habitat
COR	Cornelisse Shoal
COX	Coxon Shoal
CPCe	Coral Point Count with Excel Extensions
CTH	Cape Thouin
DCA	Dead coral with algae
EPA	Environmental Protection Authority
IDF	Intensity, duration, and frequency
LTI	Little Turtle Island
MIB	Minilya Bank
NOAA	National Oceanic and Atmospheric Administration
PER/EIS	Public Environmental Review/ Environmental Impact Statement
SCUBA	Self Contained Underwater Breathing Apparatus
SKM	Sinclair Knight Merz
TSS	Total Suspended Solids
WIS	Weerdee Reef
WQ	Water quality

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Document history and status

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1. Introduction

1.1. Background

A key component in the environmental approval process for the BHP Billiton Iron Ore Port Hedland Outer Harbour Development is to demonstrate to regulatory authorities that potential impacts on the marine environment have been adequately investigated. A key potential impact on the marine environment, which may result from the Outer Harbour Development, is the reduction in light available to benthic primary producers (BPPs) due to the increase in total suspended solids (TSS) released into the water column from dredging and spoil disposal activities.

In order to predict the effects of increased TSS produced by dredging, it is necessary to first determine the baseline health of BPPs. A measure of BPP health is the partial mortality and sub-lethal stress that BPPs are exposed to in the natural seasonal cycles before dredging begins. Baseline benthic primary producer habitat (BPPH) surveys offshore from Port Hedland (SKM 2009a) concluded that the most dominant BPP growing on the available habitat was hard corals (**Table 2-2**). Hard corals are particularly sensitive to changes in the light climate related to increases in turbidity and sedimentation (Brown et al. 1990).

Partial mortality is described as an area of live coral that has died. The area of the dead coral is dependent on the severity of the process that killed the patch of live coral. A severe bleaching event may kill the entire coral colony, whereas as coral disease may initially affect a small area of the entire coral colony. Because the surveys do not always capture the exact cause of the partial mortality, evidence of previous partial mortality is examined and may be represented by areas of sediment, turf algae and sponge on dead coral patches within the boundaries of a coral colony.

Sub-lethal stress describes a process in which environmental stressors such as high turbidity, sedimentation and temperatures do not initially cause any partial mortality of the coral colony. One indicator of sub-lethal stress is a change in the colour of the coral colony toward a lighter ‘bleached’ state. Coral colonies often recover from sub-lethal stressors unless that stress continues for a protracted time, which then leads to partial mortality or total mortality of the coral colony.

To determine the baseline partial mortality and health of hard corals occurring within the Outer Harbour Development study area, six sites offshore from Port Hedland, were selected to be monitored for at least one year, prior to dredging activities (**Figure 2-1**). Monitoring for the baseline period (1 June 2008 to 31 May 2009) captures natural seasonal changes that may affect the partial mortality or health of hard corals, such as temperature fluctuations, increases in turbidity and sedimentation, as well as non-periodic events such as storms.

1.2. Reporting

A baseline coral health monitoring program for the study area commenced in June 2008. Corals were surveyed for partial mortality and sub-lethal stress every four weeks This report is a summary of all baseline data collected to date from 1 June 2008 to 31 May 2009, and will form the basis of undertaking an environmental impact assessment for the Outer Harbour Development Public Environmental Review/Environmental Impact Statement (PER/EIS). Coral monitoring will continue up until at least November 2009. A series of monthly pro-forma progress reports summarise the data being collected after each field trip (post April 2009), and provide ongoing details of the methods used to collect, analyse and interpret the data. A summary of the coral monitoring field trip dates and deliverables completed to date are presented in (Error! Reference source not found.).

▪ **Table 1-1 Summary of coral monitoring field trips and data reporting**

Survey Period	Date	Description	Status
1	1 June 2008 to 28 June 2008	Baseline	Baseline Coral Monitoring Report Period 1 to 4 Data also summarised in this report
2	29 June 2008 to 26 July 2008	Baseline	
3	27 July 2008 to 23 August 2008	Baseline	
4	24 August 2008 to 20 September 2008	Baseline	
5	21 September 2008 to 18 October 2008	Baseline	Baseline Coral Monitoring Report Period 5 and 6 Data also summarised in this report
6	19 October 2008 to 15 November 2008	Baseline	
7	16 November 2008 to 13 December 2008	Baseline	No surveys possible*
8	14 December 2008 to 10 January 2009	Baseline	Baseline Coral Monitoring Report Period 1 to 9
9	11 January 2009 to 7 February 2009	Baseline	
10	8 February 2009 to 7 March 2009	Baseline	Data summarised in this report
11	8 March 2009 to 4 April 2009	Baseline	
12	5 April 2009 to 2 May 2009	Baseline	
13	3 May 2009 to 31 May 2009	Baseline	

*Due to adverse sea conditions and very poor underwater visibility.

1.3. Purpose and Objectives

The objectives of the baseline coral health monitoring program are to:

- provide necessary data on the partial mortality of tagged coral colonies to develop coral mortality trigger values for management of impacts from dredging activities;
- compare the health of the BPPs (in particular coral) to the data collected by the water quality (WQ) monitoring component. This will aid in developing tolerance thresholds by comparing

the intensity, duration, and frequency (IDF) of WQ events (e.g. increased turbidity and reduced light) with the results of the coral health assessments; and

- allow for comparisons of BPPs and WQ conditions within the Port Hedland region and other locations where similar data have been collected.

1.4. Other Related Studies

A water quality monitoring program is also in place at the six coral monitoring sites to enable correlations between coral partial mortality and health and water quality parameters such as turbidity, light conditions, TSS and sedimentation. Water quality monitoring is undertaken on a fortnightly basis, and a summary of baseline water quality conditions is documented in SKM (2009b).

2. Materials and Methods

2.1. Site Selection

Six coral monitoring sites were selected within a study area of 3,775 km^2 (see **Figure 2-1**) based on the following key information provided by preliminary plume modelling results, pilot field surveys of BPPH and field observations of environmental characteristics:

1. A zone of increased TSS, such as an increase of 1 mg/L, was predicted based on preliminary plume modelling to identify the spatial extent of increased TSS from proposed dredge and spoil disposal activities. The preliminary plume model was based on conceptual project information and limited environmental data such as sediment characteristics, hydrodynamic and wave models previously applied for similar projects in the Port Hedland region. The selected zone of influence was a preliminary prediction and used only as a guide to approximately define the boundaries of the study area.

2. Areas with suitable BPPs were identified using observations from field surveys undertaken within the study area. For example, the presence of corals and the suitability of substrate for the installation of site markers (see **Section 2.5).** A summary of the field survey methods and observations used to select monitoring sites are provided in SKM (2009a).

The six coral monitoring sites selected are considered to adequately represent the full range of environmental characteristics and BPP's within the study area. The details of each site are listed in Error! Reference source not found. and illustrated in **Figure 2-1**.

- **Table 2-1 Coral monitoring sites offshore from Port Hedland**

Site Name	Code	Environment	Approx. distance from the mainland (km)	Approx. mid tidal water depth (m)	Latitude	Longitude
Weerdee Reef	WIS	Inshore	3	5	20° 17.414' S	118° 28.893' E
Cape Thouin	CTH	Mid-shore	10	6	20° 14.995' S	118° 17.194' E
Minilya Bank	MIB	Mid-shore	16	9	20° 09.002' S	118° 38.157' E
Little Turtle Island	LTI	Mid-shore	19	7	20° 01.081' S	118° 47.991' E
Cornelisse Shoal	COR	Offshore	33	12	20° 02.040' S	118° 22.560' E
Coxon Shoal	COX	Offshore	28	12	20° 03.998' S	118° 27.485' E

It was intended that the location and relevancy of all sites be reviewed when the final plume modelling results are available. Following this, sites will be allocated as either 'reference' or potential 'impact' for the dredging phase of the project.

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2.2. Water Quality Environments

Measurements of light climate, turbidity, sedimentation and temperature from each monitoring site from the first nine months of water quality monitoring indicate there are three water quality environments offshore of Port Hedland; inshore (<5 m datum), mid-shore (5–10 m datum) and offshore (>10 m datum) (Error! Reference source not found. and **Figure 2-1**).

The inshore environment is characterised by high turbidity and high sedimentation rates, highly variable light and sea temperatures. The mid-shore environment has fewer extremes of water quality parameters, but still experiences occasional high gross sedimentation rates and turbidity, low light and variable temperatures. The offshore environment is much more stable in terms of all water quality parameters and is considered potentially the most at risk from reduction in light levels from elevated turbidity and sedimentation from dredging.

Two objectives were considered during the characterisation of water quality environments offshore from Port Hedland:

- provide the plume modellers with meaningful water quality thresholds to model the area of potential impact and potential influence based on spatially broad categories rather than site specific categories which are difficult to model; and
- take into account the sensitivity of coral communities which have adapted to the different water quality environments, reducing the risk to these communities when changes to the water quality during dredging and spoil disposal occur.

The inshore environment is represented by only one monitoring site at Weerdee Reef (WIS). Spot dives of specific inshore areas identified by LiDAR as potentially containing hard substrate (BPPH) concluded that there was little BPPH in this environment (SKM 2009a). The LiDAR mapping may have detected areas of hard substrate covered by a layer of sand and mud. This suggests that BPPH in these areas is likely to be covered by sediments then exposed again over short time frames. Given the extremes tidal and weather events that occur in the Port Hedland area, this is likely to be the case. The WIS monitoring site contains potentially more stable elevated BPPH that is capable of supporting extensive areas of BPP in the inshore environment. It is likely that water quality parameters measured at the WIS monitoring site therefore represent a conservative snapshot of the water quality parameters that are indicative of the inshore environment.

2.3. Site Descriptions

Table 2-2 gives the overall percentage contribution of each benthic category from baseline video transect surveys of 52 sites offshore of Port Hedland from Cape Thouin (CTH) to North Turtle Island carried out in early 2008.

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- **Table 2-2 Percentage cover of benthic categories from video transect surveys**

Benthic Category	Percentage cover (± Standard Error)
Abiotic (sand, rubble, silt, rock)	75.3 ± 2.8
Hard coral	10.0 ± 1.2
Macroalgae	6.5 ± 2.8
Sponge	6.1 ± 0.5
Soft Coral	1.7 ± 0.3
Other	0.4 ± 0.2

A general description of the six monitoring sites chosen for ongoing monitoring is provided in **Table 2-2**, including the relevant percentage contributions of benthic and abiotic categories as summarised in SKM (2009a). The baseline video transect survey results from sites not chosen for ongoing coral monitoring, are also outlined in SKM 2009a.

2.3.1. Inshore Site: Weerdee Reef

Weerdee Reef (WR1 in the baseline report, SKM (2009a)) is located approximately 12 km west of the entrance to Port Hedland Harbour and 3 km offshore of the mainland. The site is 2 km to the North of Weerdee Island and located at a depth of approximately 5 m mid tidal. The site is predominantly abiotic (69%), with a moderate percentage cover of sponges (12%), hard corals (11%) and soft corals (7%).

2.3.2. Mid-shore Sites: Cape Thouin, Minilya Bank and Little Turtle Island

Cape Thouin (CT-R1 in the baseline report) is approximately 40 km west of the entrance to Port Hedland Harbour and 14 km to the north-east of Cape Thouin. The site is located on an extensive reef platform at a depth of 6 m mid tidal. The predominant cover is abiotic (78%), hard corals (8%) and sponges (8%), with small patches of macroalgae (5%) and soft corals (1%).

Minilya Bank (MIB-1 in baseline report) is approximately 19 km north north-east of the entrance to Port Hedland Harbour and consists of a low mound rising from a depth of 11 m at the mooring to 9 m. The site is predominantly abiotic (88%), with small patches of hard coral (6%), macroalgae (5%) and sponges (2%).

Little Turtle Island (LTI-S1 in baseline report) is approximately 40 km north-east of the entrance to Port Hedland Harbour and 19 km offshore of the mainland at Spit Point. The site has low topographic complexity substratum rising from a depth of 9 m at the mooring to 7 m at the highest point of the site. The site was predominantly abiotic (76%) with a moderate cover of hard corals (18%) and lesser quantities of sponge (3%), macroalgae (3%) and soft corals (0.2%).

2.3.3. Offshore Sites: Cornelisse Shoal and Coxon Shoal

Cornelisse Shoal (CNS1 in baseline report) is part of a reef complex approximately 37 km north-west of the entrance to Port Hedland Harbour and 33 km offshore from the mainland. The site mooring is located on the top of the shoal at a depth of 9 m and begins at the crest of the shoal and follows the reef slope down to a maximum depth of 12 m. The site is predominantly abiotic (61%), with areas of hard corals (21%) and varying quantities of sponges (9%), macroalgae (5%) and soft corals (1%).

Coxon Shoal (CX3 in baseline survey report) is part of a reef system approximately 24 km north-west of the entrance to Port Hedland Harbour and 28 km offshore from the mainland. The shoal is a low mound rising from a depth of 14 m at the mooring to 12 m. The site is predominantly abiotic (73%), with patches of hard corals (22%) sponges (4%), soft corals (1%) and macroalgae (0.2%).

Additional information on the composition of the benthic community at each site was collected during surveys in February 2009 to assist in developing protocols for the future autumn coral spawning assessment in March and April 2009. These protocols included identifying the dominant hard coral taxa and the availability of sufficient coral colonies to adequately sample for the evidence of eggs to indicate the timing of coral spawning. In addition, surveys of species richness at each monitoring site were carried out opportunistically during the February 2009 coral monitoring surveys. The methods used for these additional surveys in February 2009 are summarised in **Sections 2.4** and **2.5** and the results summarised in **Sections 3.1** and **3.2**.

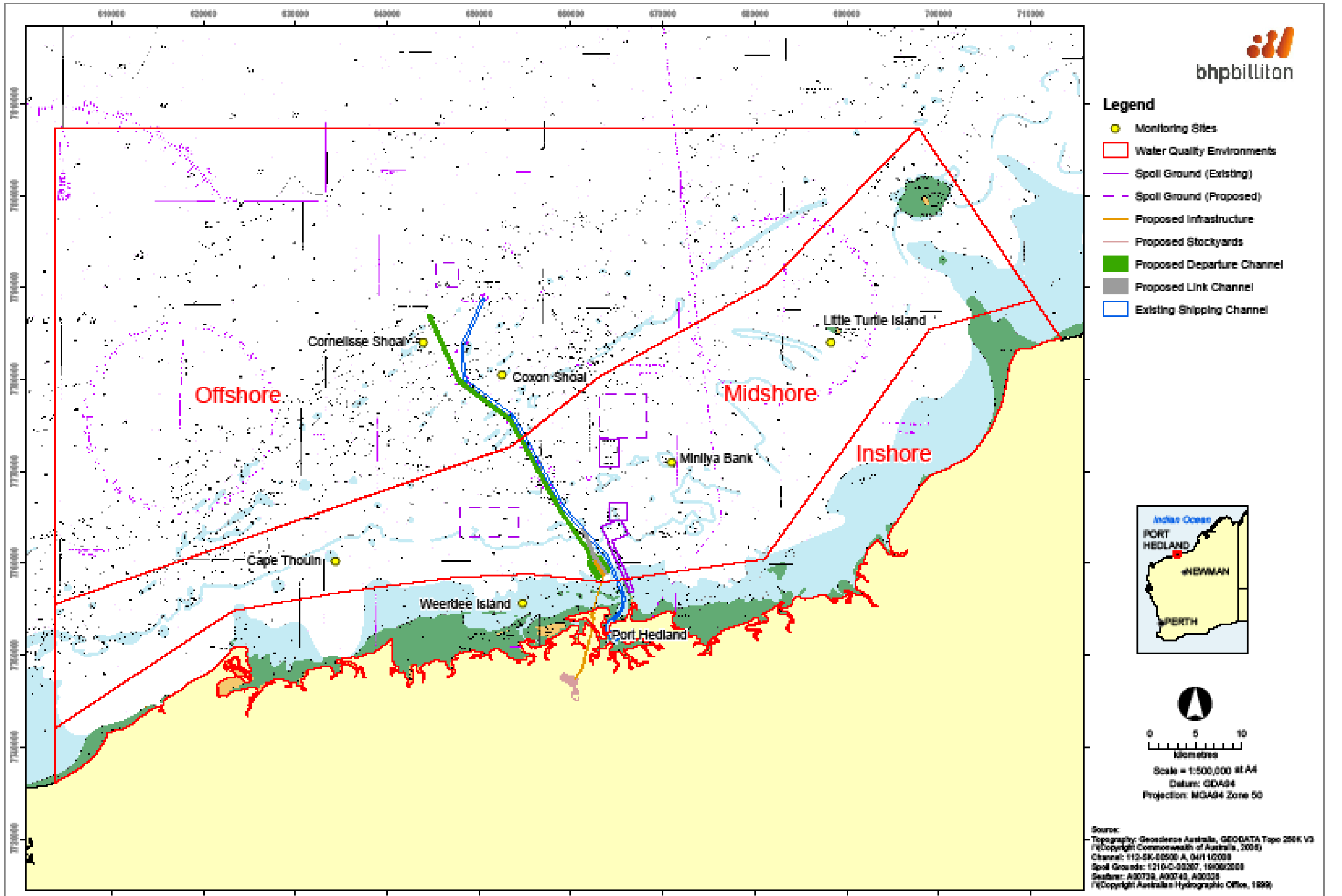

Figure 2-1 Water Quality Environments and location of coral monitoring sites offshore from Port Hedland

▪ **Figure 2-1 Water Quality Environments and location of coral monitoring sites offshore from Port Hedland**

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2.4. Dominant Coral Taxa and Coral Species Richness

The dominant coral taxa at each site was assessed using a survey technique that utilised elements of methods developed by scientists at the Australian Institute of Marine Science (AIMS) (Abdo et al. 2004). The basis of the survey technique involved taking 100 underwater photographs of the sea floor at random intervals across the entire coral monitoring site. Each photograph was taken from directly above the substrate at a distance of 35 cm. Each photograph was then analysed using software (AVTAS – AIMS Video Transect Analysis System) developed at AIMS, which superimposes five points onto that photograph in a fixed pattern. The coral taxon that occurs under each point was entered into a database, and the percentage cover of various coral taxa at each site was then ascertained. This method allowed for approximate comparisons between sites to be made. It did not, however, allow for more detailed comparisons at higher levels of taxonomy, and temporal comparisons to detect changes in benthic community composition due to the relatively small sample size and lack of repeatability.

The species richness at each site was estimated by surveying as much of the habitat at each site as possible during timed 45 minute swims on SCUBA, and scoring the number of coral species *in situ*. If *in situ* identification was not possible, photographs of the colony in question were taken, and identification was carried out back on land using reference material.

2.5. Site Establishment and Coral Tagging

After identification of suitable BPPH monitoring sites, a surface float, riser chain and permanent base were installed adjacent to the coral habitat at each of the six monitoring sites to provide for vessel tethering and site marking. This removed the potential habitat impact from temporary anchor deployment, retrieval and dragging on corals.

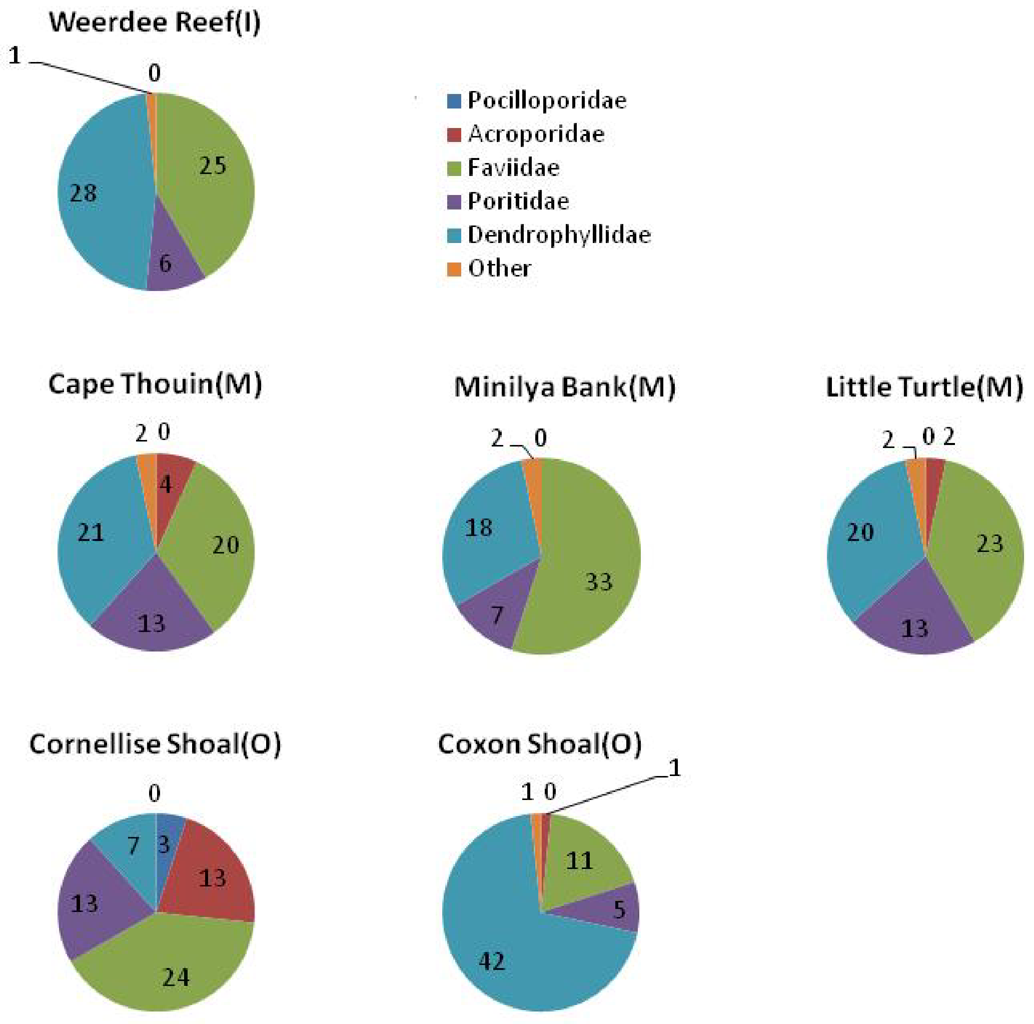
Sixty replicate colonies were selected at each site in a concerted attempt to choose appropriate coral colonies that represent the abundance of the coral taxa growing at each site (see **Figure 2-2** and **Table 2-3**). This was not always possible due to the following:

- In the prevailing turbid, low light conditions experienced at Port Hedland, the further the distance above the coral colony the photographer needs to be to frame the entire colony in the photograph, the poorer quality the image will be. This meant that only small/medium sized coral colonies were tagged to circumvent this issue.
- The shape of each colony selected needed to be uniform so photos could be taken from the same angle from period to period without adversely disrupting the post analysis of partial mortality of the tagged colony.
- The distance between each colony needed to be sensible to enable reasonable dive times, and reduce the chances of tagged colonies being 'lost' due to breakages in the chain connecting the tagged colonies.

Fifty corals per site were previously evaluated as being a sufficiently powerful sample size for a significant change in the partial mortality to be detected at each site over time (MScience 2007). The choice of 60 coral colonies per site allowed enough information on the partial mortality at a particular site to be collected given the potential death of some tagged colonies during the baseline and dredging surveys. Each of the 60 selected coral colonies were permanently tagged to ensure the unique identification of each tagged colony.

- **Table 2-3 Descriptions of hard coral genus groups within each hard coral family**

Family	Description
Pocilloporidae	Members of the genus *Pocillopora* – primarily *Pocillopora damicornis*
Acroporidae	Members of the genus *Acropora, Montipora* and *Astreopora*
Faviidae	Members of the genus *Favia, Favites, Cyphastrea, Goniastrea, Platygyra, Plesiastrea, Montastrea, Oulophyllia* and *Barabattoia*
Poritidae	Members of the genus *Porites* and *Goniopora*
Dendrophylliidae	Members of the genus *Turbinaria* and *Duncanopsammia*
Other	Members of the genus *Euphyllia, Siderastreidae, Pectinidae, Mussidae, Merulinidae,* and *Agariciidae*



Note: (I) Inshore, (M) Mid-shore, (O) Offshore

- **Figure 2-2 The relative proportions and number of tagged hard coral family groups at each coral monitoring site in each Water Quality Environment**

2.6. Data Collection

At each of the six monitoring sites, coral mortality was monitored on an approximately four-weekly basis, corresponding with the occurrence of neap tides and the maintenance of water quality loggers. Coral mortality data for each tagged colony was ascertained by taking photographs of each tagged colony. The whole-colony images were then assessed for partial and total colony mortality using Coral Point Count with Excel Extensions (CPCe; Kohler and Gill 2006) to determine the surface area of each colony that was alive versus dead. This software was developed by the US National Coral Reef Institute (Dania Beach, Florida), and is used by numerous organisations, including the US National Oceanic and Atmospheric Administration (NOAA).

2.6.1. Coral Image Analysis

The image for each coral colony was imported to the CPCe program. The extent of each coral colony was overlaid by a symmetrical nine by nine point grid (**Figure 2-3**). Points falling outside of the coral colony were excluded from the analysis, and points falling within the colony itself were scored into one of the following categories:

- live coral;
- bleached coral or pigment response;
- recently dead coral with algae (DCA);
- sediment (either fine, sand, coarse or rubble);
- turf or macroalgae;
- soft coral, sponge, other; and
- coral disease.

- **Figure 2-3 Screen snap shot of the CPC analysis of two tagged coral colonies**

Note: the colonies were overlaid with the 9x9 point sampling grid (Turbinaria on the left with a small patch of sediment in the centre of the colony, and Favia on the right).

All of the above categories are indicators or contributors to partial mortality except for live coral, bleached coral and pigment response. Bleached patches of live coral tissue and patches of live coral tissue where there is a pigment response are assumed to be alive and are therefore included in the live coral category. Partial mortality may then occur when the bleached section of the colony dies and becomes covered in a fine layer of algae (DCA), and, in time, potentially covered by turf/macroalgae, sediment, sponge or soft coral.

2.6.2. Statistical Treatments

2.6.2.1. Power Analysis

One of the primary future aims of this coral monitoring program is to detect a change (i.e. an increase) in the level of coral partial mortality at impact sites during the proposed dredging operations, and assess the likelihood that this change is a negative reaction to environmental conditions being influenced by the dredging. The ability of a monitoring program to adequately detect this change is described by the statistical term - 'power'. A power analysis of the baseline data was carried out by comparing the difference in partial mortality from one period to the next at each site and using a prerequisite lower detection level of a 3 % change in partial mortality between surveys. Results from the analysis of data from two sites (COR – offshore and WIS – inshore) indicates that the sample size used in this monitoring program (50 - 60 corals) can detect a 3 % change in the partial mortality over time.

2.6.2.2. Baseline Mortality

Partial Mortality

Partial mortality estimates were developed at the sites using statistical analyses according to methods outlined in MScience (2007). Using this approach, each coral colony image, '(i)', was assigned a percent partial mortality, or 'PM(i)', which equates to the number of points scored as partial mortality divided by the total number of points within the coral boundary. For each monitoring survey the partial mortality of coral (i) at survey '(x)' was described as 'PM (i,x)'.

The partial mortality estimate for a site was the average of all corals scored at that site for that particular survey. For example, for Site COR in baseline survey 2, PM(COR2) = ΣPM((i),(2))/N, where (i) was from 1 to N corals.

Once all of the baseline partial mortality data is collected, seasonal or site specific natural variations in partial mortality will be taken into account during the dredging phase.

Rates of Partial Mortality

The rate of partial mortality during the baseline surveys was calculated by plotting the mean gross mortality (see **Section 2.6.2.3**) for each site for each survey, and fitting a linear trend line to the data. The x-axis in this plot represents the days after the first survey, and the slope of the linear trend line represents the rate of partial mortality per day during the baseline surveys.

2.6.2.3. Mortality During Dredging

Partial Mortality

The ideal scenario for the coral monitoring program during dredging operations is to have a greater number of reference sites compared to impact sites. The reference sites should be similar to the impact sites in terms of coral community, water quality, depth, and should be outside the influence of the dredging and spoil disposal works. The six coral monitoring sites provide three pairings of impact/reference sites based on the preliminary plume modelling. Based on these sites, the following analysis of partial mortality during the dredging will be followed.

During the dredging phase of the project, gross mortality will be calculated after each survey based on the baseline data. For example, the gross mortality for dredging survey 2 at COR would be calculated as follows:

> PM(COR2) = Σ(PM(i),(2) – PM((i),B)/N, where '(i)' represents from 1 to N corals with 'N' being the number of corals measured at dredging survey 2, and '(i),B' those same corals from the baseline survey.

The net mortality at an impact site is the gross mortality at that site during a survey less the average gross mortality at the corresponding reference site during that same survey. Once a numeric coral mortality trigger level is assigned (after the baseline surveys are complete), tests of whether gross mortality exceeds the numeric trigger levels at any survey are performed as a paired t-test using the baseline and survey results for each coral at a site. The trigger level is defined as the minimum difference between means for the t-test, or in effect, the tests of a sample mean being significantly greater than a constant.

Should the test of gross mortality show the exceedence of a trigger level to be significant at the 95% level then the test is repeated with the new level of significance being the trigger level plus the average gross mortality of the reference sites. Should the latter test be significant at the 95% level then the net mortality level is deemed to have exceeded the trigger level.

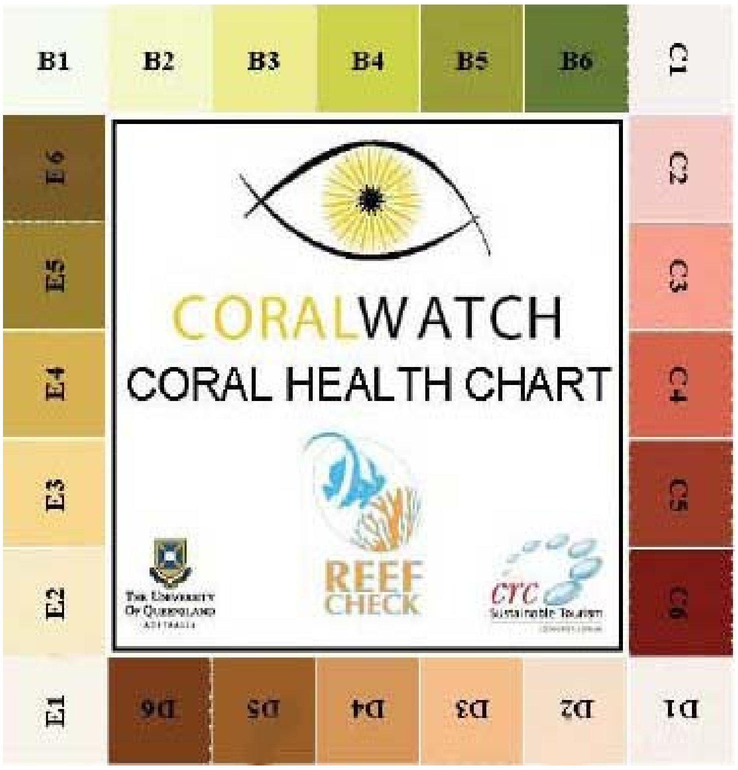
If further plume modelling causes the number of impact sites to outweigh the number of reference sites, a case may eventuate that it will be necessary to compare the partial mortality at four impact sites, for example, to the partial mortality at only two reference sites. While the method of assessing exceedences of trigger levels outlined above would still be relevant, it may lead to a false positive, indicating an exceedence of a trigger level that is not a related to the impact from dredging. In this case, further lines of evidence would need to be followed, including examining the rate of mortality and partial mortality.

Rates of Partial Mortality

The rate of partial mortality at each site during the dredging phase of the project will be compared to the rate of partial mortality at each site during the baseline period. Comparing the rates of partial mortality between impact and reference sites will aid in delineating between naturally occurring increases in the rate of partial mortality and those due to dredging. The additional information provided by the rates of partial mortality will aid in confirming that an exceedence of partial mortality triggers based on the tests between the impact site and the reference sites (see **Section 2.6.2.2**) are related to dredging and not false positives.

2.6.3. Sub-lethal Stress

Measuring sub-lethal stress can potentially provide an early warning on the deteriorating status of individual corals before the onset of mortality. The responses of a coral polyp to sub-lethal stressors may include changes in the density of the symbiotic zooxanthellae living in the live tissue which manifests as a lightening of this tissue and excess mucous secretion. The changes in the colour of live tissue were chosen as the basis for measuring the sub lethal stress of tagged coral colonies in this study. This method utilizes a hand-held underwater coral colour chart developed by Siebeck et al. (2006) (**Figure 2-4**). Colour intensity scores for each tagged colony are scored by divers during each survey period. To ascertain the change in colour intensity for the individual coral colonies, the colour intensity value of a coral at one survey is subtracted from the colour intensity value from the subsequent survey. Each individual coral colony colour intensity change is then averaged to site level. A negative change from survey period to survey period indicates a shift toward lighter intensities and therefore a more stressed state.

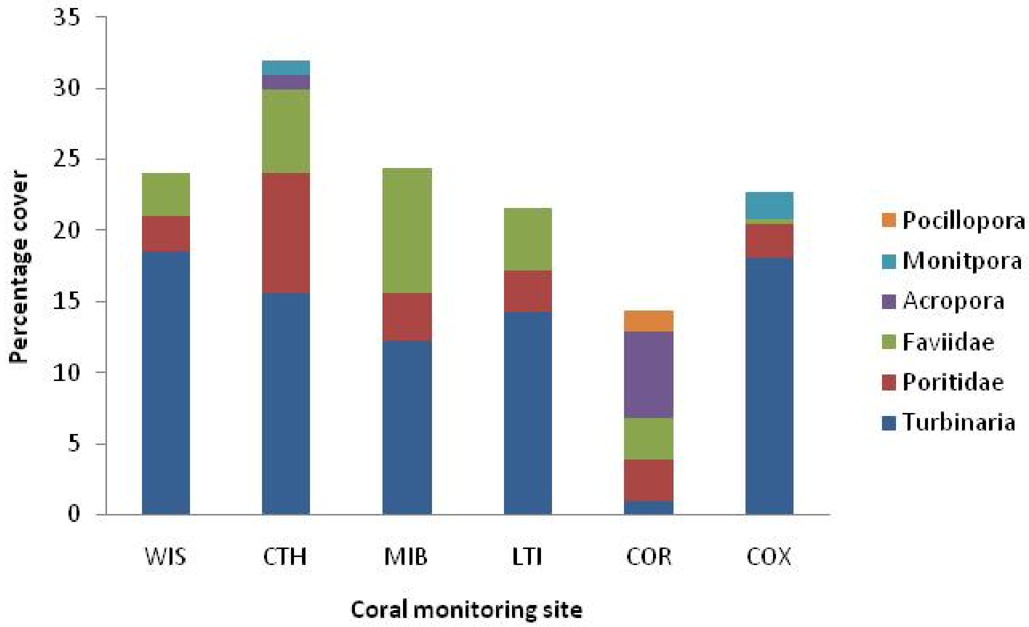


- **Figure 2-4 The Coral Health Chart developed by CoralWatch, University of Queensland**

3. Results

3.1. Dominant Coral Taxa and Coral Species Richness

The most dominant hard coral taxa at five of the six sites is *Turbinaria*; at COR the most dominant hard coral taxa is *Acropora* (**Figure 3-1**). The percentage cover of *Turbinaria* at each site, where this genus dominates, ranges from 19% at WIS to 12% at MIB. The highest hard coral cover was recorded at CTH (32%) and the lowest at COR (14%).



- **Figure 3-1 The percentage cover of the dominant coral taxa at the six monitoring sites**

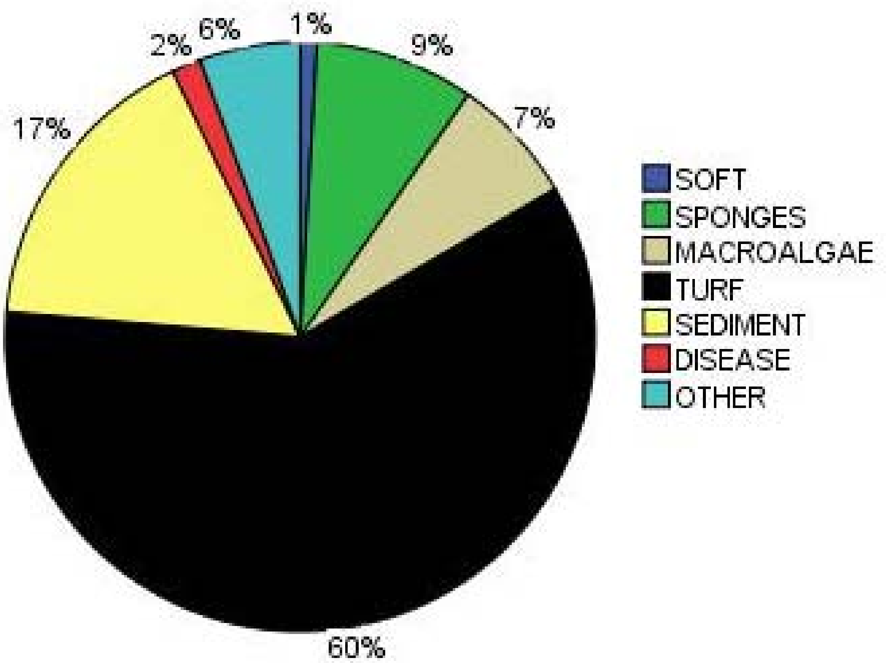
A total of 51 species of coral from 19 genera were identified from all monitoring sites (**Appendix A.1**). The highest coral species richness occurred at COR (42 species, 18 genera) and the lowest at COX (22 species, 11 genera), both offshore sites. The number of species and genera at three mid-shore sites was very consistent, ranging from the highest at MIB (33 species, 17 genera) to CTH (30 species, 14 genera). The diversity at the WIS inshore site was low (26 species, 12 genera). COR was the only site in which stands of *Acropora* and *Pocillopora* were noted.

3.2. Coral Mortality

The number of colonies analysed at each site for each of the 13 survey periods is summarised in **(Appendix A.2)**. In some cases there were less than 60 corals available for analysis due to poor image quality. The analysis of less than 60 corals is unlikely to affect the sampling power, which is contingent on at least 50 colonies being available for analysis during each survey. During period seven (December 2008), no tagged coral colonies were photographed due to adverse sea conditions and very poor underwater visibility. No photos were taken in period eight at WIS, also due to adverse seas conditions and poor underwater visibility.

3.2.1. Partial Mortality

Areas within the boundary of the coral colony that were not live coral were categorized using the categories defined in the CPCe analysis. Generally these areas provide no information on the cause of the partial mortality, but are useful as indicators of previous mortality. When all data from all surveys and all sites is combined, the main indicators of previous partial mortality within the boundary of the tagged coral colony are represented in **Figure 3-2**. Patches of turf algae growing on areas of dead coral represent the main contributor to the overall partial mortality estimates (60%). Areas of dead coral covered in sediment (17%) and other areas with small colonies of sponge (9%) represent the next main indicators of previous mortality. On some tagged colonies, areas of dead coral were covered with macroalgae (7%), soft corals (1%) and other benthos (6%) such as hydroids, and ascidians.



- **Figure 3-2 The relative proportion of indicators of previous mortality for all baseline surveys at all sites**

The partial mortality increased at all sites over the extent of the baseline surveys (**Figure 3-3**). The highest partial mortality was observed at the offshore monitoring sites at COX and COR. The lowest partial mortality occurred consistently on the mid-shore sites.

To calculate the rate of partial mortality at each site during the baseline surveys, the mean gross mortality at each site is plotted (y-axis) against the number of days (x-axis) after the first baseline survey in which that gross mortality is measured. A linear trend line is fitted and the slope of that line represents the rate of partial mortality per day (**Figure 3-3**). The trend line equations and R^2 values are listed on the figures below the titles. The R^2 values (the square of the correlation coefficient) represent how well the fitted line approximates the real data points. As this value approaches one, the better the line approximates the data. The R^2 values are statistically significant for each site, which indicates that the rate of partial mortality (the slope of this line) may be a good predictor of the values to be calculated in subsequent surveys.

The percentage partial mortality per day was the highest at the offshore site COR (**Figure 3-3**). One contributing factor to this elevated rate of mortality compared to other sites is the steady increases in the percentage partial mortality of one colony of *Turbinaria* at COR (**Figure 3-4**). The corallivore, *Drupella* spp., was observed during most surveys grazing on the live coral tissue of this colony (**Figure 5-2**). Partial mortality increased from 5% of the coral colony in June 2008 to 100% of the coral colony by February/ March 2009 (**Figure 3-4**). At the other offshore site, COX, the rate of partial mortality was also elevated primarily due to one tagged colony of *Turbinaria* spp. adversely affected by Black Band Disease (BBD) (**Figure 5-1**). The partial mortality recorded on that particular colony increased from 11% of the coral colony in June 2008 to approximately 80% by the end of the baseline surveys (**Figure 3-4**).

If we remove the partial mortality data for both of these colonies for all surveys and reanalyse the results, the rate of partial mortality at COR is reduced from 0.034% to 0.032% per day, and the rate of partial mortality at COX is reduced from 0.023% to 0.018% per day. Over longer times frames of weeks or months this may represent an important factor.

The lowest rate of partial mortality was at the CTH monitoring site (**Figure 3-3**). The rate of partial mortality at the inshore site located at WIS was higher than the mid-shore sites. At WIS, the death of one tagged colony of *Turbinaria* during baseline survey 9 lead to a slight increase in the partial mortality and rate of partial mortality.

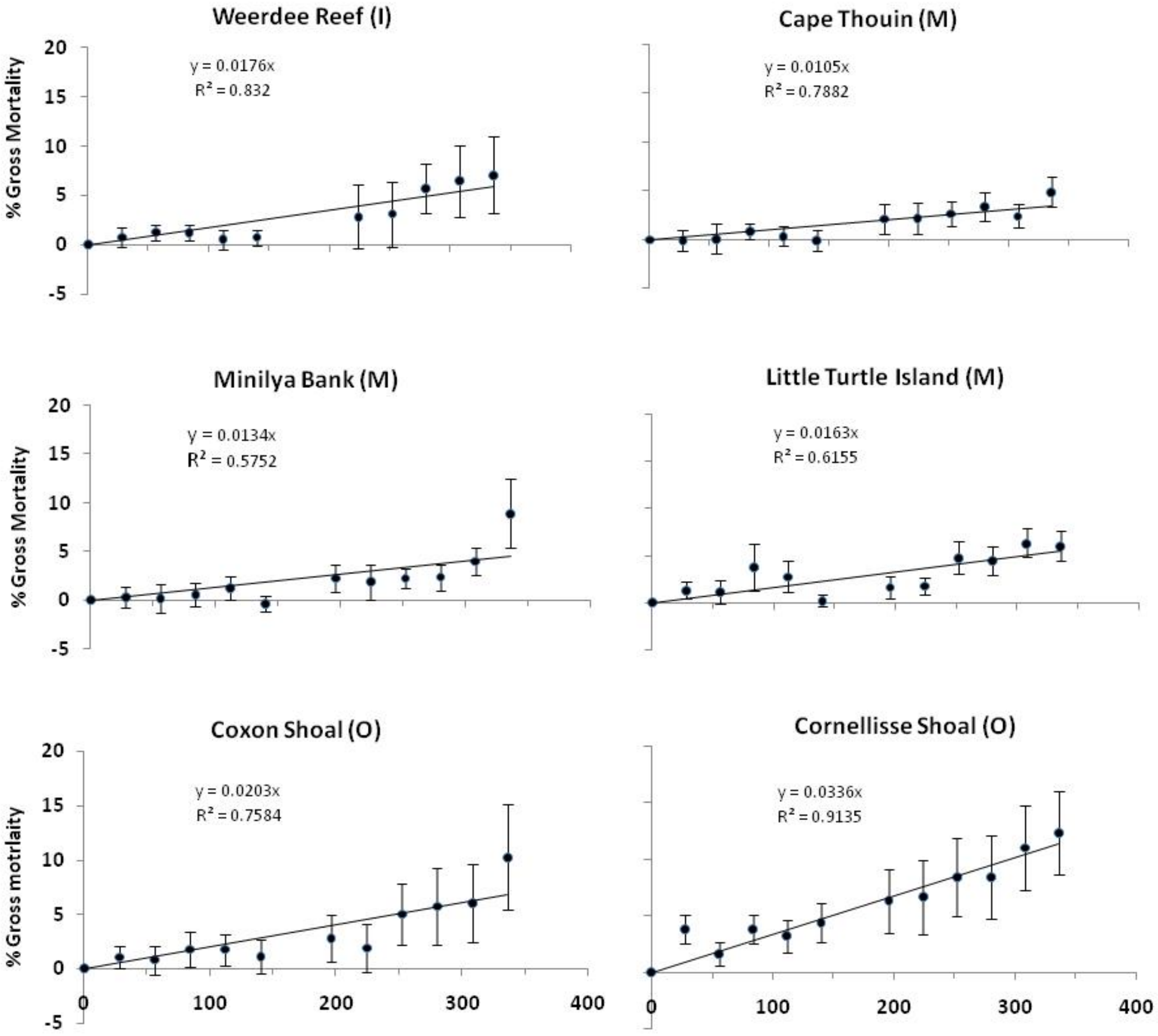
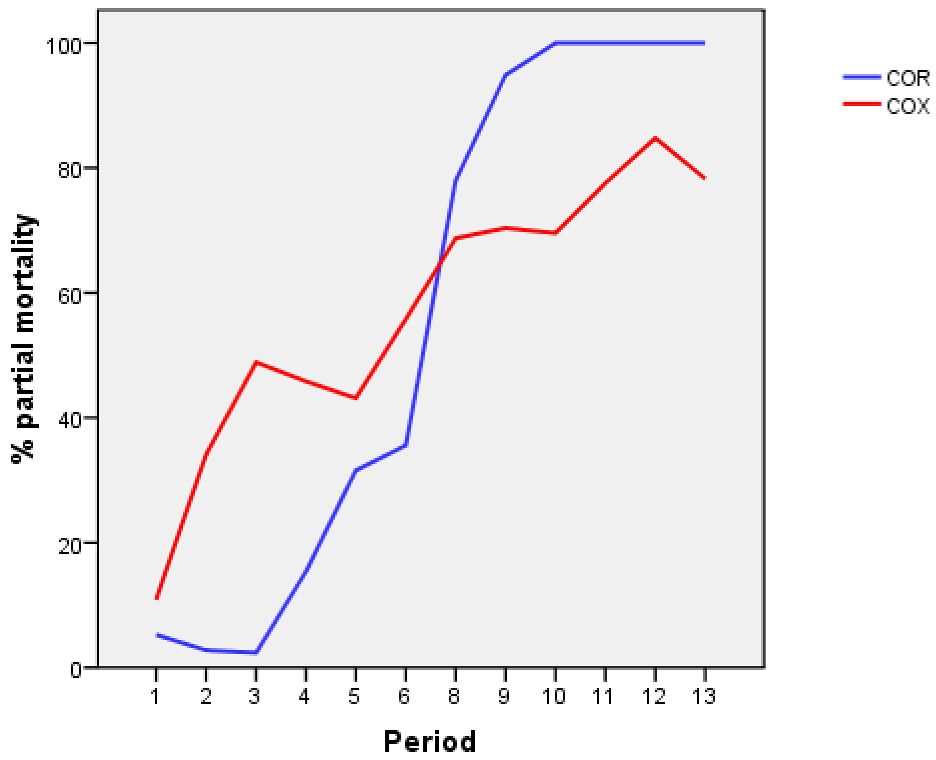


Figure 3-3 The percentage gross mortality (± 95% CI) at each monitoring site each day after the period 1 survey

Notes: Equations for each trend line are presented below each individual graph title, and represent the rate of gross mortality per day. I = Inshore, M =Mid-shore and O = Offshore.



- **Figure 3-4 The changes in percentage partial mortality of one colony of *Turbinaria* predated upon by Drupella at COR, and one colony of *Turbinaria* infected with BBD at COX, for all survey periods**

3.3. Coral Health and Sub Lethal Stress

Measuring the individual coral colony health using the Coral Colour Chart was implemented for the first time during the period 4 surveys. Comparisons between the colour chart intensity scores, the mean monthly temperatures and the percentage of bleaching recorded using the CPCe program are summarised in **Table 3-1.** Periods in which the mean monthly temperatures exceeded 30°C are highlighted in bold in this table and are of interest when comparing the two indicators of bleaching responses of the corals to sustained elevated temperatures.

The three parameters show some similar patterns primarily when and where the bleaching of coral colonies is found to be most prevalent, however the data from the Coral Colour Chart is very inconsistent. The highest mean monthly temperatures and the highest percentage of bleaching (recorded using the CPCe program) were recorded at the WIS (inshore) and CTH (mid-shore) sites during the December 2009 to February 2009 corresponding to period 8-9 (**Table 3-1, Figure 3-5**). Coral bleaching at WIS increased from 0% in November to 16% in January/February 2009. The percentage bleaching observed at CTH increased from 0% in December 2008 to 2.6% in January/ February 2009. A change in coral colour intensity also occurred at these sites during the same period (**Table 3-1**). This change indicates that the colour intensity score of the coral colonies have decreased in the January/ February survey compared to the previous survey. The large increase in bleaching at WIS compared to other sites can be attributed to extended periods of sea temperatures in excess of above 33°C during February 2009 (SKM 2009a).

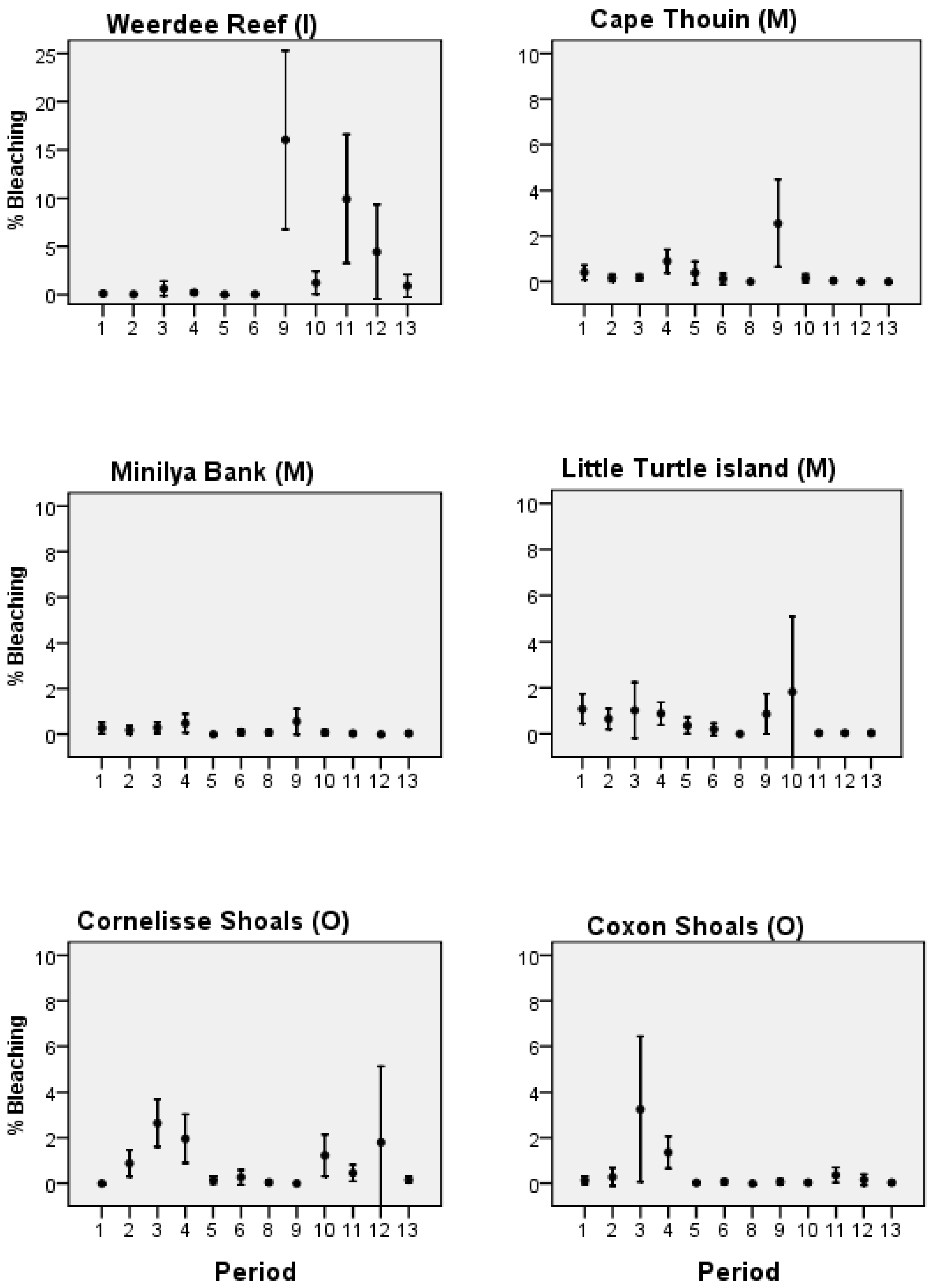
The percentage bleaching, as measured by the CPCe program at WIS and CTH, decreased during periods 9 to 10. The colour chart intensity measurements also showed an increase in the intensity of the coral colonies at these sites, indicating a recovery from bleaching at these sites. In the subsequent surveys (10 to 11), where mean monthly temperatures remained above 30°C at WIS, the bleaching measured by the CPCe analysis increased to 9% and the colour chart intensity also decreased.

During the winter/ spring periods (survey period 3 and 4) slight increases in the percentage partial bleaching of tagged colonies were observed at most monitoring sites (**Figure 3-5**). The largest increases in the partial bleaching of tagged colonies during this period occurred primarily in the offshore environment (**Figure 3-5)** where bleaching represented ~3% of recorded partial mortality. This may be related to the large stands of the transient macroalgae, *Sargassum* spp., growing at these sites during this period. The tall fronds of the *Sargassum* spp. were observed by divers rubbing on the edges of the tagged coral colonies causing some localised 'bleaching' and pigment responses from the coral at the points of contact (pers. comm. Gus Paccani 2008). The CPCe analysis of the images from this period scored many instances of patchy bleached coral.

- **Table 3-1 The average change in coral colour intensities, mean monthly temperatures and partial bleaching percentages (as recorded by the CPCe analysis) at the six monitoring sites from Periods 4 to 13.**

Survey Period	WIS			CTH			MIB			LTI			COX			COR		
	Inshore			Mid-shore			Mid-shore			Mid-shore			Offshore			Offshore		
	Coral Colour Intensity	Mean Temp (°C)	PM Bleaching	Coral Colour Intensity	Mean Temp (°C)	PM Bleaching	Coral Colour Intensity	Mean Temp (°C)	PM Bleaching	Coral Colour Intensity	Mean Temp (°C)	PM Bleaching	Coral Colour Intensity	Mean Temp (°C)	PM Bleaching	Coral Colour Intensity	Mean Temp (°C)	PM Bleaching
Period 4 - 5	-0.7	26.7	0.0	-0.6	26.9	0.4	NR	26.1	0.0	1.1	26.7	0.4	-0.1	26.1	0.0	0.2	25.5	0.2
Period 5 - 6	-0.1	27.7	0.0	-0.1	27.8	0.1	-0.3	27.8	0.1	-0.5	28.1	0.2	-0.2	27.6	0.1	-0.3	27.2	0.3
Period 6- 7	NR	29.9	NR	NR	29.1	NR	NR	29.1	NR	NR	29.2	NR	NR	28.7	NR	NR	28.7	NR
Period 6 - 8	0.6	29.2	NR	0.7	28.6	0.0	-0.1	28.6	0.1	0.3	28.9	0.0	-0.2	28.4	0.0	0.8	28.1	0.1
Period 8 - 9	**-0.8**	**32.0**	**16.0**	**-1.2**	**31.6**	**2.6**	**NR**	**31.6**	**0.6**	**-1.2**	**31.5**	**0.9**	**0.0**	**30.9**	**0.1**	**-0.3**	**30.3**	**0.0**
Period 9-10	**0.8**	**31.3**	**1.2**	**1.1**	**31.4**	**0.2**	**0.8**	**31.2**	**0.1**	**1.1**	**31.3**	**1.8**	**0.8**	**31.0**	**0.0**	**0.9**	**30.6**	**1.2**
Period 10-11	**-0.3**	**30.9**	**9.9**	**-0.6**	**31.2**	**0.0**	**-0.8**	**30.9**	**0.0**	**NR**	**31.0**	**0.0**	**-0.7**	**30.9**	**0.4**	**-1.1**	**30.7**	**0.5**
Period 11-12	-0.3	28.4	4.5	-0.3	28.9	0.0	0.1	28.8	0.0	-0.3	29.0	0.0	0.3	29.0	0.2	**0.2**	**30.0**	**1.8**
Period 12-13	-0.1	23.4	0.9	0.6	23.9	0.0	0.6	23.8	0.0	0.0	24.0	0.0	-0.8	24.3	0.0	-0.4	na	0.2

NR=Not Recorded
na= no data available



- **Figure 3-5 Percentage of coral bleaching at all monitoring sites ±95% Confidence Intervals for all survey periods**

Notes: the change in scale of y-axis on WIS figure. I= Inshore, M=Mid-shore and O= Offshore

4. Discussion

4.1. Existing BPP within the Proposed Project Area

Extensive surveys of the benthic habitat offshore of Port Hedland were undertaken between December 2007 and May 2008 (refer to SKM 2009b). These surveys indicate that the benthic habitat offshore from Port Hedland is characterised by extensive plains of sand/silt/rubble substratum and low relief ridge lines of hard pavement (often covered in a layer of sand/silt). Offshore low relief ridge lines support occasional patches of sparse biota, including hard corals, macro-algal beds, sponges and soft corals (e.g. gorgonians, sea whips). Hard corals represented the most dominant BPP (**Table 2-2**) growing along these ridges, with the dominant corals from the genus *Turbinaria* and from the families Faviidae and Poritidae. Branching *Acropora* corals were found in numbers only at the offshore ridge lines in deeper water (>12 m).

Gilmour et al. (2006) examined the water quality environment in the Pilbara region and identified a range of potential water quality stressors such as turbidity, sedimentation and reduction in light. The susceptibility of a range of coral taxa to these stressors was characterised into three categories: High, Medium and Low. The dominant coral taxa occurring in the Port Hedland area is *Turbinaria* which is described by Gilmour et al. (2006) as having low susceptibility to increases in sedimentation and the reduction in light regime due to increases in turbidity. Other sub dominant genera in the Port Hedland region such as corals from the Faviidae and Poritidae family and branching *Acropora*, were described by Gilmour et al. (2006) as having medium susceptibility to major changes in the sedimentation and light regime.

The species richness of coral taxa at the six monitoring sites is very low in comparison to other studies carried out in the Pilbara region. A total of 51 species of coral from 19 genera were identified from areas offshore from Port Hedland which is considerably lower than the 120 coral species from 43 genera recorded in the Dampier Port and inner Mermaid Sound (Blakeway and Radford 2004).

Based on the low species richness and abundance of corals and dominance of *Turbinaria* and the results of the investigations by Gilmour et al. (2006); coral communities that inhabit sub tidal habitats in the Port Hedland region can be described as predominately high turbidity (low light) and sedimentation adapted communities.

4.2. Coral Mortality

As discussed in **Section 2.6**, the percentage of partial mortality of each tagged colony was measured on a four-weekly basis. The aim of measuring the partial mortality is to track the changes in mortality during the different seasons, which may have some influence on an individual coral colony, and therefore affect the overall partial mortality at each site. Another description of the partial mortality at each site is to describe it in terms of the rate of partial mortality over a given time. This rate of partial mortality can then be compared to the rate of partial mortality during the proposed dredging phase of the project.

The rate of partial mortality per day at the offshore sites was higher than the mid-shore and inshore sites (the rate of mortality per day between sites is yet to be tested statistically) One contributing factor to the higher rates of partial mortality at the offshore sites is due to the increasing trend in partial mortality from survey to survey of the two coral *Turbinaria* colonies affected by coral disease (**Figure 5-1)** and predation (**Figure 5-2**) at the two offshore sites. The influence of a few colonies on the rate of partial mortality over longer time frames and the overall average partial mortality at particular sites, which may not relate to increases in sedimentation or turbidity at that site, needs to be taken into consideration during the dredging surveys.

Another factor influencing the partial mortality is bleaching, which may occur during the summer months in response to elevated temperatures and in winter due to interactions with macroalgae growing on the surrounding substrate. Bleached corals can recover once the temperatures return to ‘normal’ levels. Some areas of a coral colony may not recover, or some whole colonies may not recover and completely die. This was the case at the WIS monitoring site where one tagged colony bleached completely, then subsequently died. This has ramifications for calculating the partial mortality and the rate of partial mortality at each site which may potentially result in triggering an exceedence and subsequent management response.

4.3. Coral Health

The measurements of sub-lethal stress in coral colonies using the Coral Colour Chart are inconsistent. This method does not appear provide any more information on the sub-lethal stress that corals are experiencing than already provided by the CPCe analysis. The CPCe analysis was a much better indicator of the extent of the bleaching event during the periods of elevated mean monthly temperatures and extended periods of high temperatures recorded at the inshore (WIS) and mid-shore (CTH) site during January/February 2009.

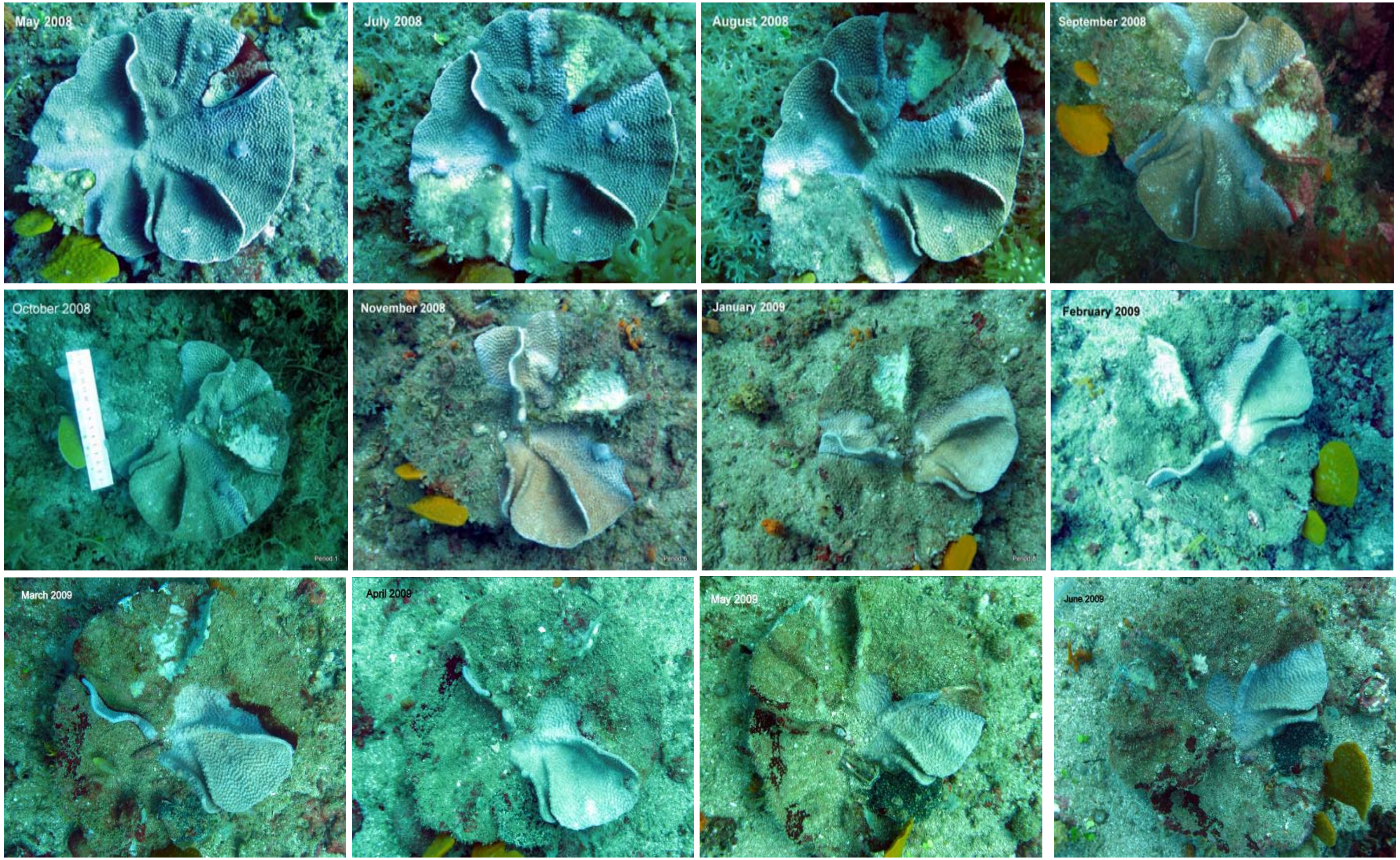
The main requirement of the Coral Colour Chart for this monitoring program is to measure sub-lethal stresses that manifest as loss of the pigmentation in the **entire** coral colony *in situ*. The potential observer errors associated with the colour chart method (as high as ±1 intensity category – Siebeck et al. 2006) can confound subtle changes in coral colony intensity due to smaller changes in the pigmentation of the entire colony not being scored and potentially give an indication of the deteriorating health of the coral colony when there is none or vice versa.

Observations by divers on the bleaching state and mucous production of tagged coral colonies may represent a better method of quickly assessing the sub-lethal stress of tagged corals.

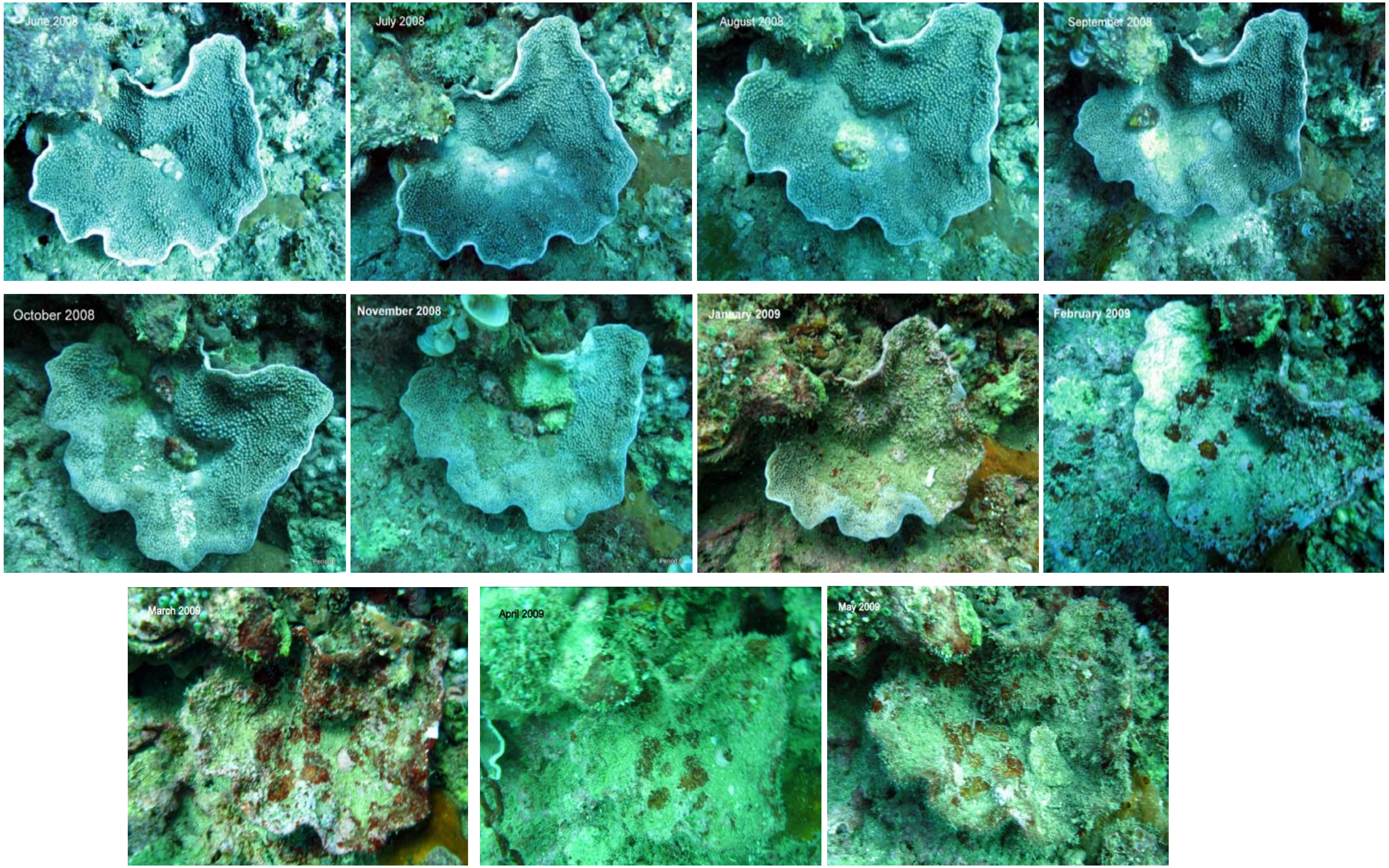
5. Conclusions

Coral health baseline monitoring at the selected six coral monitoring sites within the Outer Harbour Development study area from June 2008 to May 2009 indicated that:

- The hard coral species richness at the monitoring sites is low compared to other areas in the region.
- Inshore and mid shore coral monitoring sites are dominated by corals reported by Gilmour et al. 2006 to have a low susceptibility (high tolerance) to extremes in turbidity, sedimentation and temperature, and are able to grow in low light climate environments.
- The elevated temperatures in December 2008 and January 2009 caused hard coral bleaching at monitoring sites from the inshore and mid-shore environments. The timing and ability of the bleaching affected coral colonies to survive and return to 'normal' after such an event will help develop coral tolerances to increases in temperature.
- Partial mortality and the rate of partial mortality can be influenced by large changes in only one tagged colony due to naturally occurring events such as coral disease, predation and bleaching. Therefore, the triggers to be developed to determine the management responses to dredging activities that impact on the partial mortality and rate of partial mortality of coral need to take into account these naturally occurring events.



- **Figure 5-1 Photo sequence tracking partial mortality on a colony of *Turbinaria* spp. caused by Black Band Disease (BBD) at COX**



- **Figure 5-2 Photo sequence tracking partial mortality on a colony of *Turbinaria* spp. caused by the corallivore Drupella spp. at COR**

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Appendix A Summary Tables

A.1 The number of coral species and genera at each monitoring site

Site Name	Code	Description	Acroporidae	Faviidae	Poritidae	Dendrophylliidae	Other	Total species	Total genera
Weerdee Reef	WIS	Inner	0	14	4	7	1	26	12
Cape Thouin	CTH	Mid	1	15	5	5	4	30	14
Minilya Bank	MIB	Mid	2	14	5	7	5	33	17
Little Turtle Island	LTI	Mid	2	13	6	6	3	30	15
Coxon Shoal	COX	Outer	8	18	7	5	4	42	11
Cornelisse Shoal	COR	Outer	3	8	4	6	1	22	18

A.2 Number of coral colonies analysed for Partial mortality and health during each survey period

	May/ Jun	Jun/ Jul	Jul/ Aug	Aug/ Sep	Sep/ Oct	Oct/ Nov	Nov/ Dec	Dec/ Jan	Jan/ Feb	Feb/ Mar	Mar/ Apr	Apr/ May	May/ Jun
Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
WIS	60	57	60	60	60	60	NR	NR	60	60	60	60	60
CTH	58	59	60	60	58	58	NR	59	60	60	59	60	60
MIB	59	57	60	59	58	58	NR	60	55	58	57	59	59
LTI	56	60	60	59	60	59	NR	60	59	60	58	60	60
COR	60	59	60	60	60	59	NR	60	60	60	59	60	59
COX	59	58	60	56	59	58	NR	60	60	60	60	60	59

NR = not recorded