Appendix 8 – Phase 1 Coral Health Monitoring Review (MSA93R55).

PLUTO LNG DEVELOPMENT

CORAL HEALTH MONITORING: INTERIM REVIEW SEPT 2008

Report: MSA93R55

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Document Information

REPORT NO.	MSA93R54
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JOB	MSA93
CLIENT	WOODSIDE BURRUP PTY LTD Contract No. 0C00002273
USAGE	This report provides the results of an interim analysis of the findings of a program undertaken pursuant to the Dredge and Spoil Disposal Management Plan for the Pluto LNG Development dredging phase.
PRECIS	Levels of mortality recorded over the first 40 weeks of monitoring within the set of 24 sites surveyed under the Pluto LNG Development coral health monitoring appear mostly to derive from non-dredging causes. It is here recommended that this accumulated mortality is removed from further analysis to allow future assessment as to whether potential impacts of dredging are occurring.
KEYWORDS	coral monitoring Dampier Woodside dredging

Version-Date	Released by	Purpose
V1 15 Sept 08	JAS	Client review
V2 18 Sept 08	JAS	For final review
V2.1 3 Oct 08	JAS	Final

TABLE OF CONTENTS

TABLES

FIGURES

SUMMARY

Prior to the commencement of a major dredging project within the Dampier Harbour, Woodside Burrup Pty Ltd (Woodside) a set of 24 Operating Sites and 9 Contingency Sites was established for monitoring the health of corals during dredging. That set of corals has now been surveyed 20 times over 40 weeks, including before dredging commenced, during dredging and since June 2008 when dredging ceased temporarily.

Monitoring is conducted primarily to record the relative rates at which mortality accrues in coral communities in differing areas. During the 40 weeks of monitoring, the level of partial mortality over all coral monitoring sets has risen from 7% to 20%. That rise has not been uniform over time, between management zones or between impact and reference sites.

Gross mortality (incremental mortality occurring over the time period since the start of dredging) is frequently higher at sites designated to be potential 'impact sites' than it is at 'reference sites'. However, an attempt to examine the causation of that difference and of mortality in general, determined that it was more likely that the principal cause of differential mortality was not related to dredging. The timing of mortality observed over the period points strongly to thermal bleaching episodes as the major cause of mortality in all management zones.

Over the 40 weeks the following sources of mortality have been inferred to have occurred:

- Invasion by algae;
- Physical damage from divers, anchors, cyclones;
- Diseases of varying kinds, including 'white syndrome', 'black-band' and various other non-specific diseases;
- Sediment covering;
- Predation by corallivorous snails, fish and starfish – sometimes exacerbated by coral borers;
- Interactions between pieces of other corals that have been broken and come into contact with fixed corals within the monitoring set.

The current monitoring technique provides sufficient power and precision to detect small changes in coral mortality and to evaluate the prescribed stress or mortality triggers. Interpretation of recorded change is more difficult as environmental factors other than those related to dredging differ between impact-reference pairings of coral sets.

At present, mortality which has occurred subsequent to the start of monitoring increases the variance in estimating coral status over repeated surveys, but more importantly, precludes further tests of "no net mortality" in sites which have exceeded that level already. It is recommended that in the absence of any practical capacity to assign proportions of mortality to dredging or non-dredging causes,

- all mortality occurring thus far be assigned to non-dredging causes and removed from the analysis, and
- that the coral monitoring set be restored to 60 corals each of less than 50% partial mortality at each site.

1.0 INTRODUCTION

1.1 OVERVIEW

Woodside Burrup Pty Ltd (Woodside) is undertaking capital and maintenance dredging for the Pluto LNG development in Mermaid Sound, northern Western Australia. Environmental management is effected under a Dredging and Spoil Disposal Management Plan (the DSDMP) (SKM 2007).

In response to the requirements of Schedule 4 of the Ministerial Statement covering this project, Appendix G of the Plan has established a program of coral health monitoring to examine the status of coral communities within the zone of predicted impact and influence of the dredging and disposal operations.

Two indicators of coral health are scored under this program:

- Partial mortality of individual corals – assessed fortnightly;
- Frequency of bleaching on coral – assessed fortnightly.

Between 1 November 2007 and 9 August 2008, coral health surveys have been undertaken on a fortnightly basis. Since that time, surveys have become monthly. Survey 20 (the last reported here) was undertaken in the first half the month, so may be grouped as a fortnightly survey and the total survey period conserved as 40 weeks.

The status of coral health is compared against trigger criteria specified in the DSDMP to comply with the Ministerial Statement governing this project. Those triggers are measured predominantly as mortality, and thus this program has not measured growth or recruitment at the same intensity as the fortnightly mortality estimates. Interpretation of the results reported here should consider that all populations will exhibit a positive mortality rate and it is the comparison of rates rather than the rate per se that is significant.

Where triggers are exceeded a review of all coral health data, environmental factors and contextual data is undertaken to evaluate the degree to which it is likely that the exceedence may be caused by turbidity derived from dredging or disposal operations. To date, the following exceedences have occurred and been investigated[1]:

- February 2008: bleaching observed above 10% of coral cover at many sites (MSA93R17);
- March 2008: coral mortality at site ANG2 exceeds ‘no net mortality’ (MSA93R24);
- April 2008: coral mortality at site GIDI exceeds ‘no net mortality’ (MSA93R28);
- April 2008: coral mortality at site ANG3 exceeds ‘no net mortality’ (MSA93R31);
- May 2008: coral mortality at site NELS exceeds ‘no net mortality’ (MSA93R34).

No investigation determined that there was a clear link of coral stress or mortality with dredging. An intensive review of date (MSA93R40) concluded that the primary cause of mortality was consistent with the impacts of the thermal bleaching event recorded from February 2008. That finding was endorsed by a review the report undertaken by a coral specialist from James Cook University.

Under the plan for phased dredging in this project, dredging activity concluded in June 2008 and is not planned to restart until October 2008 or beyond. This review provides an interim assessment of mortality patterns prior to the restart of dredging to determine whether the monitoring program requires any revision.

[1] Investigations are contained in numbered MScience reports referenced in parentheses for each exceedence.

2.0 METHODS

2.1 SURVEYS TO DATE

Surveys conducted thus far are listed in Table 1 along with the status of dredging works during that survey period. Sites omitted from surveys due to weather constraints are shown in Table 2 with the location of sites shown in Table 3 and Figure 1.

Table 1. List of surveys to this time.

Survey #	Dates	Sites	Dredging**
1(Baseline)	1 – 14 Nov 07	All Operating sites	-
2	26 Nov – 9 Dec 07	All Operating sites	C
3	10 -23 Dec 07	Sites incomplete*	C
4	30 Dec 07 – 12 Jan 08	Sites incomplete*	C^P
5	13 – 26 Jan 08	All sites sampled	C, T^P
6	28 Jan – 9 Feb 08	All sites sampled	C, T
7	10 Feb – 23 Feb 08	Sites incomplete*	C^P, T^P
8	24 Feb – 8 Mar 08	Sites incomplete*	C, T^P
9	9 – 22 March 2008	All sites completed	C,T, B^P
10	23 Mar – 5 April 08	Sites incomplete*	C^P, T^P, B^P
11	6 – 19 April 08	All sites completed	C, T^P,B
12	20 April – 3 May 08	All sites completed	C^P, B
13	4 – 17 May 08	All sites completed	B
14	18 – 31 May 08	Sites incomplete*	B
15	1 – 14 June 08	All sites completed	B^+
16	15 – 28 June 08	Sites incomplete	B^+
17	29 June – 12 July 08	Sites incomplete	-
18	13 July – 26 July 08	Sites incomplete *	-
19	27 July – 9 August 08	Sites incomplete*	-
20	10 August – 8 Sept 08	All sites completed	-

* sites omitted from this survey were recorded in the next survey

** Dredging – operating within fortnight: T- TSHD; C- CSD; B-backhoe dredge : ^{P} next to a dredge indicates it only worked part of that period

$^+$ Dredge working on ancillary project

- No dredging

Table 2. Sites omitted in surveys are marked X.

	SURVEY																			
Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ZONE B - Impact																				
NWIT			X				X			X									X	
SCON				X			X												X	
SUP2							X												X	
SWIT			X				X			X										
ZONE B - Reference																				
INTI			X				X			X										
MIDI								X												
WINI			X					X		X										
WLI1																				
ZONE C INNER - Impact																				
ANG2							X													
ANG3				X															X	
ANGI							X												X	
COBN																				
CONI																				
GIDI							X											X		
ZONE C INNER - Reference																				
FFP1							X												X	
MALI			X																	

Table 2 cont.

	SURVEY																		
Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ZONE C OUTER - Impact																				
NELS								X								X			X	
HAM3														X			X	X		
HAM4														X			X			
CRTS								X								X	X	X		
LANI								X										X		
ZONE C OUTER - Reference																				
LEGD							X										X			
MAL2																				
MIDR								X												

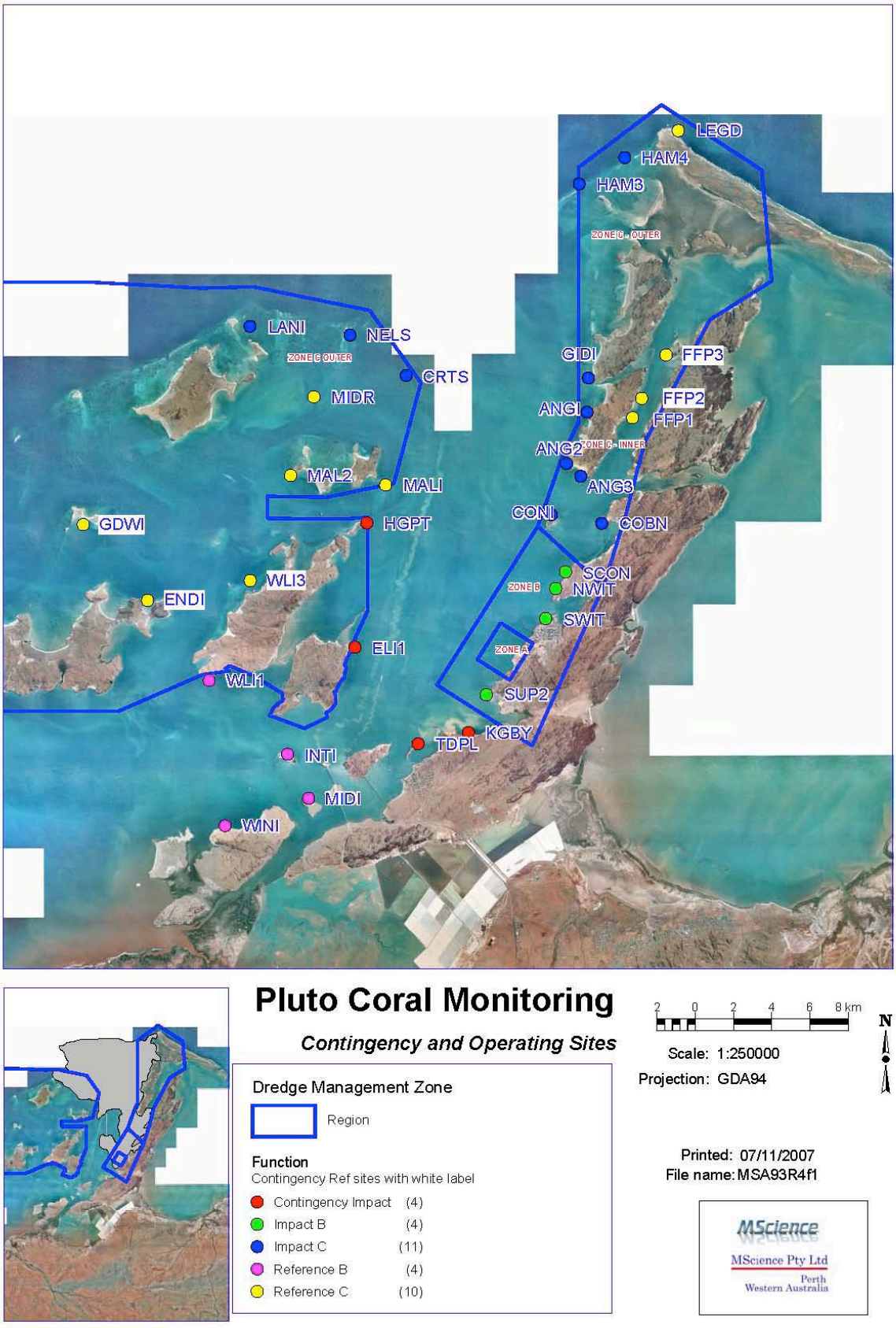
2.2 SAMPLING LOCATIONS

Current operating sites are listed in Table 2 and shown in Figure 1. The rationale for site selection is contained in Appendix G of the DSDMP.

Table 3. Operating sites for coral health monitoring.

Site Name	Position (GDA94 Zone 50)		Coral Community Type
	Easting	Northing	* see Blakeway & Radford 2005
Zone B Impact			
NWIT	477059	7725275	TFPo
SCON	477692	7726335	FPo
SWIT	476529	7723696	FTO
SUP2	473437	7719662	FTO
Zone B Reference			
INTI	462909	7716536	PoPvO
MIDI	464008	7714219	OPvF
WLI1	458896	7720645	PoO
WINI	459616	7712772	PoO
Inner Zone C Impact			
ANG2	477632	7731862	FAcPo
ANG3	478431	7731179	AcPo
ANGI	478711	7734574	FTO
COBN	479487	7728716	PoT
CONI	476837	7729162	Po
GIDI	478784	7736380	OTF
Inner Zone C Reference Sites			
FFP1	480988	7734091	OT
MALI	468088	7730742	Po
Outer Zone C Impact Sites			
CRTS	469188	7736562	AcO
HAM3	478293	7746613	O
HAM4	480692	7748006	AcO
LANI	460674	7739214	AcF
NELS	466203	7738649	OPoAc
Outer Zone C Reference			
LEGD	483389	7749405	OPo
MAL2	464559	7730303	Po
MIDR	464301	7735390	PoFO

Figure 1. Map of all coral health sites.



2.3 HEALTH MEASURES

2.3.1 PARTIAL MORTALITY

Coral mortality may be recorded on entire colonies, however partial mortality, where a part of the coral colony has died, may also be evident.

Partial mortality has been scored here as:

- coral tissue which has clearly lost its original colour – other than 'white-bleached' , which represents a 'sub-lethal' stress measure;
- any coral which has been covered with algae growing on the coral; and
- coral with tissue covered by a depth of sediment sufficient to obscure vision of the underlying coral.

Physical Damage - coral mortality often occurs via the loss of entire colonies, or parts of colonies, from physical damage. In the Dampier Archipelago, this form of loss can occur through wave action, anchor damage or diver damage. Where a coral is physically damaged, the outline of coral for scoring on the validation set will be adjusted to remove the area lost.

2.3.2 BLEACHING

Coral bleaching is defined here as the loss of a coral's symbiotic algae to the point where the colour has been lost (as judged by *in situ* observation) from the living tissue of a hermatypic coral, but the living tissue remains intact. This state cannot be determined using only photographic images of entire coral colonies as a photograph cannot determine whether white areas on a coral represent live tissue or a bleached skeleton. To address this in addition to a photograph being taken, bleaching will be confirmed by diver observation on whether there is live coral tissue (polyps) present. If there is no coral tissue, and just the white skeleton then the coral will be recorded as dead. If it is classed as bleaching the photograph will be analysed using the same technique as the assessment of coral partial mortality.

The same set of corals used in Section 2.2.1 is also evaluated for bleaching.

2.3.3 STATISTICAL TREATMENT

Each coral image is assigned a percent partial mortality (for coral i – PM_i) where

$$PM_i = (\text{points scored as partial mortality/number of points within the coral boundary})$$

where PM_{ix} is the partial mortality of coral i at survey *x*.

The Partial Mortality estimate for a site is the average of that for the corals scored at that site for that survey – eg for Site ANGI in Survey 2:

$$PM(ANGI_2) = \Sigma PM_{i2}/N \quad \text{(Eq. 1)}$$

where i goes from 1 to N corals;

The Gross Mortality at a site is calculated as (eg for site ANGI at Survey 2)

$$GM(ANGI_2) = \Sigma(PM_{i2-} PM_{iB)}/N \quad (eq. 2)$$

where i goes from 1 to N corals with N corals being the corals measured at time 2 and iB those same corals from the baseline survey.

Gross Mortality may be negative where Partial Mortality decreases to a level below the baseline – such as can occur when sediment cover on top of a live coral is reduced between monitoring events.

For this assessment, rates of increase have been calculated over the period from Survey 1 to Survey 20 by fitting a line of least squares through the mean of GM for each survey and forcing that line to pass through the origin (Survey=1, GM=0). The slope the line was then rounded to the nearest 0.05% GM per week.

Mortality is unlikely to be consistent between coral species. The corals used for image assessments here have been identified to a genus level. However, some genera occur at only a few sites and many are represented by only 1 or 2 individuals at many sites. A more generalised categorisation of coral taxonomy (Table 4) has been used to allow more informative analysis by using the major coral groupings defined for the area in Blakeway & Radford (2005).

Table 4: Taxonomic classes used to reflect broad groupings of corals.

Class	Description
Acropora	Members of the genus *Acropora*
Faviids	Members of the family Faviidae – a wide range of species with the most common *Goniastrea australensis* or *Platygyra sinensis*
Pavona	Members of the genus *Pavona* – almost exclusively *P. decussata* here
Porites	Members of the genus *Porites* – most commonly *P. solida* and *P. lobata*
Turbinaria	Members of the genus *Turbinaria* – mostly comprising the 4 species common in Mermaid Sound
Other	All scleractinian coral species not included above – plus Milleporid corals

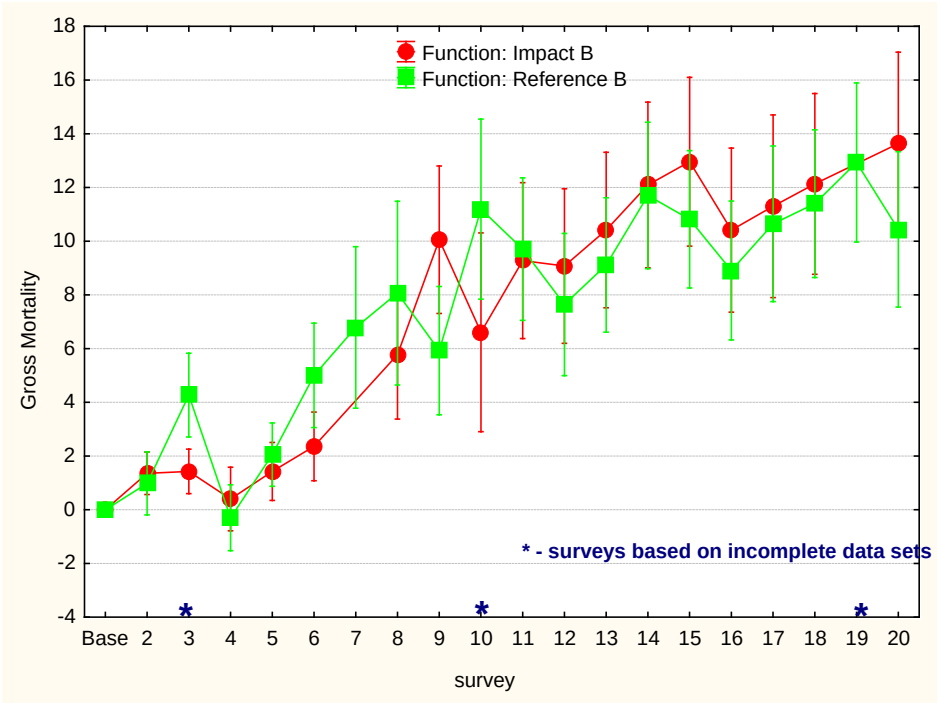
3.0 OUTCOMES

3.1 ZONE B

Zone B (Figure 1) represents the area within which some mortality of corals was predicted from the impact assessment for this project. Allowable thresholds of decline in the density of coral communities for this Zone were permitted to be up to 10% above that of reference sites under the Ministerial Statement applied to this project. Figure 2 shows that the mean of impact and reference sites has not been significantly different for any survey with a full set of sites recorded up to Survey 20.

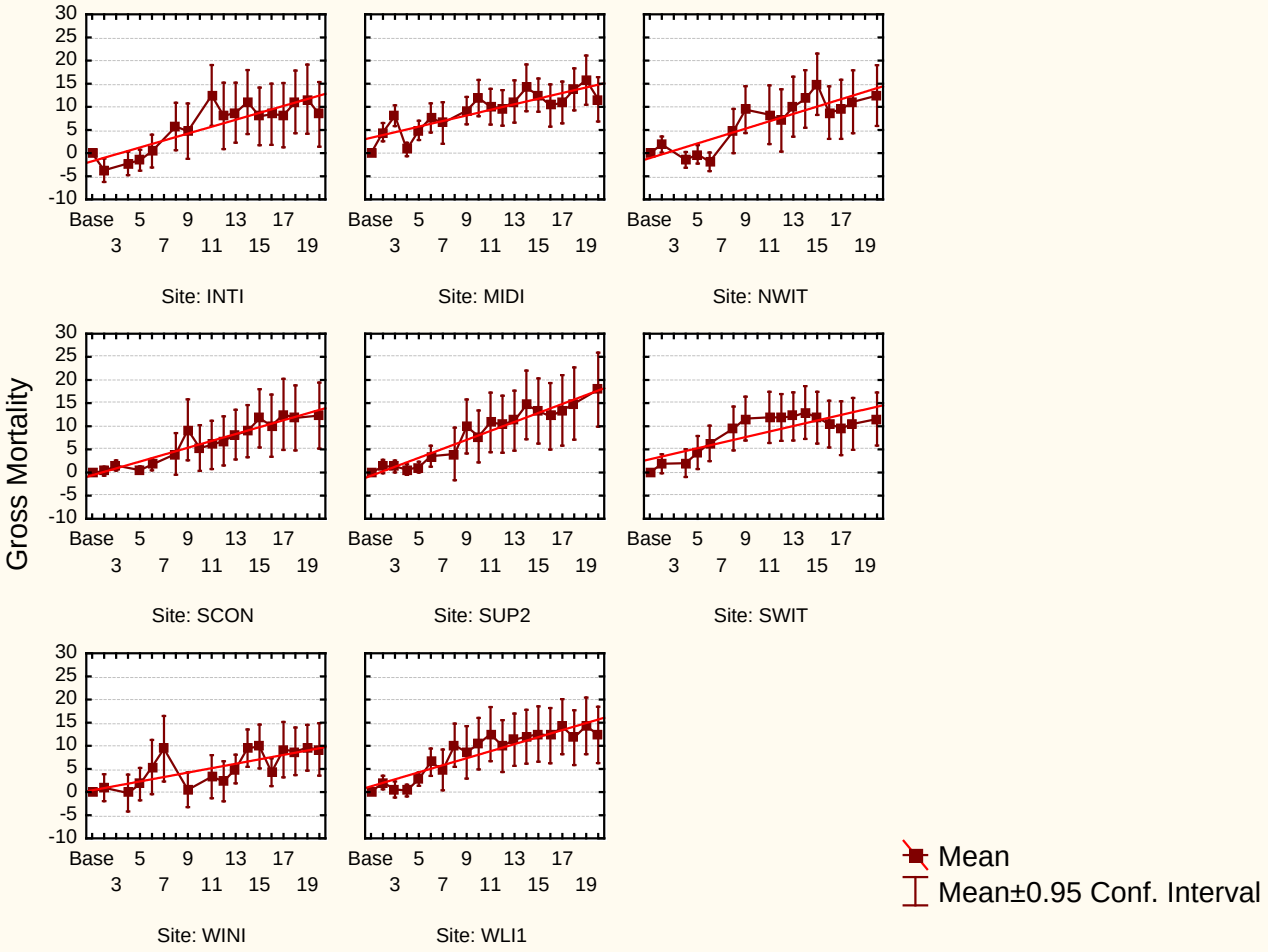
Average mortality patterns for Impact and Reference sites within Zone B are similar, showing a relatively steady mortality rate of 0.35% per week.

Figure 2. Mean gross mortality by survey for Zone B site functions.



Mortality patterns at individual sites are also relatively similar (Figure 3) with gross mortality typically around 10-15% by survey 20. In general rates of mortality appear relatively uniform (compared to Zone C sites – see later) throughout the monitoring period.

Figure 3. Mean gross mortality by survey for individual sites in Zone B.

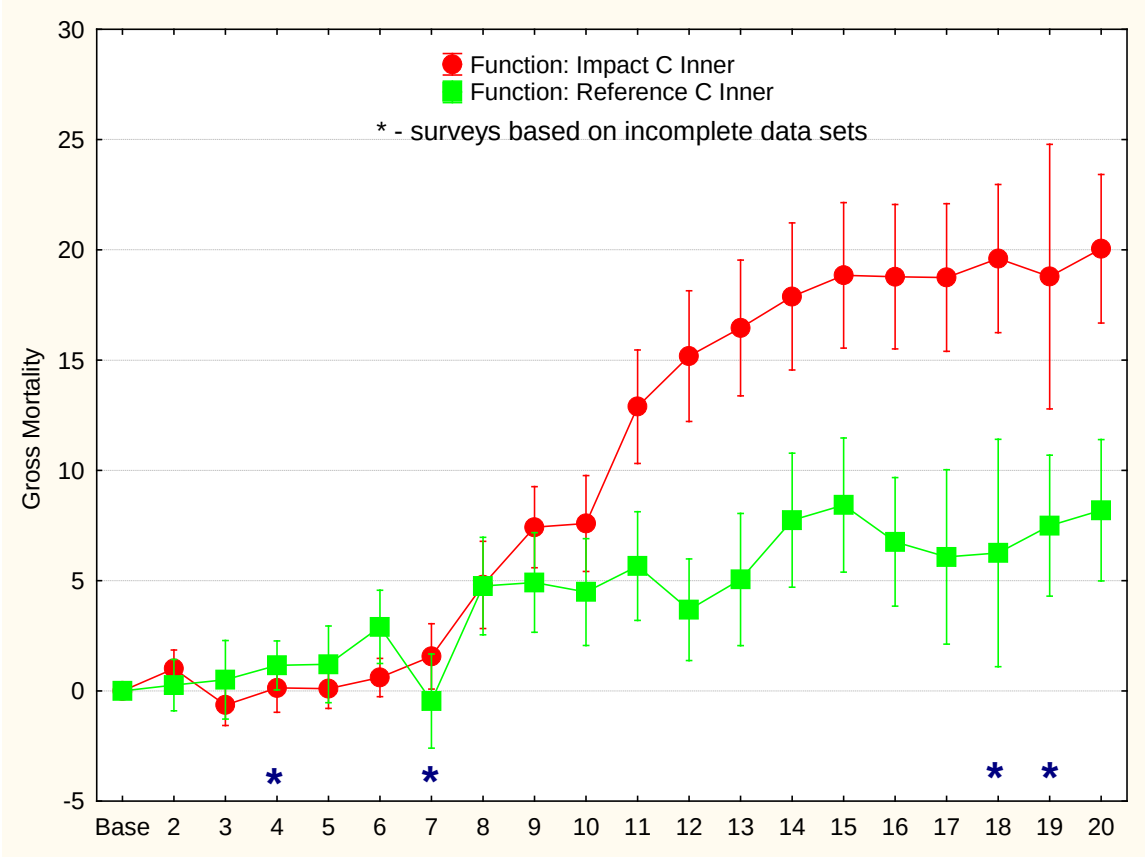


3.2 Zone C Inner

Averaged Zone C Inner Reference and Impact sites show similar rates of mortality up until survey 8 (Figure 4). Between surveys 8 and 15 (Feb – June) sites within the Impact category show higher mortality rates than those of the Reference sites. After survey 15, mortality is similar (and relatively low) for both groups.

Over the entire period, mortality rates average to 0.5% per week for impact sites and 0.25% per week for reference sites.

Figure 4. Mean gross mortality by survey for Zone C Inner site functions.

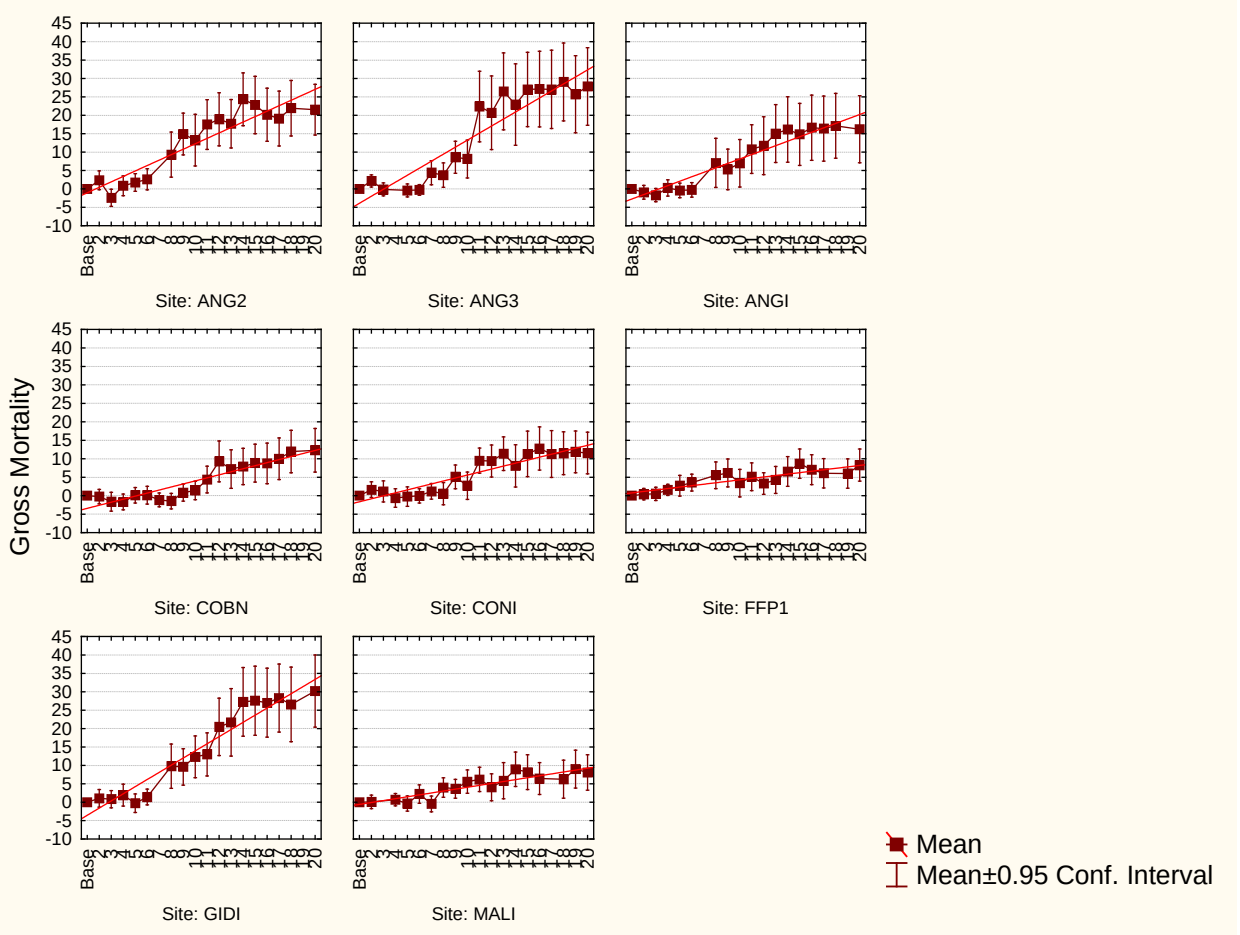


Examining the mortality trends for individual sites in the Zone C Inner area (Figure 5) shows that the elevated mortality levels of the Impact category are caused predominantly by 3 sites – ANG2, ANG3 and GIDI. Mortality levels at each of these sites exceed the target set in the Ministerial Statement of "zero net detectable mortality at any monitoring site" for Zone C sites. In this case, that trigger is evaluated as when mean gross mortality for a site is statistically greater than that of the mean gross mortality of the pooled reference sites.

The potential causation of elevated mortality levels at these sites has been examined in context with a major thermal bleaching event which occurred in February 2008 across the Pilbara. It was concluded on the balance of evidence that the elevated mortality rates of bleached corals at Impact sites was a consequence of physical conditions at those sites and not related to dredging (MScience 2008). The sites GIDI, ANG2 and ANG3 all occur on the shallow fringes of Gidley and Angel Islands and were impacted by swell and slightly higher temperatures than sites in Zone C Inner showing less bleaching-related mortality.

The timing of mortality within sites ANG2, ANG3 and GIDI is clearly linked to the aftermath of the bleaching event. Mean mortality is above average (the red lines of Figure 5) immediately following the bleaching event and below average before and after that period (see Sect 3.4).

Figure 5. Mean gross mortality by survey for individual sites in Zone C Inner.

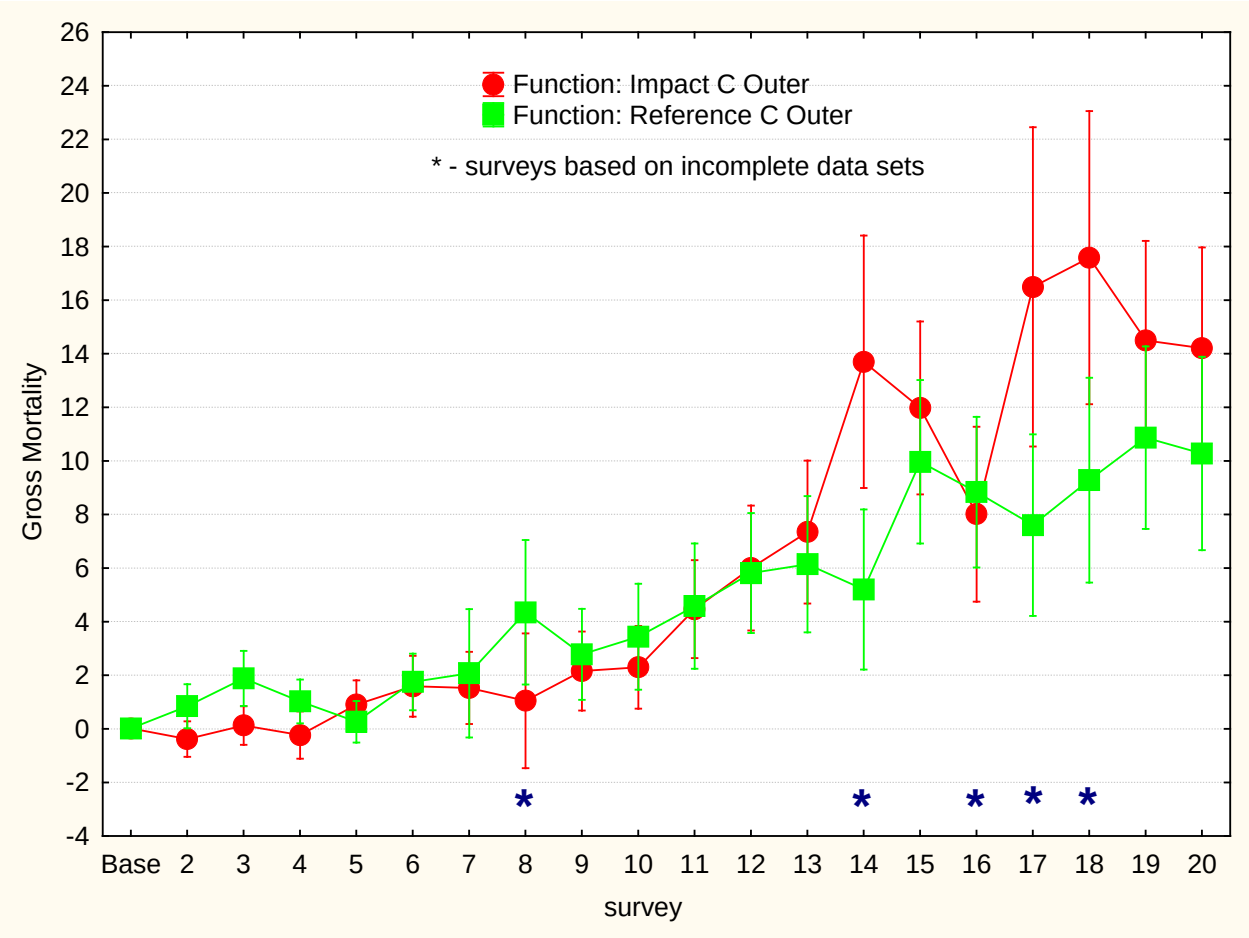


3.3 ZONE C OUTER

Averaged Zone C Outer Reference and Impact sites show similar rates of mortality up until survey 13 (Figure 6). Between surveys 13 and 17 (May - July) sites within the Impact category show higher mortality rates than those of the Reference sites. The exact timing of mortality events within this period is partially obscured as bad weather prevented complete surveys on several occasions. After survey 15, mortality is similar (and relatively low) for both groups.

Over the entire period, mortality rates average to 0.35% per week for impact sites and 0.25% per week for reference sites.

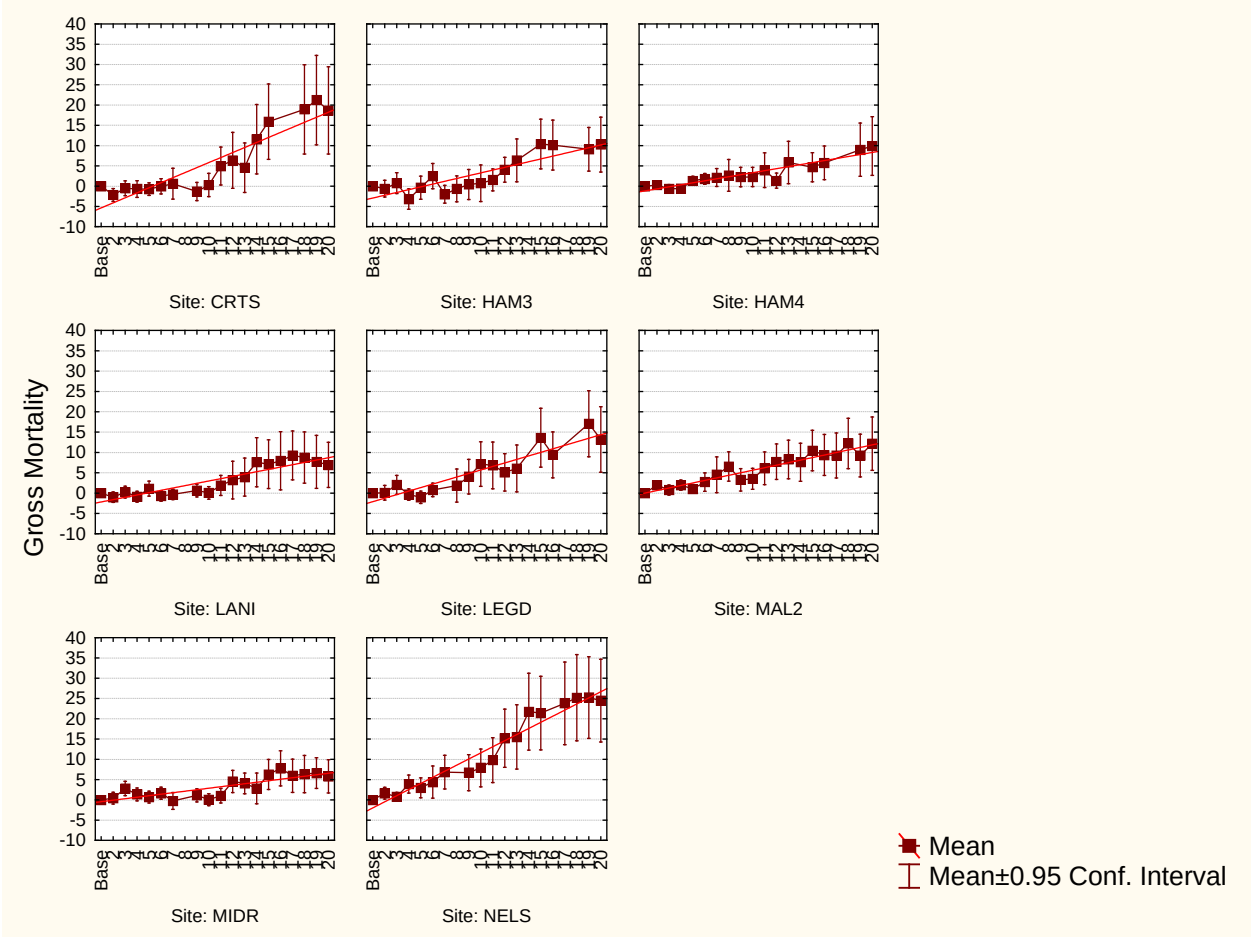
Figure 6. Mean gross mortality by survey for Zone C Inner site functions.



The elevation in mortality rates for Impact sites is derived principally from sites NELS and CRTS (Figure 7). As for Zone C Inner sites, survey means of gross mortality during the peak bleaching levels are above the average mortality line. For the Outer sites, this occurs later than for the Inner or Zone B sites, which is probably associated with the peak in offshore water temperature occurring approximately a month later than for inshore water temperature (MScience 2008).

Amongst these Zone C sites, only NELS shows a level of Gross Mortality significantly greater than that of the pooled reference sites. Again, the detailed examination of possible causation of that elevation did not conclude that elevated suspended sediment concentrations or elevated deposition of sediment were likely contributing factors.

Figure 7. Mean gross mortality by survey for individual sites in Zone C Inner.



3.4 Mortality Rates and Timing of Mortality

Table 5 presents a comparison of the rates of mortality estimated over the 40 weeks of monitoring conducted to date. Given the variance between corals within sites, between sites and between surveys, the confidence intervals surrounding these estimates of slope of the mortality trend will be large. Thus they should be interpreted as indicative rather than robust measures. Mean gross mortality per site will continue to be a more rigorous measure. However, the trend data is generally indicative of that latter measure and may be used to summarise events to date.

Table 5. Comparative rates of mortality at all sites.

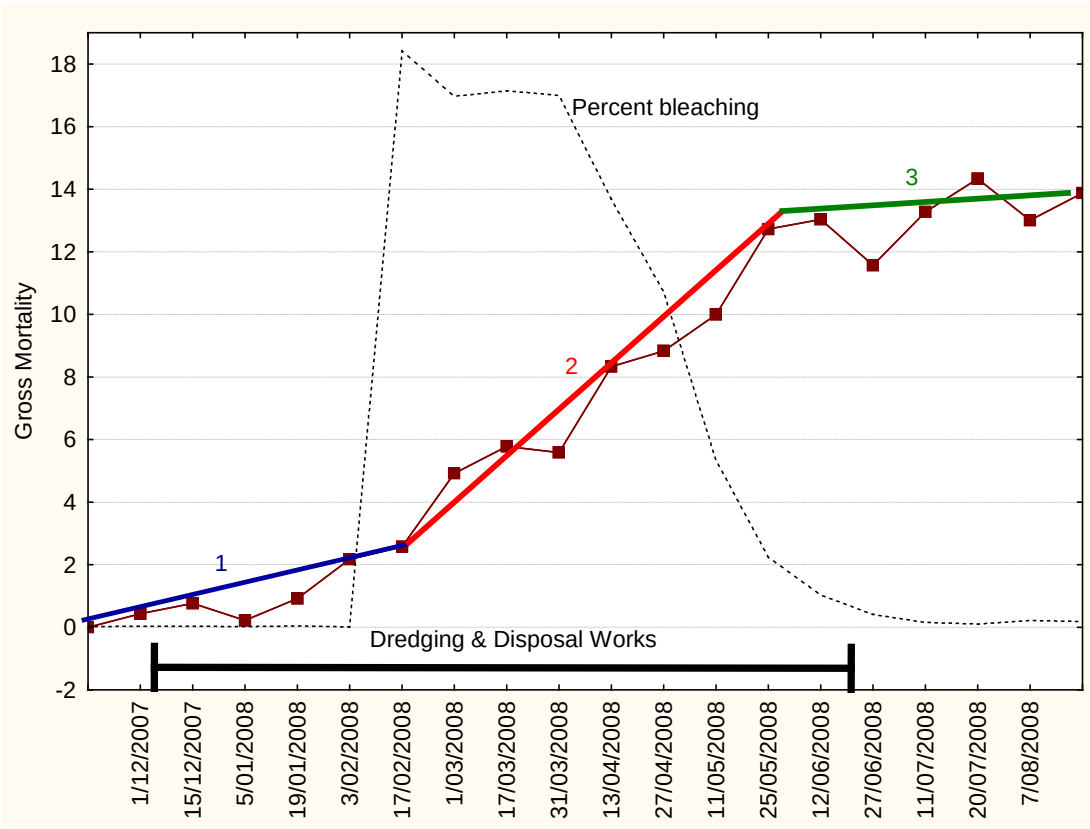
Site	Mortality Rate (% per week)
Zone B Impact	**0.35**
NWIT	0.35
SCON	0.35
SWIT	0.4
SUP2	0.5
Zone B Reference	**0.35**
INTI	0.35
MIDI	0.4
WLI1	0.4
WINI	0.25
Inner Zone C Impact	**0.50**
ANG2	0.7
ANG3	0.8
ANGI	0.5
COBN	0.3
CONI	0.35
GIDI	0.85
Inner Zone C Reference Sites	**0.25**
FFP1	0.2
MALI	0.25
Outer Zone C Impact Sites	**0.35**
CRTS	0.45
HAM3	0.25
HAM4	0.25
LANI	0.25
NELS	0.65
Outer Zone C Reference	**0.25**
LEGD	0.4
MAL2	0.3
MIDR	0.15

In general Table 5 shows that, for Zone C sites, impact sites have higher rates of mortality than reference sites. As discussed above, this appears more likely to be the result of local influences on coral stress at some sites causing differential levels of mortality to result from a thermal bleaching event. That conclusion is further supported by comparison of mortality rates within Zone B. Dredging should have the

greatest impact on environmental conditions in that Zone, but Zone B shows the least difference between mortality rates of impact and reference sites.

It is useful to subdivide the monitoring into discrete time period rather than use average rates of mortality. Mortality values for individual sites (Figure 3, Figure 5, Figure 7) show levels above the trend line in the mid-program surveys and below at either end. This indicates a higher rate of mortality within that period (associated with the major bleaching events). Subdividing the monitoring period by eye to reflect change in slope of the mortality rate suggests that there is a period of elevated mortality rate that coincides more closely with the effects of the bleaching event than the duration of dredging (Figure 8).

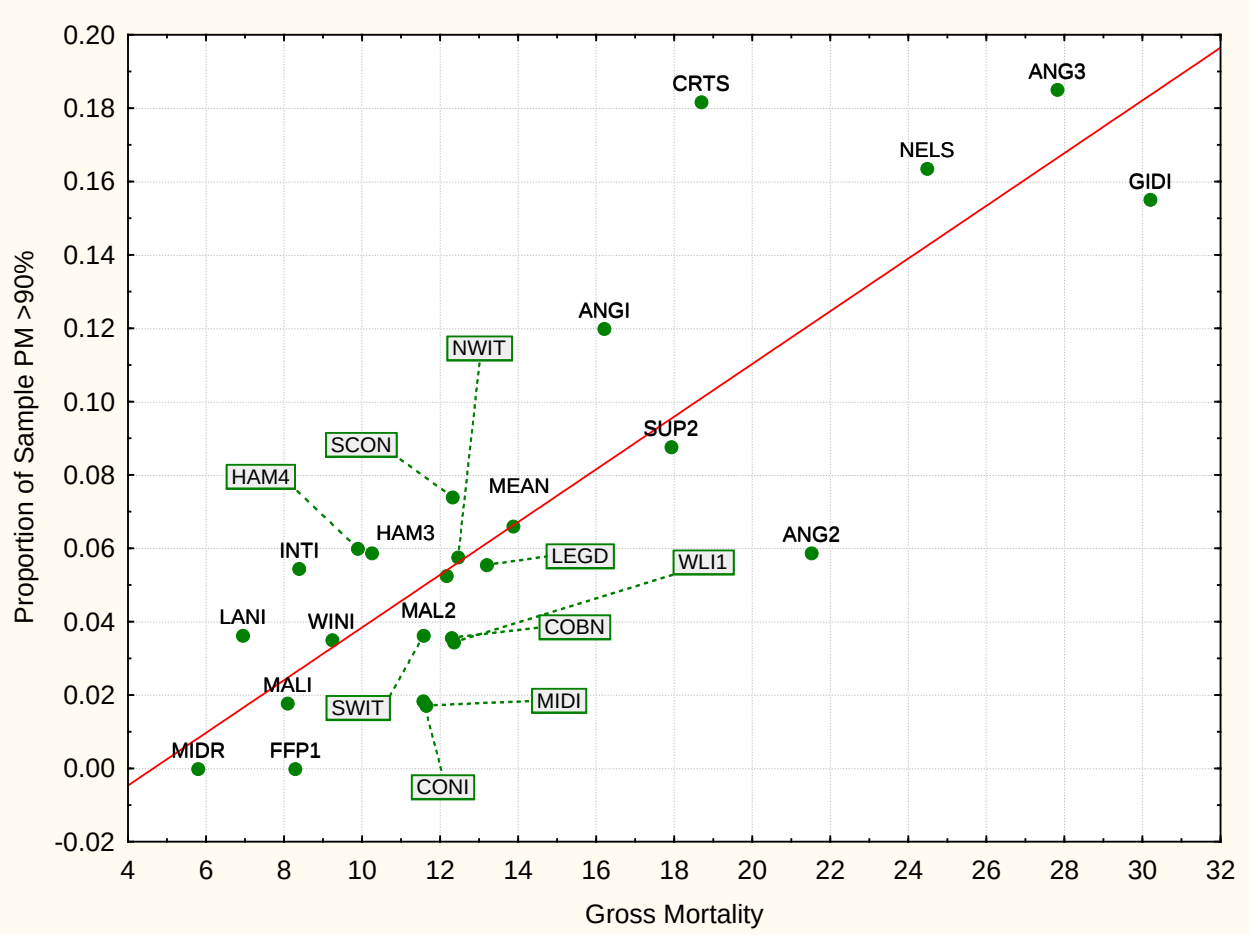
Figure 8. Timing of mortality.



Previous coral monitoring studies for other projects within Mermaid Sound suggest that mortality rates in winter are below those of summer (MScience unpublished data). This is consistent with the low (1% in 12 weeks) mortality rates seen in the present winter period once the effects of bleaching had disappeared.

The above gross mortality estimates include all partial mortality up to whole colony mortality. It is possible that the mortality of whole colonies may be derived from different causal factors to those causing small amounts of tissue death. However, the average gross mortality per site is well correlated with the average proportion of corals at a site showing mortality above 90% of the colony (Figure 9; $r=0.84$, $p<0.05$). Thus the proportion of coral mortality occurring as “whole colony mortality” is not greatly different between sites and unlikely to represent different causes of mortality between sites.

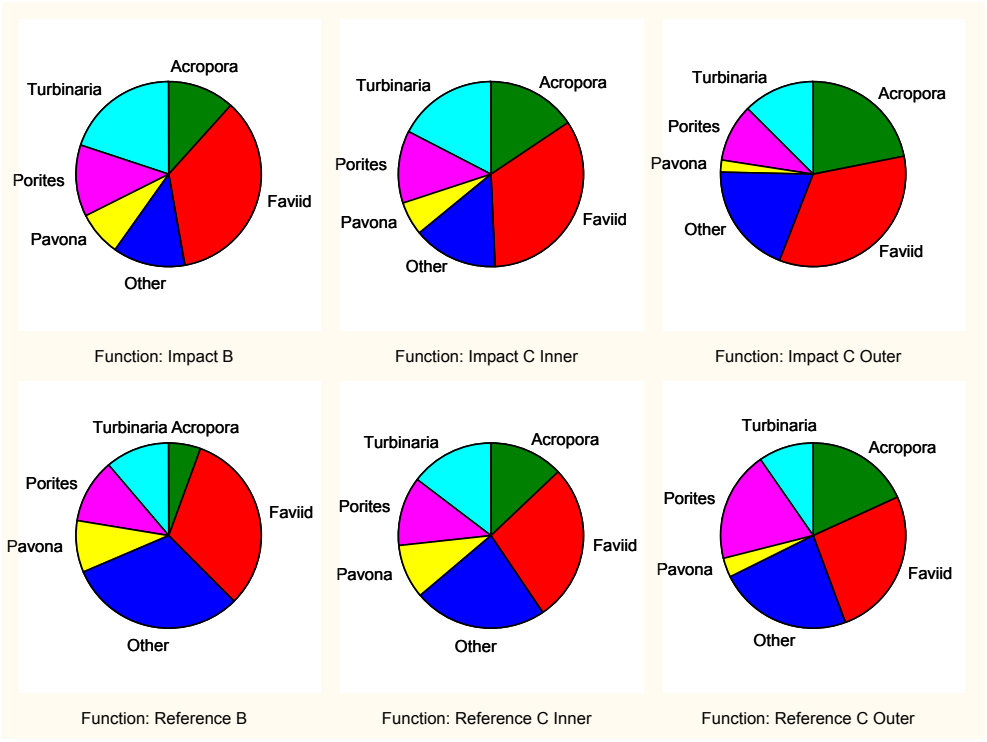
Figure 9. Gross mortality correlates to whole colony mortality at sites.



3.5 TAXONOMIC DIFFERENCES

The taxonomic composition of the coral monitoring sets is described here using a set of taxonomic groupings which reflect the most common groups of corals in Mermaid Sound and have been used previously (Blakeway and Radford 2005) to show patterns in community structure that vary according to site characteristics. While there are some differences in the composition of Zone B, Zone C Inner and Zone C Outer (increasing *Acropora* and decreasing *Turbinaria* components) consistent with the broader community composition at those sites, the composition of reference and impact groups within each zone is consistent (Figure 10).

Figure 10. Taxonomic composition of corals monitored at sites.



Mortality rates can vary between taxa as a result of differential susceptibility to potential stressors. Some coral species are noted as r-strategists being quick to colonise but having high mortality rates while others may be slower growing and more persistent (Loya 1976). The former are typically branching species while the latter are dominated by the massive or sub-massive species. Most species of the genus *Acropora* are thought to be r-strategists.

By the end of the current surveys, levels of mortality for *Acropora* are higher than for other taxa at most sites where they occur (Figure 11). Mortality in the acroporids also makes the largest contribution of any taxon to differentiating morality between impact and reference categories within each monitoring Zone.

Acropora are characteristic of clear water environments and typically are more common on the outer reefs of Mermaid Sound (Simpson 1988; Blakeway and Radford 2005). This is commonly accepted as indicating their vulnerability to the direct or indirect effects of sediment in the water column, although experimental studies do not always confirm that outcome (e.g. Anthony et al. 2007). However, *Acropora* are also particularly susceptible to mortality caused by bleaching (Jones 2008).

Relating the timing of the inshore-mid and offshore bleaching events to the timing of mortality appearing within *Acropora* (Figure 12) shows that mortality events start in this group coincident with the onset of bleaching and continue until bleaching levels return to zero. There is also clearly a separation of the timing of those events between these areas. That timing reflects the later rise in water temperatures seen offshore (MScience 2008).

Figure 11. Levels of gross mortality per taxon by survey 20.

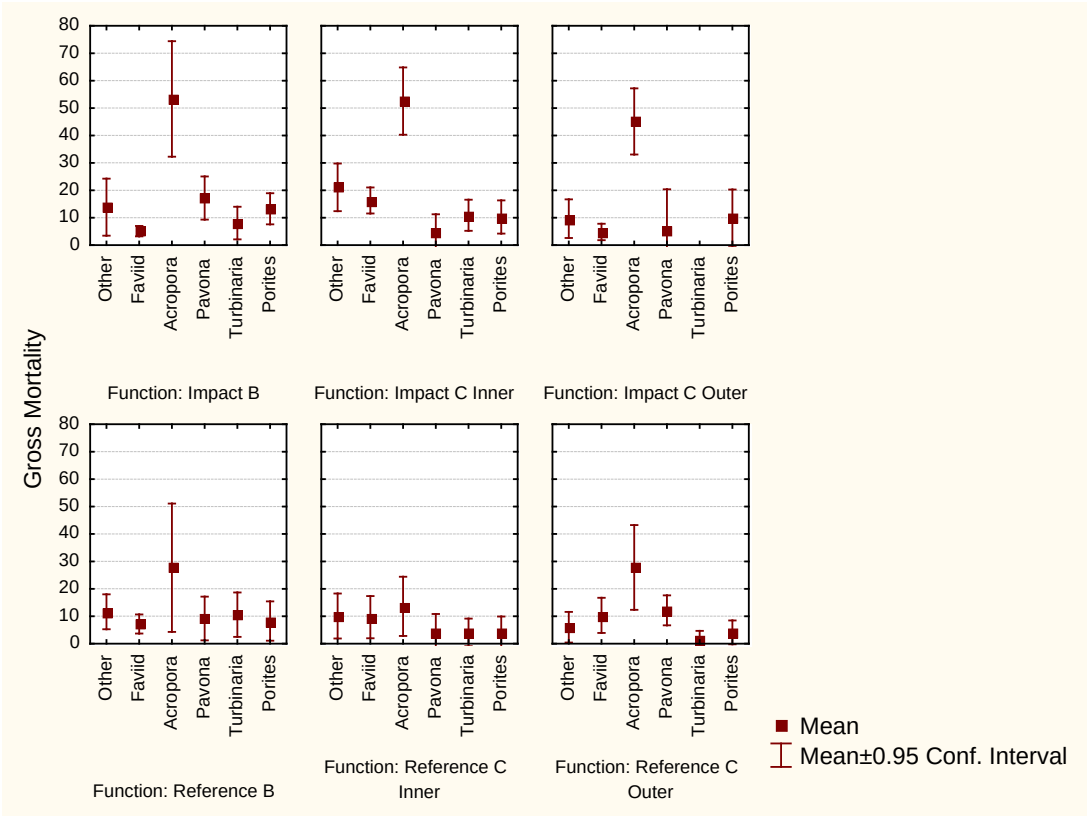
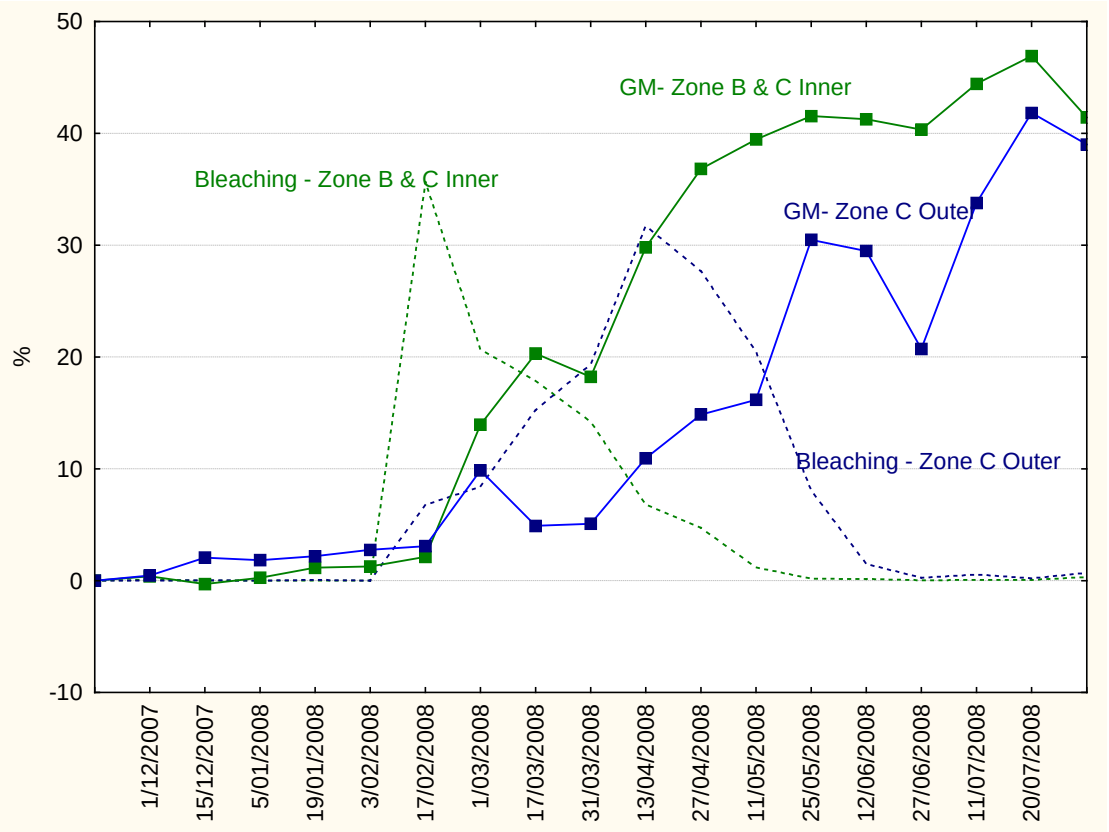


Figure 12. Timing of mortality and bleaching for *Acropora* in different zones.



3.6 RESTORING MONITORING POWER

The original coral monitoring sets at each site were established to contain 60 corals to allow a potential minimum number of 50 corals per site, as some corals are not found each survey and some were expected to be lost from mortality sources clearly not associated with dredging. Corals killed by thermal bleaching, disease, anchor or diver damage and predators were included within the latter. At present, all sites retain at least 50 corals that are included in the scoring set (Table 6), although continuing loss of corals from 'other' causes will see this drop below that critical value.

Table 6. Levels of partial mortality in individual corals within monitoring sets at each site.

Site	N. of corals per class				
	<25%	25-50	50-75	>75%	Total
ANG2	25	14	8	4	51
ANG3	33	7	2	12	54
ANGI	39	3	2	6	50
COBN	43	5	2	6	56
CONI	41	7	4	2	54
CRTS	42	2	1	10	55
FFP1	43	8	1	1	53
GIDI	31	7	5	15	58
HAM3	42	4	2	3	51
HAM4	45	1	1	3	50
MIDI	50	4	2	2	58
INTI	39	11	2	3	55
LANI	49	4	0	2	55
LEGD	42	2	5	5	54
MAL2	49	4	0	4	57
MALI	39	12	3	2	56
MIDR	53	5	1	1	60
NELS	39	2	4	10	55
NWIT	39	8	2	3	52
SCON	47	3	0	4	54
SUP2	45	3	4	5	57
SWIT	41	11	1	2	55
WINI	39	12	3	3	57
WLI1	48	5	2	3	58

In addition, the monitoring sets at most sites contain 10-25% of corals with partial mortality above 50%. This leads to increased variability in scoring coral mortality between surveys as these corals often have complex shapes or indistinct boundaries between live and dead surfaces.

The coral health monitoring program was established to provide estimates of dredging derived mortality or stress by comparing estimates of those parameters for impact and reference sites. Restoring the full coral monitoring set to 60 corals with partial mortality levels of <50% will provide a more robust estimate of the level of ongoing mortality than retaining the current sets of corals by reducing scoring variance.

Investigations undertaken thus far have not been able to identify a clear linkage between observed mortality and the impacts of dredging or disposal. If we represent gross mortality (GM) to be:

$$GM_{TOTAL} = GM_N + GM_D$$

where GM_{TOTAL} is total gross mortality estimated in the most recent survey (here #20), with GM_N that derived from non-dredging causes and GM_D that from dredging, then we may assume that GM_D is effectively zero and that all gross mortality to date has been GM_N.

It would be useful to be able to remove GM_N from this equation. This was the intent of the EPA recommendation to use reference sites to represent only non-dredging mortality:

$$GM_{TOTAL} = GM_N$$

so that net mortality was calculated as Impact(GM_{TOTAL}) – REFERENCE(GM_{TOTAL}), or

$$IMPACT(GM_N) + GM_D – REFERENCE(GM_N)$$

However, as IMPACT(GM_N) <> REFERENCE(GM_N), their difference does not equate to GM_D.

We are now faced with four sites (ANG2, ANG3, GIDI & NELS) which have exceeded the “no net mortality” status. Without evidence linking that mortality to a dredging source, it can only be assumed that the net mortality is a result of the difference in GM_N between these sites. Until that differential is removed, it will not be possible to use these sites to test for any significant level of GM_D.

While it is possible that GM_D is not zero at all sites, there is no way to test that or apportion a figure to GM_D. To restore the potential to trigger the ‘no net mortality’ criterion, the most straightforward approach is to assume GM_D=0 and reset the coral baseline to the level of partial mortality present in a set of restored corals as close as possible to the restart of dredging.

4.0 DISCUSSION

During the 40 weeks of monitoring conducted between the baseline survey and survey#20, the level of partial mortality over all coral monitoring sets has risen from 7% to 20%. That rise has not been uniform over time, between management zones or between impact and reference sites.

Gross mortality (incremental mortality occurring over the time period since the start of dredging) is frequently higher at sites designated to be potential 'impact sites' than it is at 'reference sites'. However, an attempt to examine the causation of that difference and of mortality in general, determined that it was more likely that the principal cause of differential mortality was not related to dredging but to differences in the temperature history and exposure to swell and waves between these sites (MScience 2008).

The timing of mortality observed over the period points strongly to thermal bleaching episodes as the major cause of mortality in all management zones.

The form of monitoring used here includes the capture of an image of each coral in the monitoring set every two weeks. This provides an insight into the cause of partial mortality where that may be assessed visually. Over the 40 weeks the following sources of mortality have been inferred to have occurred:

- Invasion by algae;
- Physical damage from divers, anchors, cyclones;
- Diseases of varying king, including 'white syndrome', 'black-band' and various other non-specific diseases;
- Sediment covering;
- Predation by corallivorous snails, fish and starfish – sometimes exacerbated by coral borers;
- Interactions between pieces of other corals that have been broken and come into contact with fixed corals within the monitoring set.

While it is possible that these factors may have led to greater mortality of corals within 'impact sites' due to stress from dredging impacts, there is no clear indication that coral communities outside of those adjacent to the dredging site have suffered such water quality impacts from dredging or disposal activities. Further, corals of the 'impact sites' of Zone B (surrounding the dredging site) show less difference from their reference sites than do corals in sites more distant from this source of suspended sediment.

At present, mortality which has occurred subsequent to the start of monitoring introduces unnecessary variance into monitoring, but more importantly, precludes further tests of "no net mortality" in sites which have exceeded that level already. It is recommended that in the absence of any practical capacity to assign proportions of mortality to dredging or non-dredging causes,

- all mortality occurring thus far be assigned to non-dredging causes and removed from the analysis, and
- that the coral monitoring set be restored to 60 corals each of less than 50% partial mortality at each site.

5.0 REFERENCES

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Appendix 9 – Level 3 Criterion Exceedance Correspondence Register.

All Level 3 Coral Condition Management Trigger Criterion Exceedances to date have been attributed to mortality resulting from this regional thermal bleaching event. This assessment has been endorsed by the Pluto DEMG and the James Cook University Centre of Excellence for Coral Reef Studies. Below lists all previously submitted L3C Criterion Exceedance compliance reports and related DEMG advice.

Subject	***Exceedance Number***	***Site***	***Reference Correspondence***		
			To	***From***	***Date(s) and/or WBPL Reference Number(s)***
Exceedance Reported to DEC	L3C-1	ANG2	Minister for the Environment	Woodside	PLU/GOV/00213; 1/04/2008
Exceedance Reported to DEC	L3C-2	GIDI	Minister for the Environment	Woodside	PLU/GOV/00221; 14/04/2008
Exceedance Reported to DEC	L3C-3	ANG3	Minister for the Environment	Woodside	PLU/GOV/00232; 29/04/2008
Exceedance Reported to DEC	L3C-4	NELS	Minister for the Environment	Woodside	PLU/GOV/00332; 16/05/2008
Level 3 trigger criterion Exceedance (L3C-4) Additional Investigations	L3C 1-4	-	Minister for the Environment	Woodside	PLU/GOV/00258; 11/06/08
Exceedance Reported to DEC	L3C-5	ANGI	Minister for the Environment	Woodside	PLU/GOV/00301; 21/10/2008
DEMG Recommendation Regarding the review by Dr A.Baird of "Bleaching Patterns across the Pilbara in Early 2008"	All Level 3 Exceedances	-	Minister for the Environment and Woodside	DEMG	20/10/2008
Letter to the Minister for the Environment regarding Zone C, Level 3 Exceedances L3C1-5.	All Level 3 Exceedances	-	Minister for the Environment	Woodside	PLU/GOV/00301; 21/10/2008

Note: All L3C exceedances are made available to the DEMG via email distribution and access to Woodside maintained website. Survey reports are posted following completion of each survey.