Port Hedland Outer Harbour Development

BASELINE CORAL HEALTH MONITORING REPORT: PERIODS 1–23

- WV03716-MV-RP-0038
- Revision 2b
- 6 July 2011

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Executive Summary

Background

As part of the environmental approval process for the BHP Billiton Iron Ore Outer Harbour Development there is a requirement to demonstrate that potential impacts on the marine environment have been adequately investigated. A 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 aim of baseline monitoring in subtidal benthic primary producer habitats (BPPH) is to document the current state of BPPs and examine natural levels of change in BPPs through time, as well as to correlate any such changes in BPPs with the natural variability in environmental conditions. Data collected provide an understanding of the present state and background temporal dynamics of BPPs in the area and will allow any potential dredge and spoil disposal impacts to be put into perspective.

Purpose

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

- establish a baseline of coral health and dynamics in order to put monitoring data collected during dredging and spoil disposal in perspective and determine the potential (ecological) significance of any predicted impact;
- provide information on the extent and trends of partial mortality of tagged coral colonies to inform the development of coral mortality trigger values for management of impacts from dredging activities;
- investigate linkages between trends in the health of the monitored BPPs (coral) and trends in water quality variables. The investigation of potential linkages informs the process of developing tolerance thresholds by comparing the intensity, duration, and frequency (IDF) of water quality events (e.g. increased turbidity and reduced light) with the results of the coral health assessments; and
- allow characterisation of the BPPs in terms of present distribution, community composition and associated water quality conditions in a regional (Pilbara) context.

This report details the methods and results of the Baseline Coral Monitoring Program undertaken between 1 June 2008 and 02 April 2010.

Methods

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

Summary of Results

Coral health baseline monitoring at the selected six coral monitoring sites within the Outer Harbour Development study area from June 2008 to April 2010 indicated that:

- based on the low species richness (51) and abundance (up to 33% cover) of hard corals and dominance of *Turbinaria* (13 to 19% of all corals at five of the six monitoring locations) hard coral communities that inhabit subtidal habitats in the Port Hedland region can be described as predominately high turbidity/sedimentation (low light) adapted communities;
- during the summer months, elevated sea temperatures at shallower sites precipitated a mild bleaching event (up to 15% bleaching at Weerdee Reef). There was a subsequent increase in partial mortality of corals following the bleaching event (e.g. an increase from less than 4% gross mortality to approximately 8% at Weerdee Reef); one tagged coral colony at Weerdee Reef showed total mortality;
- partial mortality at all sites increased progressively over the baseline program, although recovery was evidenced at all monitoring sites;
- additional coral stressors included: (i) grazing on live tissue by the corallivore, *Drupella* spp., and (ii) coral disease (Black Band Disease). These additional stressors were rare, affecting only two *Turbinaria* colonies out of the 360 tagged, eventually resulting in the 100% mortality of these two colonies; and
- coral health or sublethal 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 in areas where the bleaching was moderate to severe. However coral colour was not found to provide added benefit to coral health evaluation over and above CPCe monitoring data and was discontinued after survey period 13.

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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

SKM

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1. Introduction

1.1. Background

As part of the environmental approval process for the BHP Billiton Iron Ore Outer Harbour Development there is a requirement to demonstrate that potential impacts on the marine environment have been adequately investigated. A potential impact on the marine environment 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, during the Outer Harbour Development.

The detection of any effects of increased TSS levels produced by turbidity-generating activities (e.g. dredging and spoil disposal) requires determination of the baseline health of BPPs, prior to monitoring of BPP health during dredging. Baseline data should also provide information on the impact to BPPs from seasonal and episodic stresses such as natural fluctuations in water quality (temperature, turbidity and sedimentation), storm damage, predation and disease (Sofonia and Unsworth 2010).

Baseline benthic primary producer habitat (BPPH) mapping surveys offshore from Port Hedland (SKM 2009) concluded that most of the seabed surveyed did not support BPP's, and that the most dominant BPP present on the available BPPH was hard corals, the majority of which is located in Commonwealth waters of the proposed project area (**Table 2-1**). Hard corals are considered particularly sensitive to changes in the light climate related to increases in turbidity and sedimentation (Brown *et al*. 1990).

In hard corals, partial mortality is defined as an area of tissue of a live coral colony that has died. The relative proportion of the area of a patch of dead coral tissue, relative to the amount of live coral tissue remaining on a colony, is typically dependent on the severity (intensity, duration) of the process(es) that leads to coral mortality. For example, a severe bleaching, predation or disease event may kill entire coral colonies, and affect many species within a coral community, whereas smaller scale manifestations of these events may affect only a small area of individual colonies, and may be confined to only a few colonies of a few species. Field surveys cannot always capture the exact cause or timing of any partial mortality, and evidence of previous partial mortality is often inferred by areas of sediment, turf algae and sponge on dead coral patches within the boundaries of a coral colony.

Sublethal stress is defined as that set of processes in which environmental stressors such as high turbidity, sedimentation and temperatures have negative impacts on hard coral health but without evidence of partial (tissue) mortality on the coral colony. Sublethal stress is difficult to detect, but a widely accepted indicator of sublethal stress, in relation to light and temperature stress, is a change in the colour of the coral colony toward a lighter 'bleached' state (Fabricius 2006). Coral colonies often recover from the impact of sublethal stressors unless the stress is of sufficient magnitude and duration to cause partial or even total mortality of the coral colony.

For assessment of the baseline health and trends in partial mortality of hard corals occurring within the Outer Harbour Development study area, six sites offshore from Port Hedland were monitored (**Figure 2-1**), between 1 June 2008 to 2 April 2010. This was considered an adequate period in which to capture natural dynamic events, including changes in water quality, predation activity and disease prevalence may affect the health of hard corals, including trends in partial mortality.

1.2. Reporting

This report is a summary of all baseline data collected to date from 1 June 2008 to 2 April 2010 and provides a basis for the environmental impact assessment of potential impacts to hard corals that may occur as a result of the Outer Harbour Development. A series of periodic progress reports were produced to summarise the data collected on each field trip and to provide details of the methods used to collect, analyse and interpret the data. A summary of the coral monitoring field trip dates and deliverables are presented in **Table 1-1**.

1.3. Objectives

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

- establish a baseline of coral health against which monitoring program data collected during dredging and spoil disposal activities could be assessed for detection of impact and the potential significance of any (ecological) impact;
- provide information on the extent and trends of partial mortality of tagged coral colonies to inform the development of coral mortality trigger values for management of impacts from dredging activities;
- investigate linkages between the health of monitored hard corals and trends in the water quality data; and
- allow characterisation of the BPPs in terms of distribution, community composition and associated water quality conditions in a regional (Pilbara) context.

1.4. Other Related Studies

Parallel to the coral monitoring program, a water quality monitoring program was conducted at the six coral monitoring sites to investigate the strength of correlations between coral health and water quality parameters such as turbidity, light conditions, TSS and gross sedimentation rates. Water quality monitoring was continuous until March 2010 with data downloaded from loggers on a fortnightly basis. A summary of methods and results of this baseline water quality monitoring program is documented in SKM (2011b).

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

Survey Period	Date	Deliverables
1	1 June 2008 to 28 June 2008	Baseline Coral Monitoring Report Period 1 to 4 (Data also summarised in this report)
2	29 June 2008 to 26 July 2008	
3	27 July 2008 to 23 August 2008	
4	24 August 2008 to 20 September 2008	
5	21 September 2008 to 18 October 2008	Baseline Coral Monitoring Report Period 5 and 6 (Data also summarised in this report)
6	19 October 2008 to 15 November 2008	
7	16 November 2008 to 13 December 2008	No surveys possible*
8	14 December 2008 to 10 January 2009	Baseline Coral Monitoring Report Period 1 to 9 (Data also summarised in this report)
9	11 January 2009 to 7 February 2009	
10	8 February 2009 to 7 March 2009	Baseline Coral Monitoring Report Period 1 to 13 (Data also summarised in this report)
11	8 March 2009 to 4 April 2009	
12	5 April 2009 to 2 May 2009	
13	3 May 2009 to 31 May 2009	
14	1 June 2009 to 28 June 2009	Data summarised in this report
15	29 June 2009 to 21 August 2009	
16	22 August 2009 to18 September 2009	
17	19 September 2009 to 16 October 2009	
18	17 October 2009 to 13 November 2009	
19	14 November 2009 to 11 December 2009	
20	12 December 2009 to 8 January 2010	
21	9 January 2010 to 5 February 2010	
22	6 February 2010 to 5 March 2010	
23	6 March 2010 to 2 April 2010	

*Due to adverse sea conditions and very poor underwater visibility

2. Materials and Methods

2.1. Site Selection Strategy

Six coral monitoring sites were selected within a study area of 3,775 km^2 (**Figure 2-1**) based on assessment of preliminary dredge plume modelling results, pilot field surveys of BPPH and field observations of environmental characteristics. The key factors for site selection were:

1. The preliminary Zone of Influence comprising the area where the modelling predicted some probability of an increase of 1 mg/L or more in TSS, one or more times, from proposed dredge and spoil disposal activities (APASA 2009). 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 Zone of Influence was therefore a preliminary prediction and used only as a guide to approximately define the boundaries of the study area.

2. Areas with suitable BPPs were then identified using observations from field mapping surveys undertaken within the study area. As the monitoring program targeted hard corals, their presence and the suitability of substrate for the installation of site markers (see **Section 2.4)** were important factors**.** More details of the field survey methods and observations used to select monitoring sites are provided in SKM (2009).

2.2. Study Area Surveys

Baseline video transect surveys of 52 sites offshore of Port Hedland from Cape Thouin to North Turtle Island were carried out in early 2008 to establish the benthic communities present. **Table 2-1** shows the overall percentage contribution of each benthic category. The data from the transect surveys show that most of the substrate surveyed does not support BPP and therefore is not classified as BPPH. Most of the substrate supports only a small proportion of non-BPP including sponges and soft corals.

- **Table 2-1 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 (BPP)	10.0 ± 1.2
Macroalgae (BPP)	6.5 ± 2.8
Sponge	6.1 ± 0.5
Soft Coral	1.7 ± 0.3
Other	0.4 ± 0.2

2.3. Site Descriptions

The six coral monitoring sites selected (**Figure 2-1**) are considered representative of the full range of environmental characteristics (e.g. depth, WQ), where there is habitat supporting coral communities within the study area. The details of each site are listed in **Table 2-2**.

- **Table 2-2 Location and depth for each of the six Baseline Hard Coral monitoring sites**

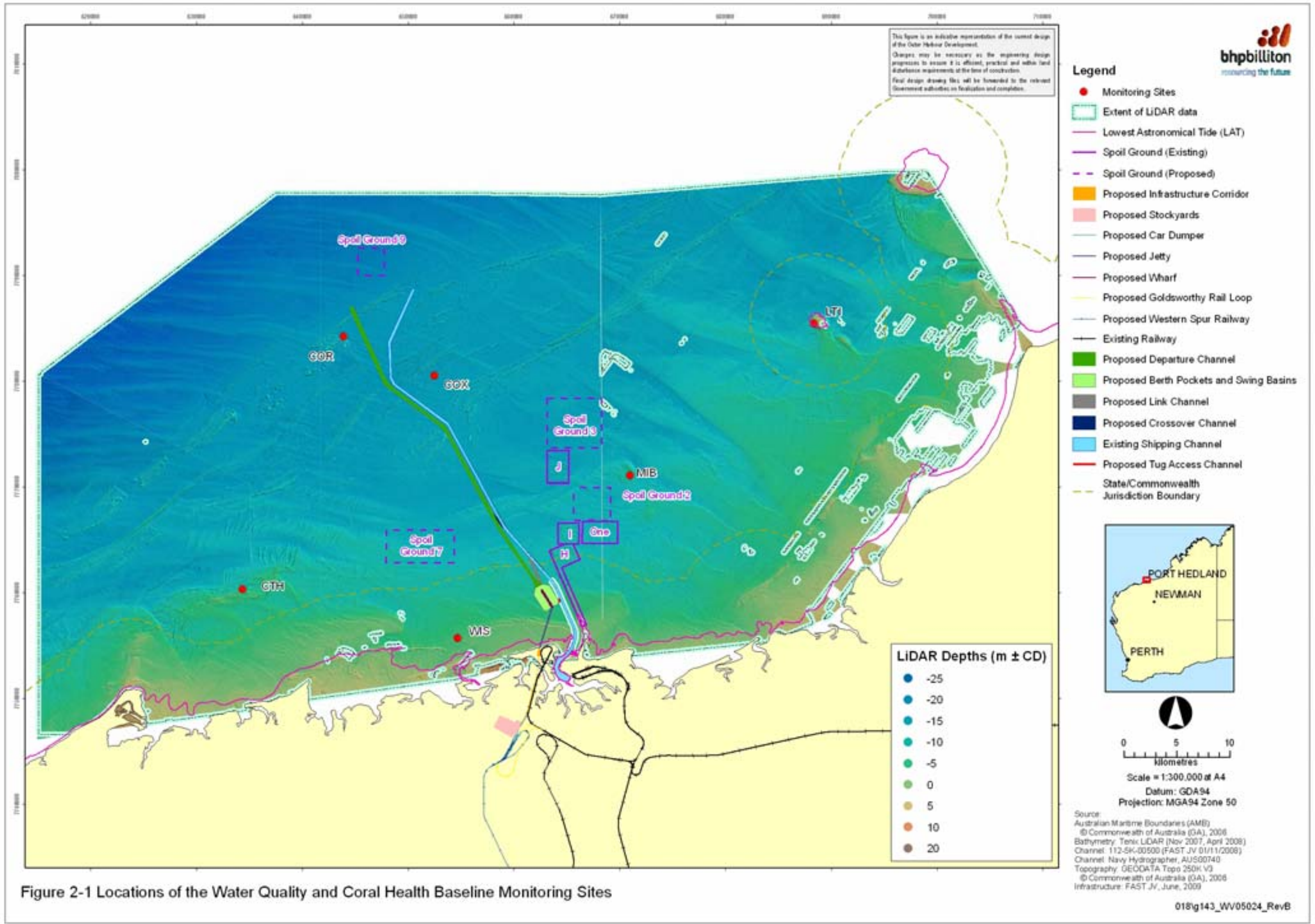
Site Name	Code	Approx. distance from the mainland (km)	Approx. mid tidal water depth (m)	Latitude	Longitude
Weerdee Reef	WIS	3	5	20° 17.414' S	118° 28.893' E
Cape Thouin	CTH	10	6	20° 14.995' S	118° 17.194' E
Minilya Bank	MIB	16	9	20° 09.002' S	118° 38.157' E
Little Turtle Island	LTI	19	7	20° 01.081'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

Weerdee Reef (WIS) is located approximately 12 km west of the entrance to Port Hedland Harbour and 3 km offshore of the mainland. This site is referred to as WR1 in an earlier report (SKM 2009). The site is situated some 2 km to the North of Weerdee Island at a depth of approximately 5 m mid tidal. The site is predominantly abiotic (74.7%), with a moderate cover of sponges (8.0%), hard corals (8.0%) and macroalgae (8.2%) and a low cover of soft corals (1.1%).

Cape Thouin (CTH) is located approximately 40 km west of the entrance to Port Hedland Harbour and 14 km to the north-east of Cape Thouin. This site is referred to as CT-R1 in an earlier report (SKM 2009). 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) is located approximately 19 km north north-east of the entrance to Port Hedland Harbour. This site is referred to as MIB-1 in an earlier report (SKM 2009). The site is on (near) 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 (1%).

Little Turtle Island (LTI) is located approximately 40 km north-east of the entrance to Port Hedland Harbour and 19 km offshore of the mainland at Spit Point. This site is referred to as LT1 in an earlier report (SKM (2009). The site is on a 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 (76.4%) with a moderate cover of hard corals (17.8%) and lesser quantities of sponge (2.9%), macroalgae (2.7%) and soft corals (0.2%).



- **Figure 2-1 Location of the Water Quality and Coral Health Baseline Monitoring Sites**

Cornelisse Shoal (COR) is part of a reef complex situated approximately 37 km north-west of the entrance to Port Hedland Harbour and 33 km offshore from the mainland. This site is referred to as CNS1 in an earlier report (SKM 2009). 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%), soft corals (1%) and other (epi-) benthic organisms (3%).

Coxon Shoal (COX) is part of a reef system situated approximately 24 km north-west of the entrance to Port Hedland Harbour and 28 km offshore from the mainland. This site is referred to as CX3 in an earlier report (SKM 2009). The shoal is a low mound rising from a depth of 14 m at the mooring to 12 m. The site is predominantly abiotic (73.1%), with patches of hard corals (21.8%) sponges (3.6%), soft corals (0.9%), macroalgae (0.2%) and other (epi-) benthic organisms (0.4%).

2.4. Site Establishment and Coral Tagging

After identification of suitable 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 mooring and site marking. This removed the potential habitat impact from temporary anchor deployment, retrieval and dragging on corals.

Sixty coral colonies were selected at each site and were chosen to represent the abundance of the taxa present at each site (see **Figure 2-2** and **Table 2-3**). This was not always possible because:

- 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 the quality of the image. Thus only small/medium sized coral colonies were tagged so photographic images of the colony are likely to be of sufficient quality;
- each colony selected needs to be relatively uniform in shape to reduce the problems inherent in scoring photographs taken from different angles; and
- the distances between tagged colonies must allow survey by divers in a reasonable time frame (e.g. one dive).

How many coral colonies to tag and monitor at each site was determined by information gathered from previous dredge monitoring programs in the Pilbara. In all recent dredge monitoring programs the state ministerial conditions governing the approval of dredging projects has specified that all reactive monitoring programs for coral health should have a statistical power of at least 0.8 for tests to detect change. As the prescribed level 3 management trigger for any zone of influence sites is the observation of net detectable mortality, then ‘detectable’ is typically taken to mean the smallest effect size that can be detected with 0.8 statistical power.

In a power analysis of the results of the Cape Lambert A monitoring program for coral health, MScience (2007) demonstrated that fifty tagged corals provided a statistical power of 0.8 or greater for tests of detection of change in partial mortality with an effect size of less than 5%. More recently, baseline coral health data where used by Chevron Australia (2009) to predict that 40 tagged corals were sufficient to provide statistical power of 0.8 or better in tests for an effect size of 6%. Results of power analyses of data from two monitoring sites used in this program (COR and WIS) indicate that the sample sizes used (50–60 corals) were sufficient to detect an effect size of 3% change in partial mortality with a statistical power greater than 0.8. Therefore the tagging of 60 coral colonies per site in the present study was considered sufficient to allow the detection of effect size of less than 5% change at the required statistical power.

A series of power analyses of baseline data is required to demonstrate that the statistical tests to be used in the monitoring program as described in the dredge management plan (0.8) are likely to have the required level of statistical power. As the actual level of statistical power attained during the dredge monitoring program can only be analysed upon completion of the entire monitoring program, the only way to provide an *a priori* test of the likely statistical power is by use of the baseline data as a proxy. Preliminary power analyses on baseline data from two sites (COR and WIS) indicated that sample sizes of 50–60 corals are sufficient to detect an effect size of 3 % change in partial mortality with a statistical power greater than 0.8 (**Section 2.6.2.1**).

The other rationale for tagging 60 colonies at each site is that in each survey period (based on previous experience), at least a few of the photographs of corals will be deemed unsuitable for use due to quality assurance/ control issues with the quality of the images, and sometimes divers do not manage to photograph all the colonies on each transect[1]. It is also the case that over the life of the baseline (and subsequent impact) monitoring programs some corals will be lost from the transect and others will die.

Each of the 60 selected coral colonies at each site were permanently tagged to ensure the unique identification of each tagged colony.

2.5. Overview of the corals tagged at the monitoring sites

At each monitoring site the sixty colonies tagged represented a range of families, genera and species. The families of corals tagged are shown in **Table 2-3** with a description of which genera have been tagged, and in one case, which species. There are five families listed in **Table 2-3** and a sixth category 'other' which holds an assortment of families and genera that although selected for tagging were not widespread or common at all sites. The five families from the list and the category other from **Table 2-3** were analysed and their distributions and relative proportions by site are shown in **Figure 2-2**.

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[1] 'Transects' referenced in relation to the tagged coral monitoring was a navigational tool that allowed divers to track from one coral colony to the next to ensure all tagged corals could be located under low visibility conditions.

Ideally, the relative proportions of these families among the tagged corals should reflect their relative proportions among the assemblage at each site, but as discussed earlier, there are many constraints which mean these proportions of tagged corals are not a reliable guide to the proportions of these families in the wider assemblage. Across all sites Faviid corals are well represented among the tagged corals, as are Poritids and Dendrophyllids.

Table 2-3 Descriptions of hard coral genus groups tagged 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*

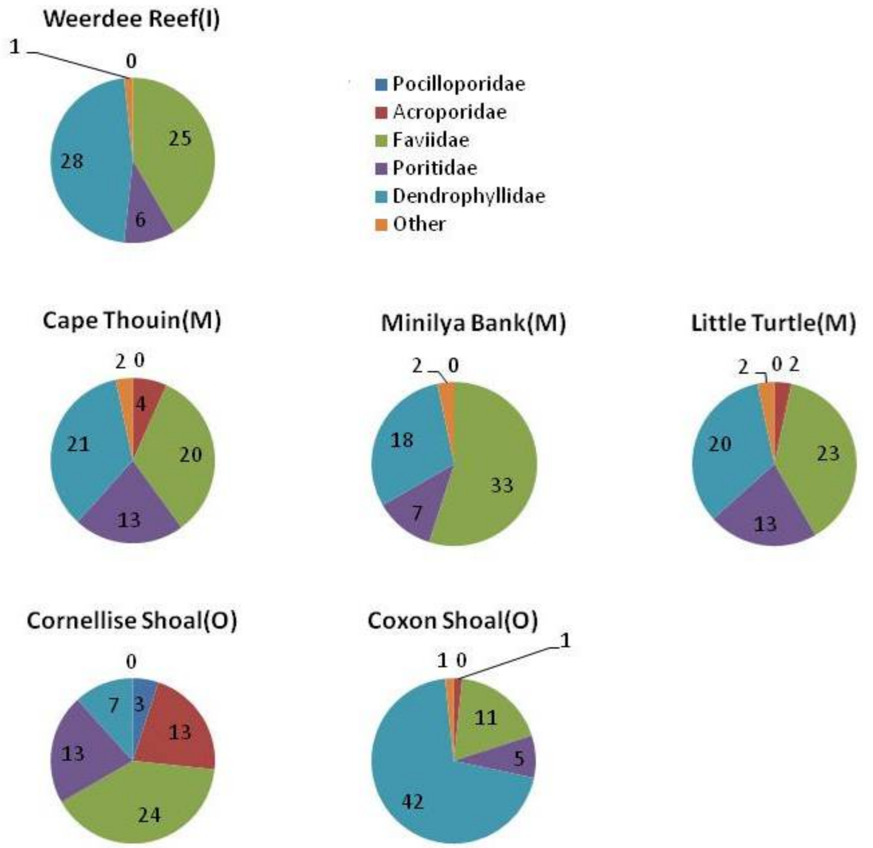


Figure 2-2 The relative proportions and number of tagged hard coral family groups at each coral monitoring site in each Water Quality Zone

2.6. Monitoring of Coral Health Indicators

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 requirements for maintenance of water quality loggers. Each tagged coral colony was photographed on each survey. The photographs for each site were then assessed using QA/QC procedures to ensure only images that met specified quality standards were used for the assessment of partial mortality. The subset of images suitable for assessment from each site (between 50–60) 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 overlain 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.

All of the above categories are indicators of, or contributors to, partial mortality except for the categories 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.

Assessment of bleached areas on a colony in subsequent periods may show the coral has recovered and appears normal, or the bleached area may have progressed to partial mortality 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.

- **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).

2.6.2. Statistical Treatments

2.6.2.1. Power Analysis

During the proposed dredging and spoil disposal program it is possible that a reactive monitoring program for coral health will be required. The aim of reactive coral monitoring programs is to detect change, in this case 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 generated by the dredging. The ability of a monitoring program to adequately detect this change is described by the statistical term ‘power’.

A preliminary power analysis of the baseline data from two sites was performed by comparing the difference in partial mortality from one period to the next at each of the two sites using a prerequisite effect size of a 3 % change in partial mortality between surveys. Results of power analyses of data from two sites (COR and WIS) indicates that the sample sizes used in this monitoring program (50–60 corals) were sufficient to detect an effect size of 3% change in partial mortality with a statistical power greater than 0.8.

2.6.2.2. Baseline Mortality

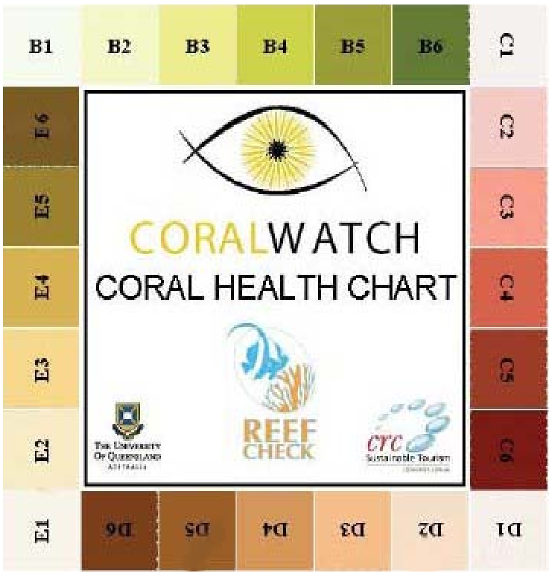
Partial mortality estimates were developed at the sites using statistical analyses according to methods outlined in MScience (2007). Using this approach, each coral colony image, ‘(i)’, was assigned a percent partial mortality, or ‘PM(i)’, which equates to the number of points scored as partial mortality 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.

The rate of change in partial mortality over time 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 observed rate of change in partial mortality per day during the baseline surveys.

2.6.3. Sublethal Stress

Measuring sublethal stress can potentially provide an early warning for effects on the health status of corals before the onset of mortality. The responses of a coral polyp to sublethal stressors may include changes in the density of the symbiotic zooxanthellae living in the live tissue (determining the colour of the tissue) and excess mucous secretion. Change in the colour of live tissue was chosen as the basis for measuring sublethal stress in 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 were 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 was subtracted from the colour intensity value from the subsequent survey. Each individual coral colony colour intensity change was then averaged to site level. A negative change from survey period to survey period indicates a shift toward lighter intensities and can indicate a more stressed state. Although Cooper *et al*. (2009) have indicated that corals can sometimes become darker in response to stress, if a colour change (whether lighter or darker) is recorded that clearly deviates from controls this result may indicate stress.



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

2.7. Additional Benthic Community Data

Additional information on the composition of the (epi-) benthic community at each site was collected during surveys in February 2009 to assist in developing protocols for the 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.

2.7.1. Dominant Coral Taxa

The dominant coral taxa at each site were 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 50 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 (e.g. species) or for temporal comparisons to detect changes in benthic community composition due to the relatively small sample size and lack of repeatability.

2.7.2. Species Richness

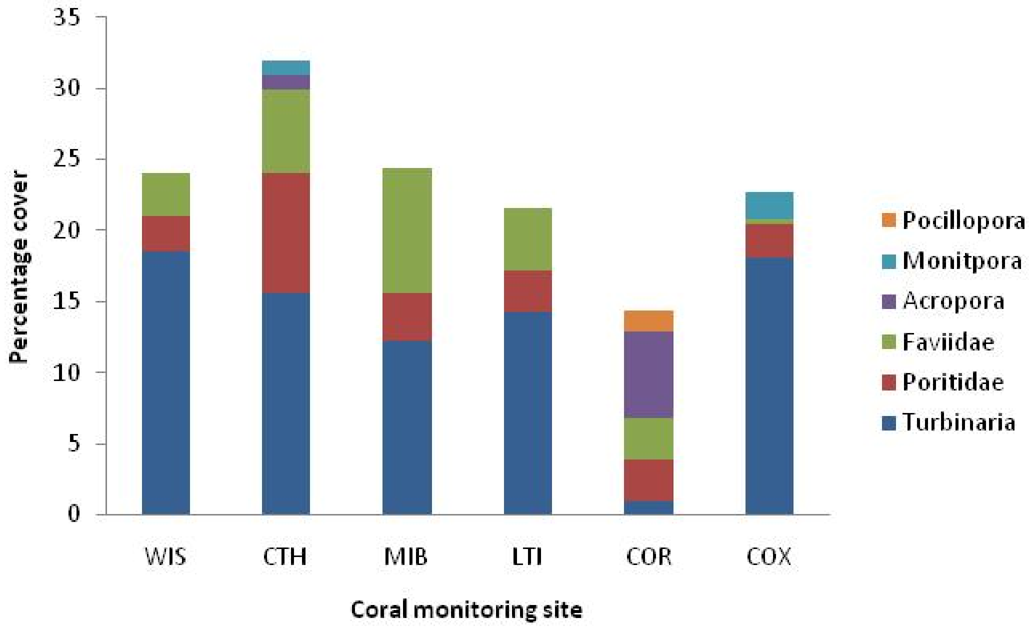
The species richness at each site was estimated by surveying as much of the habitat at each site as possible during timed 45 minute swims on SCUBA, and scoring the number of coral species *in situ*. If *in situ* identification was not possible, photographs of the colony in question were taken, and identification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

3. Results

3.1. Dominant Coral Taxa and Coral Species Richness

The data presented here represent an assessment of the coral assemblages (communities) at each of the six monitoring sites and is not to be confused with the data presented in **Section 2.5** and **Figure 2-2** which show the relative proportions of different taxa among the **tagged** corals at each of the six sites.

At COR the dominant hard coral taxa was the genus *Acropora* (6% cover) while the dominant hard coral taxa at the other sites was the genus *Turbinaria* (12 to 19% cover) (**Figure 3-1**). The highest total 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 in the coral assemblages at the six monitoring sites**

A total of 51 species of coral from 19 genera were recorded when survey data for all monitoring sites is pooled (**Appendix A.1**). The highest coral species richness occurred at COX (42 species, 11 genera) and the lowest at COR (22 species, 18 genera), and between these results at MIB (33 species, 17 genera) and CTH (30 species, 14 genera). The diversity at WIS was comparatively low (26 species, 12 genera). COR was the only site at which stands of *Acropora* species and *Pocillopora* species were noted.

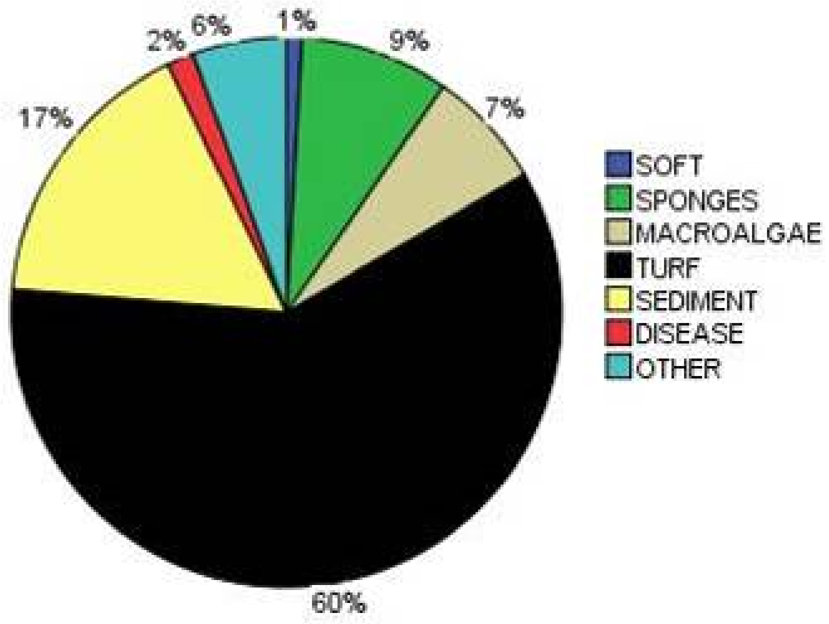
The number of colonies analysed at each site for each of the 23 baseline survey periods is summarised in **Appendix A.2**. In some cases there were less than 60 corals available for analysis due to poor image quality, but there were always more than 50 colonies included in the analyses.

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. Partial Mortality

Areas within the boundary of the coral colony that were not live coral were evaluated 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 in most corals[2].

When all data from all surveys and all sites was combined, the main indicators of previous partial mortality within the boundary of the tagged coral colony were turf algae (60%) followed by sediment (17%; **Figure 3-2**). 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.

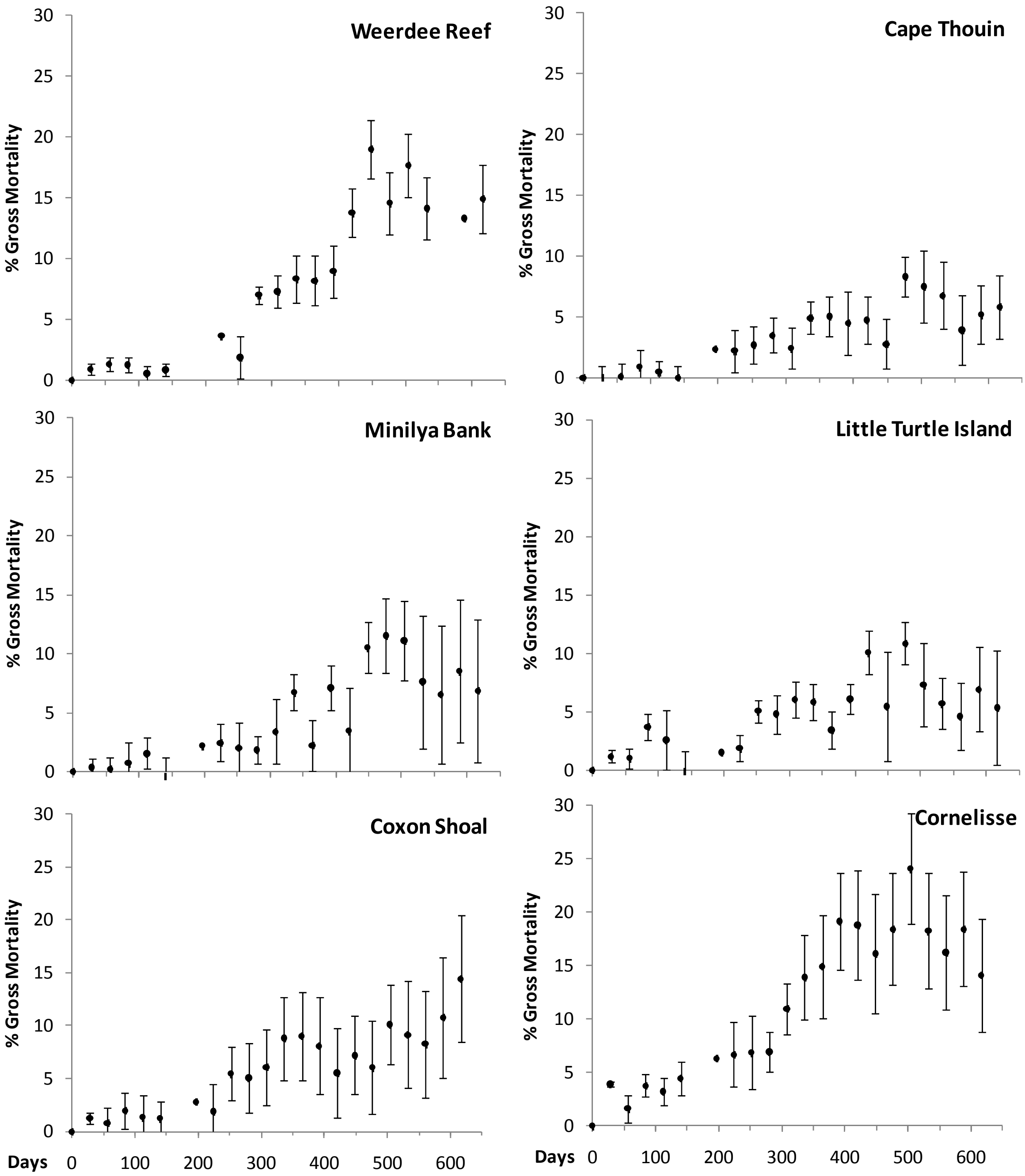


- **Figure 3-2 The relative proportion of indicators of previous mortality for all baseline surveys at all sites**

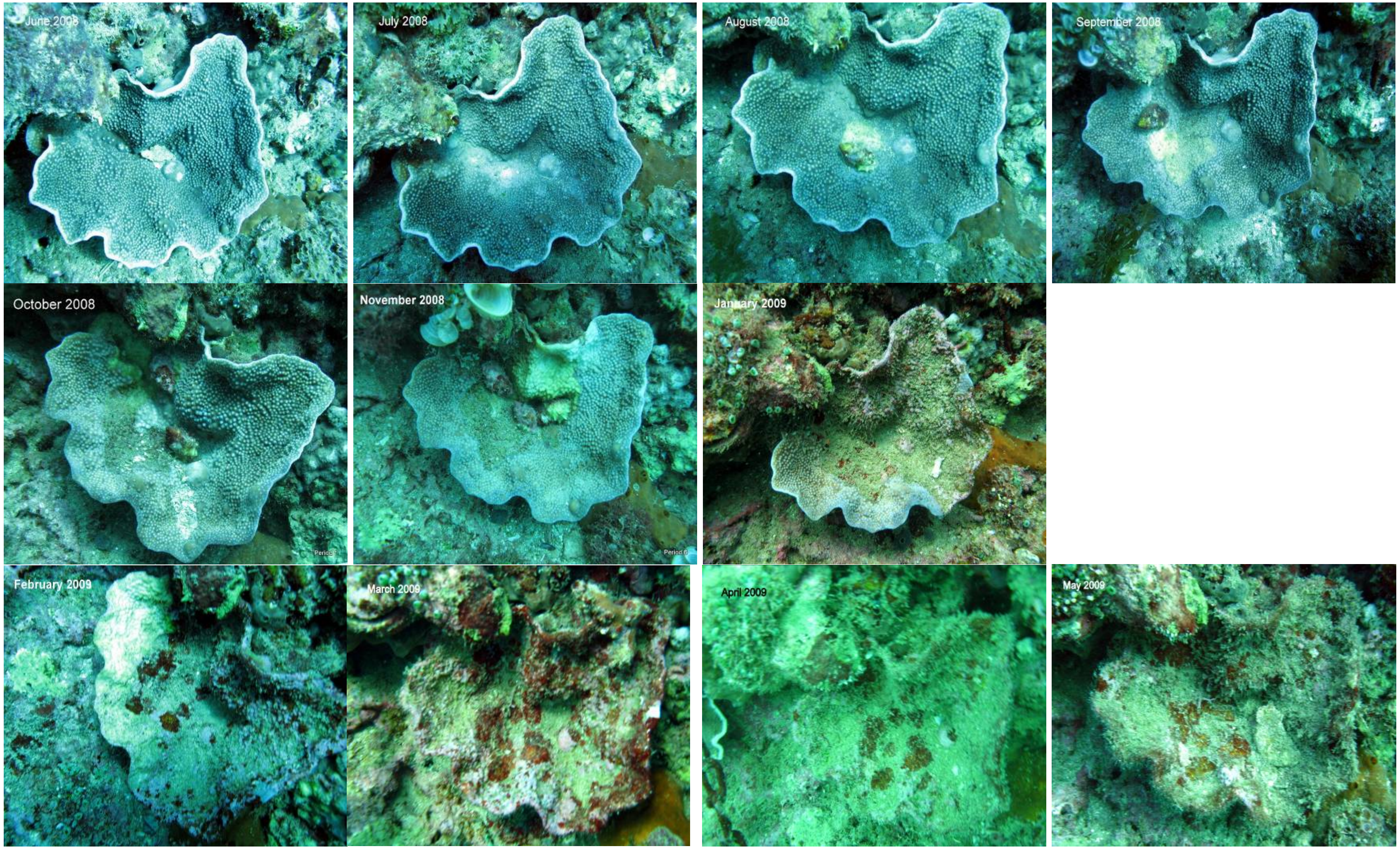
The partial mortality of tagged corals increased at all sites over the extent of the baseline surveys (**Figure 3-3**). The highest mean gross partial mortality was observed at the monitoring site Cornelisse Shoal (24%) and Weerdee Reef (24%). The lowest partial mortality occurred consistently at Cape Thouin (0–9%), Minilya Bank (0–11%) and Little Turtle Island (0–11%).

[2] For example, the use of these indicators of previous mortality may not be appropriate in the case of encrusting forms of corals.

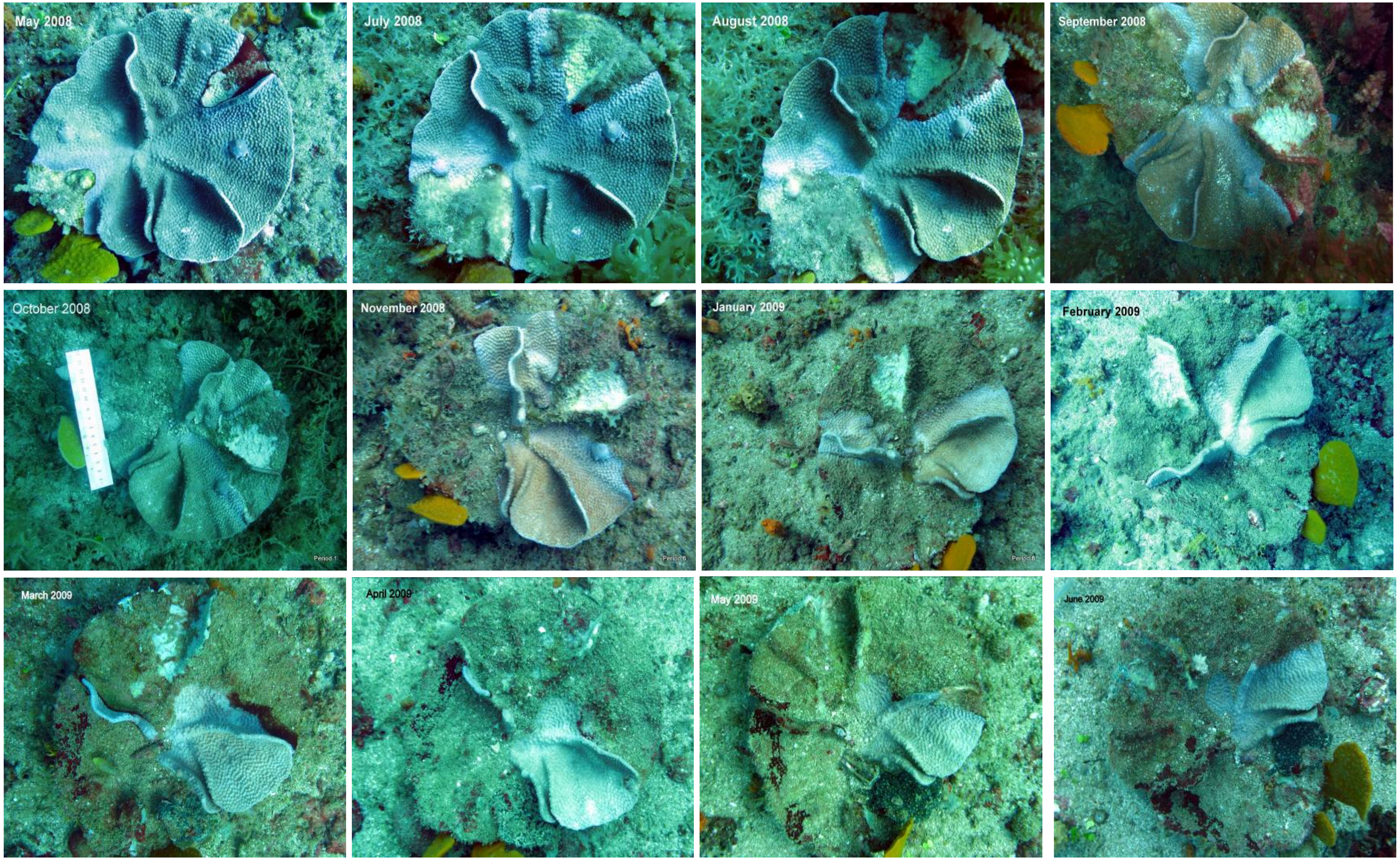
The mean gross mortality estimated for each site for each survey is shown for each of the 23 surveys (no data from survey #7) in **Figure 3-3** as a series of points, and for each point the 95% CI is also shown as a bar.



- **Figure 3-3 The mean gross partial mortality (± 95% CI) at each monitoring site for each survey period**



- **Figure 3-4 Photo sequence tracking partial mortality on a colony of *Turbinaria* spp. caused by the corallivore *Drupella* spp. at Cornelisse Shoal**



- **Figure 3-5 Photo sequence tracking partial mortality on a colony of *Turbinaria* spp. caused by Black Band Disease (BBD) at Coxon Shoal**

3.3. Sublethal Stress

Table 3-1 presents the mean water temperature recorded for each monthly survey period, and coral colour data collected during surveys 4 to 13, inclusive, including colour intensity and bleaching. The three parameters show similar patterns, primarily when and where the bleaching of coral colonies is most prevalent.

The highest mean monthly water temperatures and the highest percentage of bleaching (measured using the CPCe program) were recorded at the Weerdee Reef and Cape Thouin sites in period 8–9 (December 2008 to February 2009) (**Table 3-1**). Coral bleaching at Weerdee Reef increased from 0% in period 4–5 (August 2008 to October 2008) to 16% (± 9.2% CI) in period 8–9 (December 2008 to February 2009). The coral bleaching observed at Cape Thouin increased from 0% in period 7–8 (November 2008 to January 2009) to 2.6% (± 1.9% CI) in period 8–9 (December 2008 to February 2009).

A concurrent change in coral colour intensity also occurred at these sites (**Table 3-1**). Specifically, the colour intensity scores of the affected coral colonies decreased in period 8–9 (December 2008 to February 2009) compared to the previous survey period 7–8 (November 2008 to January 2009). The large increase in bleaching at WIS compared to other sites is attributed to extended periods of sea temperatures in excess of 33°C during February 2009 (SKM 2009) as opposed to mean water temperatures recorded at the other sites which varied between 30 and 31.6°C.

The percentage bleaching, as measured by the CPCe program at Weerdee Reef and Cape Thouin sites decreased during periods 9–10 (February to March 2009). The colour chart intensity measurements also showed a concurrent increase in the intensity of the coral colonies at these sites, indicating a recovery from bleaching. In the subsequent surveys (10–11; March to April 2009), where mean monthly water temperatures remained above 30°C at WIS, the bleaching measured by the CPCe analysis increased to 9% (± 6.7%) and the colour chart intensity decreased (**Table 3-1)**.

During the winter/ spring periods (survey period 3–4; July to August 2008) slight increases in the percentage partial bleaching of tagged colonies were observed at most monitoring sites (**Figure 3-6**). The largest increases in the partial bleaching of tagged colonies during this period occurred primarily at the deeper sites (**Figure 3-6**). This may be related to the large stands of the transient macroalga *Sargassum* spp. growing at these sites at this time. The tall fronds of *Sargassum* spp. were observed by divers to be rubbing on the edges of tagged coral colonies, causing some localised ‘bleaching’ and pigment responses from the corals at the points of contact (*pers. comm*. G. Paccani 2008). The CPCe analysis of the images from this period scored many instances of inconsistently bleached coral.

- **Table 3-1 Average change in coral colour intensities, mean monthly temperatures and partial bleaching percentages at monitoring sites, Periods 4–13.**

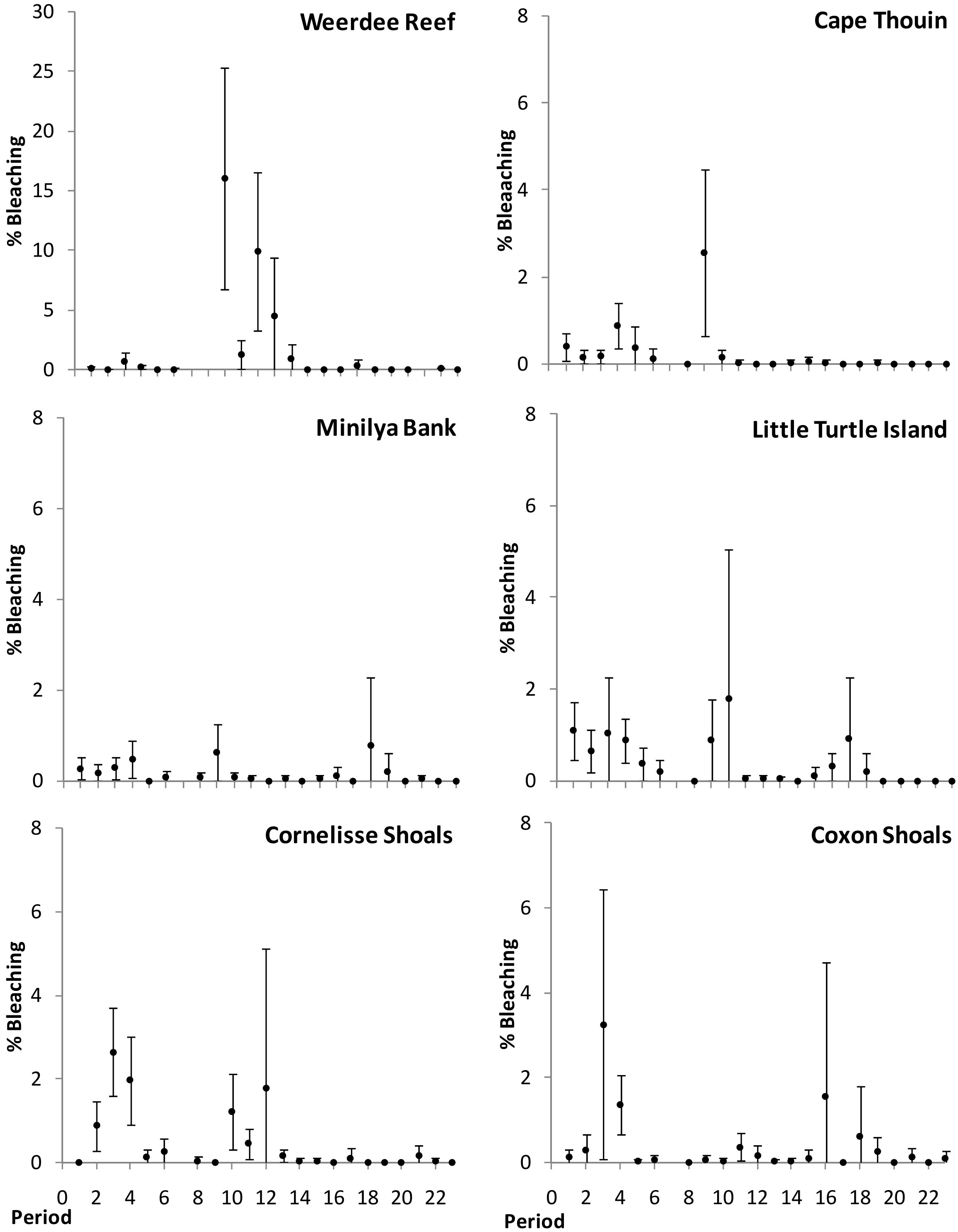
Survey Period	WIS			CTH			MIB			LTI			COX			COR		
	Coral Colour Intensity	Mean Temp (°C)^	Partial Bleaching*	Coral Colour Intensity	Mean Temp (°C)^	Partial Bleaching	Coral Colour Intensity	Mean Temp (°C)^	Partial Bleaching	Coral Colour Intensity	Mean Temp (°C)^	Partial Bleaching	Coral Colour Intensity	Mean Temp (°C)^	Partial Bleaching	Coral Colour Intensity	Mean Temp (°C)^	Partial 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 7–8	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

* As recorded by the CPCe analysis

^ Periods in which the mean monthly water temperatures exceeded 30°C data are highlighted in bold.



- **Figure 3-6 Percentage of coral bleaching at all monitoring sites ±95% Confidence Intervals for all survey periods**

Note: different y-axis scale for WIS

4. Discussion

4.1. Existing Benthic Primary Producers within the Proposed Project Area

Surveys of the benthic habitat offshore of Port Hedland were undertaken between December 2007 and May 2008 (SKM 2011). 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, macroalgal beds, sponges and soft corals (e.g. gorgonians, sea whips). Hard corals represented the most dominant BPP (**Table 2-1**) growing along the 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 (greater than 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 light reduction. 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 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 increased sedimentation and turbidity.

The species richness of coral taxa at the six monitoring sites is low in comparison to studies carried out elsewhere in the Pilbara region. The total of 51 species of coral from 19 genera identified in this study off Port Hedland 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 the dominance of *Turbinaria* spp. and the results of the investigations by Gilmour *et al*. (2006), coral communities that inhabit subtidal habitats in the Port Hedland region can be described as predominately high turbidity (low light) and high sedimentation adapted communities.

4.2. Measuring Partial Mortality on Tagged Corals

As detailed in **Section 2.5**, the percentage of partial mortality of each tagged colony was measured on a four weekly periodic basis, over 23 periods. The aim of measuring partial mortality was to track changes in mortality over seasons, as differences in seasonal environmental characteristics may have some influence on an individual coral colony, and therefore affect the overall partial mortality at each site.

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 seasonally elevated water temperatures drop upon change of season. Some areas of a coral colony may not recover; alternatively some whole colonies may not recover and will completely die. This was the case at the WIS monitoring site where one tagged colony bleached completely and subsequently died. This relationship and result has ramifications for calculating partial mortality, and consequently using partial mortality as a trigger for response in environmental management programs.

4.3. Sublethal Monitoring of Coral Health Indicators

The main requirement of the Coral Colour Chart for this monitoring program is to measure sublethal 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. In addition, the Coral Colour Chart method does not appear to provide any further information on the sublethal 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. Observations by divers on the bleaching state and mucous production (qualitative measure) of tagged coral colonies may represent a better method of quickly assessing the sublethal stress of tagged corals than the coral colour method.

5. Conclusions

Coral health baseline monitoring at the selected six coral monitoring sites within the Outer Harbour Development study area from June 2008 to April 2010 indicated that:

- hard coral species richness at the monitoring sites is low (51 species) compared to other areas in the region (e.g. 120; Blakeway and Radford 2004);
- shallower coral monitoring sites are dominated by coral species 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;
- elevated temperatures in December 2008 and January 2009 caused hard coral bleaching at monitoring sites in shallower water depths. The timing and ability of the bleach-affected coral colonies to survive and recover a temperature tolerance for corals in the region; and
- 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. Tagged coral monitoring therefore has a statistical susceptibility that would likely be a substantial weakness in the application of environmental monitoring/management of a development activity.

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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

	2009							2010												2011			
	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	Jun/ Jul	Jul/ Aug	Aug/ Sep	Sep/ Oct	Oct/ Nov	Nov/ Dec	Dec/ Jan	Jan/ Feb	Feb/ Mar	Mar/ Apr
Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
WIS	60	57	60	60	60	60	NR	NR	60	60	60	60	60	59	59	59	59	59	59	59	NR	58	59
CTH	58	59	60	60	58	58	NR	59	60	60	59	60	60	60	60	60	60	60	60	60	60	60	60
MIB	59	57	60	59	58	58	NR	60	55	58	57	59	59	60	60	60	60	60	60	60	60	60	60
LTI	56	60	60	59	60	59	NR	60	59	60	58	60	60	60	60	58	60	60	57	59	58	60	60
COR	60	59	60	60	60	59	NR	60	60	60	59	60	59	58	60	60	60	60	60	60	60	59	58
COX	59	58	60	56	59	58	NR	60	60	60	60	60	59	59	60	60	59	59	58	59	58	60	60