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COCKATOO ISLAND MARINE MONITORING

SEPTEMBER 2010 NINTH CONSTRUCTION SURVEY

Report: MSA113R14

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Document Information

REPORT NO.	MSA113R14
TITLE	Cockatoo Island Marine Monitoring - September 2010 Ninth Construction Survey
DATE	7 January 2010
JOB	MSA113
CLIENT	Cockatoo Mining Pty Ltd
USAGE	This report provides the results of the ninth marine environmental monitoring survey during construction of the Cockatoo Island Stage Three Embankment.
PRECIS	Nearshore turbidity recorded in the current survey was relatively low. Minor plumes were recorded from the Embankment after heavy rainfall and from the Sediment Pond throughout the survey period. Sediment particle size distributions remain close to baseline levels. Coral mortality increased at the Impact and Reference sites but remained stable at the Impact Risk site. At least some of the mortality at the Impact site appears to be caused by sedimentation, although it is unclear whether this is natural or derived from the minesite. Mortality at the Reference site is interpreted to be due to subaerial exposure at low tide.
KEYWORDS	coral embankment sediment sedimentation turbidity

Version-Date	Released by	Purpose
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SUMMARY

MScience Pty Ltd (MScience) undertakes a marine environmental monitoring program for the Stage Three Embankment Project at Cockatoo Island on behalf of Cockatoo Mining Pty Ltd. Construction of the Stage Three Embankment, a 375m long, 13.5m high rock armoured embankment, commenced in August 2008 and is due for completion in December 2010. This report presents the results from the ninth construction survey period, including May, June, July, August and September 2010. Monitoring comprises regular photographic surveys of sediment plume generation, water sampling for turbidity as total suspended solids, coral health monitoring, sediment sampling, NTU monitoring, and light attenuation monitoring. The first two components are undertaken by minesite staff and the latter four components are undertaken by MScience staff at approximately three month intervals, depending on tidal constraints.

The median nearshore turbidity recorded in the water sampling by minesite staff was relatively low. The occurrence and intensity of sediment plumes has decreased substantially since the Stage Three Embankment was built to full height, probably because the construction zone is no longer inundated by the tide. The largest sediment plumes observed in this survey period occurred on the 16th and 19th May and were attributed to runoff from the island after heavy rainfall. Leakage through the wall of the Sediment Pond during dewatering caused occasional smaller point source plumes throughout the survey period.

Since the last monitoring period the proportion of fine sediment has increased slightly at the Impact Risk site and remained stable at the Reference and Impact sites. Despite the slight rise at the Impact Risk site in this period there are no indications of consistently increasing fine sediment, or iron content.

Coral mortality increased at the Impact site and the Reference site, but remained stable at the Impact Risk site. Sedimentation is a possible cause for partial mortality of at least two colonies, although it is not clear whether the sediment is natural or derived from the minesite.

Coral mortality at the Reference site exceeds that at the other sites and has been increasing steadily for more than two years. Investigations undertaken in this survey indicate that the mortality is probably natural, caused by low tide exposure affecting the Reference site disproportionately due to its higher elevation. Thus the Reference site probably overestimates natural background coral mortality and is therefore unsuitable for the purpose of impact assessment.

In contrast to the Reference site, mortality at the original Impact Risk site, CT3-200, has been stable since the baseline. CT3-200 is therefore used as a Reference for coral impact assessment in this report.

1.0 INTRODUCTION

Cockatoo Mining Pty Ltd (Cockatoo Mining) Ltd has commissioned MScience Pty Ltd (MScience) to undertake a marine environmental monitoring program for the Stage Three Embankment Project at Cockatoo Island (the Project). The monitoring program was developed by Sustainability Pty Ltd with input from environmental scientists at Cockatoo Mining and MScience (Sustainability 2008) and has been reviewed by the Western Australian Department of Mines and Petroleum (DMP).

The monitoring program includes components on water quality, sediment quality and coral health. Details on the rationale and design of the individual components are provided in report MSA113R1, the first in this series (MScience 2008a; MScience 2008b). Report MSA113R1 also presents the results of the first pre-construction baseline survey carried out in April/May 2008. A second pre-construction baseline survey was undertaken in June/July 2008 (MScience 2008a). Since construction commenced, surveys have been undertaken in:

- August/September 2008 (MScience 2008a)
- September/October 2008 (MScience 2008b)
- November 2008 (MScience 2008c)
- February/March 2009 (MScience 2009a)
- July 2009 (MScience 2009b)
- September 2009 (MScience 2009c)
- February 2010 (MScience 2010a)
- May 2010 (MScience 2010b)

This report presents the results of the ninth construction survey, incorporating data collected from May to September 2010.

2.0 METHODS

This report covers:

- photographic monitoring of sediment plumes undertaken by Cockatoo Mining staff from May to September 2010
- water quality monitoring undertaken by Cockatoo Mining and MScience staff from May to September 2010
- coral monitoring and sediment sampling undertaken on the 10th and 11th September 2010 by MScience staff

Figure 1 shows the complete set of sampling sites, and Table 1 provides a breakdown of sites according to their status (Impact, Impact Risk or Reference sites) and the parameters measured at each.

2.1 WATER QUALITY

Photographic monitoring of the sampling area by Cockatoo Mining staff occurred daily from three points: 'Lookout' (overlooking the construction site), 'Town Beach' (overlooking the REF and TB transects, see Figure 1) and 'North Bay', on the north side of the Island opposite the TB transects.

Water quality monitoring was undertaken at fixed distances from the shore along eight transects running across the reef (Figure 1, Table 1). The fixed distances were 10, 50, 100 and 200m but 10, 20, 50 and 100m for all transects except RP-100, directly off Stage Three, which was sampled at 10, 20, 50 and 100m. Sampling was undertaken on the following dates: 29th May 2010, 6th, 23rd and 28th June, 21st July, 7th and 21st August, 4th and 10th September 2010.

The sampling included Secchi depth measurements and collection of filtered surface water samples for analysis of total suspended solids (TSS) by dry weight. Secchi depth measurements were made by lowering a standard 20 cm diameter black and white Secchi disk and recording the depth at which the disk was no longer visible. Water samples were collected at the same time, by filling pre-cleaned and dried 2L bottles from the water's surface.

On the 10th of September 2010, two additional parameters were measured: turbidity as nephelometric turbidity units (NTU) and light intensity. NTU and light intensity were recorded both at the top and bottom of the water column (0.5 m below the surface and 1 m above the seafloor respectively). NTU turbidity values were obtained using an Analite NEP160 turbidity meter which was 3-point calibrated prior to use. Light intensity was measured with a Li-Cor underwater sensor and Li-250A meter. The sensor recorded photosynthetically active radiation (PAR) in the spectrum 400–700 nm. The light attenuation coefficient K was calculated using the formula:

$$K = [\ln(\text{surface light intensity in } \mu\text{mol s}^{-1}\text{ m}^{-2}) - \ln(\text{bottom light intensity in } \mu\text{mol s}^{-1}\text{ m}^{-2})] / \text{water column depth in metres}$$

Water samples were filtered through preweighed 47 mm Whatman GF/C 1.2 µm papers using a 1 L Nalgene vacuum flask and a 12 V vacuum pump. After filtration the filter papers were rinsed thoroughly with distilled water. Filter papers were processed for total suspended solids (TSS) by the Marine and Freshwater Research Laboratory at Murdoch University (NATA accredited). The papers were dried at 103-105°C overnight then cooled in a desiccator to ambient temperature and weighed. This cycle was repeated until the weight change was less than 4% of the previous weight or 0.5 mg, whichever was smaller (APHA 2005). As this method does not detect particles less than 1.2µm diameter, TSS is slightly underestimated. The nominal level of resolution of the technique is 1 mg/L.

Summary statistics displayed graphically in the results section include the median value and the range of each parameter from the survey period. Typically, only a subset of the data is displayed in the graphs to exclude confounding influences. Specifically, the graphs only show surface data from sites no more than 50m from shore. The data is presented in this way firstly to avoid the confounding effects of different depths at different sites and secondly because turbid plumes from the Stage Three construction generally remain within 50m of the Embankment; hence inclusion of the 100m and 200m samples in the comparisons has the potential to mask the plume's effects. Appendix A shows the full water quality data set including the 100m and 200m data.

The number of readings differs for each parameter; TSS and Secchi depths are recorded on several separate occasions in each survey period whereas NTU and light attenuation are only recorded once in each survey period.

2.2 Sediment Quality

Sediment quality monitoring sites were located 10, 50, 100 and 200m from shore along 6 of the cross-reef transects (REF, TB, CT2, CT3, CT4 and SP, Figure 1, Table 1). Sites were sampled by reefwalking and located by GPS. The precision of spatial positioning at these sites is estimated at ±5 m. Sites which are also used for coral monitoring (REF-300, CT3-200 and STS) are more precisely located because they are referenced to steel stakes hammered into the reef (see section 2.1.1 below).

At each site approximately 300g of surface sediment from the upper 2cm of the sediment profile was collected in a Whirlpak plastic bag. Excess water was decanted after allowing the sediment to settle. Samples were frozen and transported cold to ALS Laboratories in Perth for analysis of total iron content and particle size (particle size analyses were subcontracted to Golder Associates, Mansfield QLD). Total iron was analysed by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) to a resolution of 50mg/kg. Particle size was analysed by wet sieving at mesh sizes of 75µm, 150µm, 300µm, 425µm, 600µm, 1.18mm, 2.36mm, 4.75mm, 9.5mm and 19mm as per Australian Standards AS1726.

Sediment quality monitoring sites were located 10, 50, 100 and 200m from shore along 6 of the cross-reef transects (REF, TB, CT2, CT3, CT4 and SP, Figure 1, Table 1). All sites except those at the reef crest were located by GPS. The precision of spatial positioning at these sites is estimated at ±5 m. Reef crest sediment sampling sites are more precisely located because they are referenced to steel stakes hammered into the reef.

At each site 300g of surface sediment from the upper 2cm of the sediment profile was collected in a Whirlpak plastic bag. Excess water was decanted after allowing the sediment to settle. Samples were frozen and transported cold to ALS Laboratories in Perth for analysis of total iron content and particle size (particle size analyses were subcontracted to Golder Associates, Mansfield QLD). Total iron was analysed by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) to a resolution of 50mg/kg. Particle size was analysed by wet sieving at mesh sizes of 75µm, 150µm, 300µm, 425µm, 600µm, 1.18mm, 2.36mm, 4.75mm, 9.5mm and 19mm as per Australian Standards AS1726.

2.2.1 Reef crest sediment quality

Sediment sampling at the nine reef crest subsites involved collecting and analysing 300g of surface sediment as described above, and also measuring the position of the sediment surface against steel stakes that had been hammered into pockets of sediment on the reef during the baseline survey. The distance from the top of the stake to the sediment surface is measured in each survey, allowing calculation of net deposition or erosion.

Figure 1. Site location diagram. Colour coding indicates parameters monitored at each site. Blue: water quality, Green: water quality + sediment, Yellow: sediment + coral, Orange: water quality + sediment + coral.

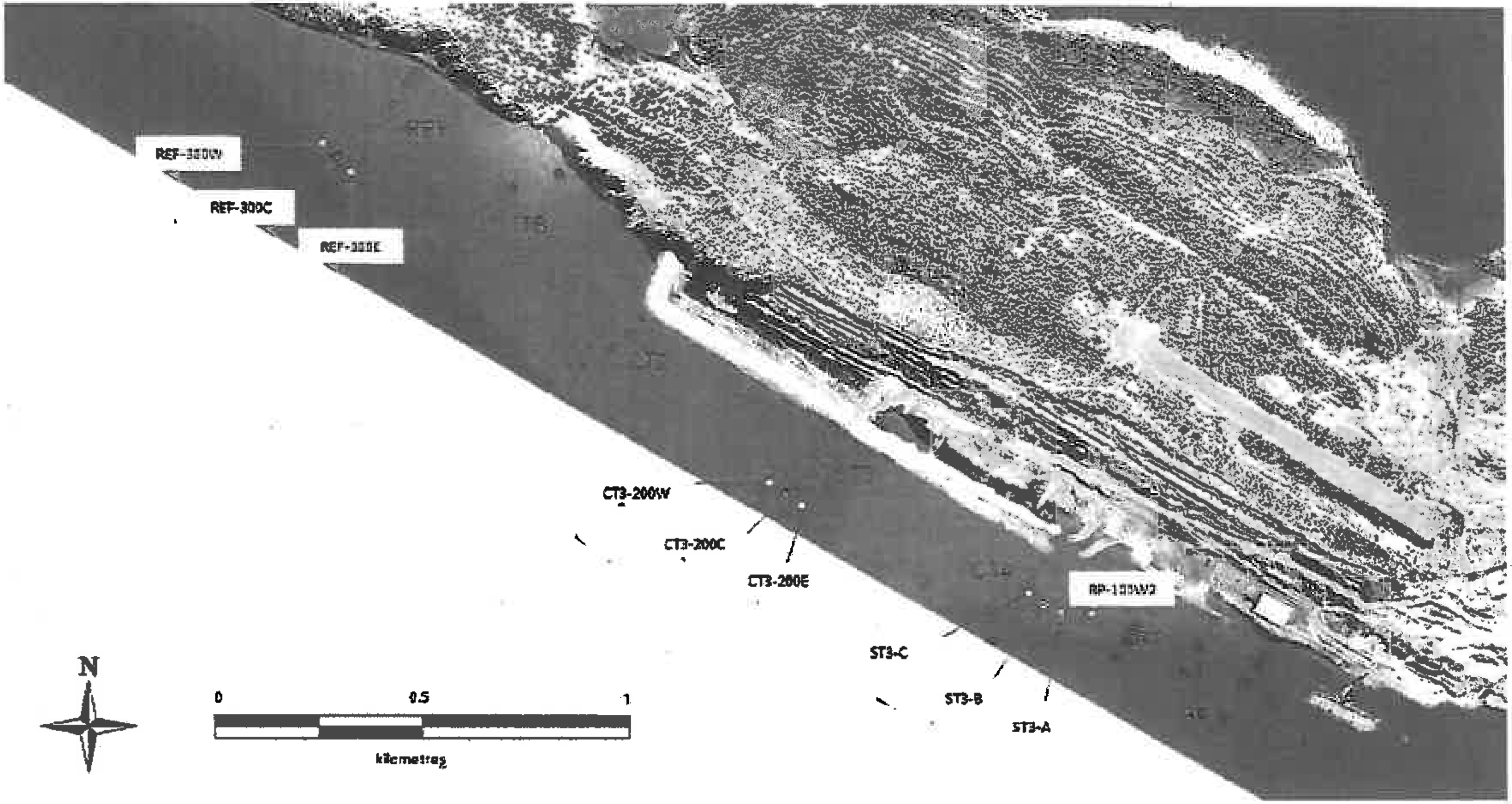


Table 1. List of all current monitoring sites. The prefix of the site name indicates the transect and the numeric suffix indicates the distance from shore or from the Embankment. Transects include REF = Reference, TB = Town Beach, CT2 = original *Ecologia* transect 2, CT3 = original *Ecologia* transect 3, CT4 = original *Ecologia* transect 4, RP = Rom Pad, SL = Shiploader, SP = Sediment Pond and D1 = Dolphin 1 (see Figure 1).

Site	*Position (GDA94, zone 51K)*		*Parameters recorded wq=water quality sed=sediment*	*Status*
	Easting	*Northing*		
REF-10	*563331*	*8221195*	*wq, sed*	*Reference Site*
REF-50	*563306*	*8221166*	*wq, sed*	*Reference Site*
REF-100	*563270*	*8221115*	*wq, sed*	*Reference Site*
REF-200	*563205*	*8221056*	*wq, sed*	*Reference Site*
REF-300	*563136*	*8220986*	*wq, sed, coral*	*Reference Site*
REF-300E	*563168*	*8220951*	*wq, sed, coral*	*Reference Site*
REF-300W	*563100*	*8221021*	*wq, sed, coral*	*Reference Site*
TB-10	*563694*	*8220982*	*wq, sed*	*Impact Risk Site*
TB-50	*563671*	*8220949*	*wq, sed*	*Impact Risk Site*
TB-100	*563555*	*8220912*	*wq, sed*	*Impact Risk Site*
TB-200	*563510*	*8220845*	*wq, sed*	*Impact Risk Site*
CT2-10	*563868*	*8220602*	*wq, sed*	*Impact Risk Site*
CT2-50	*563836*	*8220565*	*wq, sed*	*Impact Risk Site*
CT2-100	*563800*	*822535*	*wq, sed*	*Impact Risk Site*
CT2-200	*563723*	*8220479*	*wq, sed*	*Impact Risk Site*
CT3-10	*564332*	*8220319*	*wq, sed*	*Impact Risk Site*
CT3-50	*564309*	*8220287*	*wq, sed*	*Impact Risk Site*
CT3-100	*564270*	*8220240*	*wq, sed*	*Impact Risk Site*
CT3-200	*564213*	*8220174*	*wq, sed, coral*	*Impact Risk Site*
CT3-200E	*564251*	*8220144*	*wq, sed, coral*	*Impact Risk Site*
CT3-200W	*564173*	*8220202*	*wq, sed, coral*	*Impact Risk Site*
CT4-10	*564835*	*8220015*	*wq, sed*	*Impact Risk Site*
CT4-50	*564805*	*8219965*	*wq, sed*	*Impact Risk Site*

Site	Position (GDA94, zone 51K)		Parameters recorded wq=water quality sed=sediment	Status
	Easting	Northing		
CT4-100	564780	8219900	wq, sed	Impact Risk Site
CT4-200	564736	8219818	wq	Impact Risk Site
RP-10	565055	8219852	wq	Impact Site
RP-50	565034	8219819	wq	Impact Site
RP-100	565008	8219780	wq	Impact Site
RP-100W2	564949	8219884	sed, coral	Impact Site (from Sep 08)
SP-10	565246	8219866	wq, sed	Impact Site
SP-50	565231	8219839	wq, sed	Impact Site
SP-100	565210	8219801	wq	Impact Site
SP-200	565174	8219739	wq	Impact Site
D1-10	565386	8219822	wq	Impact Site
D1-50	565364	8219784	wq	Impact Site
D1-100	565340	8219741	wq	Impact Site
D1-200	565305	8219689	wq	Impact Site
ST3-A	564797	8219934	sed, coral	Impact Site (from Sep 09)
ST3-B	564834	8219906	sed, coral	Impact Site (from Sep 09)
ST3-C	564874	8219885	sed, coral	Impact Site (from Sep 09)

2.3 Coral

Coral monitoring was undertaken at three sites located in a zone of relatively high coral cover and diversity just behind the reef crest. The sites were classified by their distance from the construction area; the three sites ST3, CT3-200 and REF-300 were respectively designated as Impact, Impact Risk, and Reference sites (Figure 1). Each site is comprised of three replicate subsites, 50m apart, to provide an estimate of within-site variation in coral abundance and health.

Two monitoring techniques were employed at each subsite; one to obtain percentage live coral cover and one to obtain detailed information on the fate of individual coral colonies. The first technique involved photographing rectangular 1 x 1.5 m 'quadrats' of the reef substrate. The quadrats were centred on the star picket at each subsite, with their long axes oriented east-west. Quadrats were recorded with four overlapping photographs, each covering approximately 0.8 x 0.6m.

The second technique involved taking close-up photographs of individual colonies. The species selected were a representative cross-section of those present at each site. Ten coral colonies were selected at each subsite, mapped (as distance and direction from the star picket) and photographed at close range with a 150 mm scale bar in the field of view. The same ten colonies are photographed from the same distance and direction in each survey.

Images were analysed using standard methods developed by MScience during earlier coral monitoring programs (MScience 2007). The four quadrat photographs from each subsite were analysed by projecting 25 randomly positioned points onto each image and classifying the substrate beneath each point as either live coral (to genus or family), dead coral, flora, fauna, abiotic (sand and rubble) or 'unknown' (Table 2). Individual coral images were analysed by outlining the colony boundary, projecting a grid of 64 points on the image, and classifying each point within the coral boundary as either live coral, dead coral, bleached coral, algae, sediment, or unknown. The 'unknown' category included unidentifiable points or points falling in shadowed areas and was excluded from subsequent calculations. The categories dead coral, algae and sediment were combined to give a partial mortality value for each colony, which was used in impact assessment as described below.

Table 2. Benthic categories scored in quadrats.

Category	Description
Live Coral	
Acropora	Members of the genus *Acropora*
Faviids	Members of the family Faviidae – a wide range of species with the most common *Goniastrea australiensis*
Pavona	Members of the genus *Pavona* – primarily *P. decussata*
Porites	Members of the genus *Porites*
Turbinaria	members of the genus *Turbinaria* – primarily *T. reniformis* and *T. mesenterina*
Other	all scleractinian coral species not included above – plus Milleporid corals
Non- coral substrate	
Dead Coral	Colonies that retain the 'all-white' appearance of freshly dead coral before being colonised by turf algae. After colonisation by algae the coral is scored as rubble.
Fauna	All benthic fauna other than scleractinians: soft corals, urchins, zoanthids, sponges
Flora	All attached or floating flora: macro-algae, seagrasses, dense turf algae
Abiotic	Rock, rubble, sand, incl. sparse cover of turf algae and fine sediment
Unknown	Items which are either part of the monitoring equipment (rope, stake) or unable to be identified – these are excluded from further analyses

2.3.1 Impact Assessment

The general approach used for impact assessment in coral health monitoring programs is to calculate the change in live coral cover at each site since the baseline survey then compare the calculated values at Impact sites to those of Reference site(s). If, during construction, live coral cover at the Impact site declines significantly more than at the Reference site, then construction is inferred to be affecting coral health and measures should be taken to further assess or mitigate the impact. Impact assessment in this program focuses on the individual colonies, as prior studies have demonstrated that individual colony monitoring is more powerful in detecting impacts than the quadrat technique (Stoddart 2008).

The main parameter of interest in monitoring individual coral colonies is the change in net mortality over time. Net mortality at each site is calculated through a sequence of steps. First, each individual colony is assigned a partial mortality (PM) at each survey period, defined as:

> PM_{ix} = (the number of points scored as dead coral, algae or sediment on colony *i* at survey *x* ÷ the total number of points within the colony *i* boundary at survey *x*)

The partial mortality estimate for a site is the average partial mortality of the colonies scored at that site for that survey, for example at site RP-100 in Survey 2:

$$PM\ (RP\text{-}100_2) = \Sigma\ PM_{i2}/N$$

The gross mortality (GM) at a site is then calculated by subtracting the baseline partial mortality from the observed partial mortality for each colony, for example at site RP-100 in Survey 2:

$$GM\ (RP\text{-}100_2) = \Sigma\ (PM_{i2} - PM_{iB})/N$$

Net mortality (NM) at a site is the average gross mortality at that site during survey *x* less the average gross mortality of Reference site colonies during survey *x*, for example at site RP-100 in Survey 2:

$$NM\ (RP\text{-}100_2) = GM\ (RP\text{-}100_2) - GM\ (REF_2)$$

The proposed criterion for distinguishing a significant impact is a net mortality exceeding 30% at the Impact or Impact Risk site. A net mortality of 30% is slightly higher than would normally be used, however the relatively small sample sizes in this program mean that the probability of type I error (a 'false positive' result) would be excessive at effect sizes below 30%. A value of 30% decline is used as a significant impact based on the precedent of Connell's study examining the level of decline that coral communities may readily recover from (Connell 1997).

3.0 RESULTS

3.1 WATER QUALITY

3.1.1 SEDIMENT PLUME DYNAMICS

Based on the daily plume monitoring descriptions and photographs, the frequency and intensity of sediment plumes appear to have decreased by approximately half since the Stage Three Embankment was built to full height. Small plumes still occur relatively frequently from the sediment pond, depending on the volume and turbidity of the water pumped into the Pond (e.g. Figure 2). Occasional larger and more diffuse plumes were observed along the seawall and at other locations around the island after rainfall and runoff events (e.g. Figure 3). However, background conditions during this monitoring period generally remained calm and clear (e.g. Figure 4).

Figure 2. Small sediment plume from the Stage Three Sediment Pond. Photo taken at 1112, 22nd May 2010.

Figure 3. Sediment plume after heavy rainfall. Photo taken 1038, 18th May 2010.

Figure 4. Calm-water neap tide conditions. Photo taken 0857, 21st May 2010.

3.1.2 Water quality parameters

Figures 5 to 9 depict variation in the median values of the four water quality parameters—TSS, Secchi depth, NTU and light attenuation—measured on the Impact, Impact Risk and Reference transects in this and previous surveys (see Appendix A for raw data).

Total Suspended Solids (TSS)

Median surface TSS at the Impact sites decreased slightly relative to the previous survey period, returning to approximately baseline levels (Figure 5). The maximum TSS value recorded in this survey period was relatively low, at just over 10mg/L. TSS records for each transect and each survey date are presented graphically in Figure 6 and are tabulated in Appendix A. The range of TSS recorded in this survey period was similar to previous periods, falling mostly in the 1 to 5 mg/L range. As in previous surveys, the highest TSS values tend to be recorded during spring tides. However, the distinction between neap and spring tide TSS values in this survey period was less pronounced than in previous surveys.

Secchi depth

Median Secchi depths increased slightly relative to the previous survey (Figure 7), consistent with the reduction in TSS.

Nephelometric Turbidity Units (NTU)

Median surface NTU values recorded on the 10th September were relatively low on the Reference transects but slightly higher on the Impact and Impact Risk transects (Figure 8). This is probably due to residual fine particulates being removed from the Embankment on the very large spring tide (10.48 m range). As in most previous surveys there was relatively little depth variation in Reference site NTU, indicating a well-mixed water column. Impact sites generally had a slightly higher bottom NTU, although the highest reading, 9.7 NTU, was recorded in a highly localised visible surface plume 10 m from the Embankment on the CT4 transect.

Light attenuation

Median light attenuation values recorded on 10th September 2010 were slightly higher than the previous survey (Figure 9), consistent with the variation in NTU.

Figure 5. Variation in median total suspended solids (TSS) in surface water samples from the Reference, Impact risk and Impact transects since the pre-construction baseline (inner sites only, 10 and 50m from the Embankment, see Figure 1 for transect locations). Bars indicate minimum and maximum records recorded in each monitoring period.

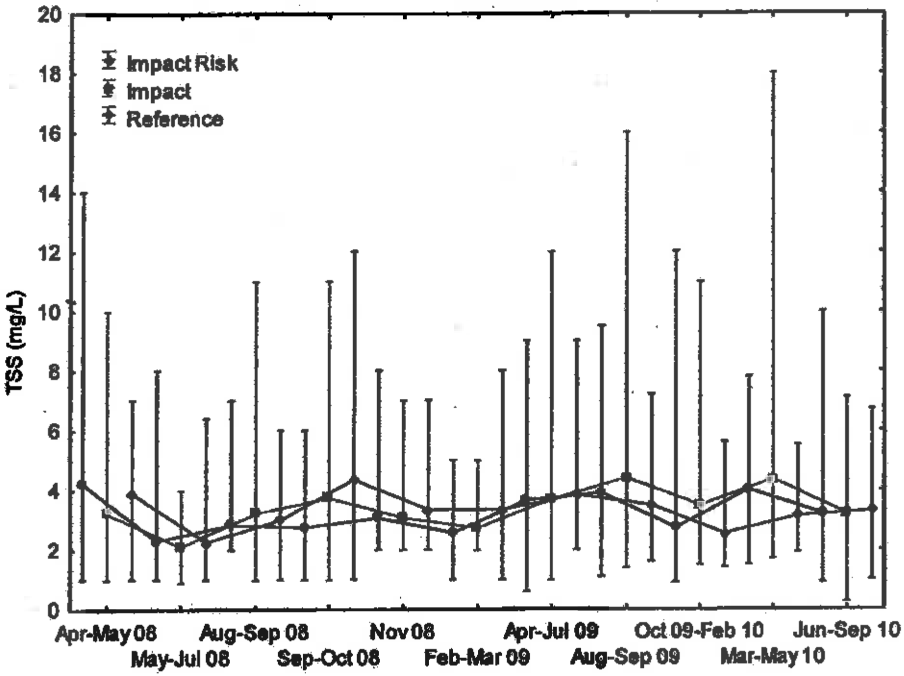


Figure 6. TSS values recorded along the 8 transects during the survey period. Red and blue colouration corresponds to spring and neap tides respectively.

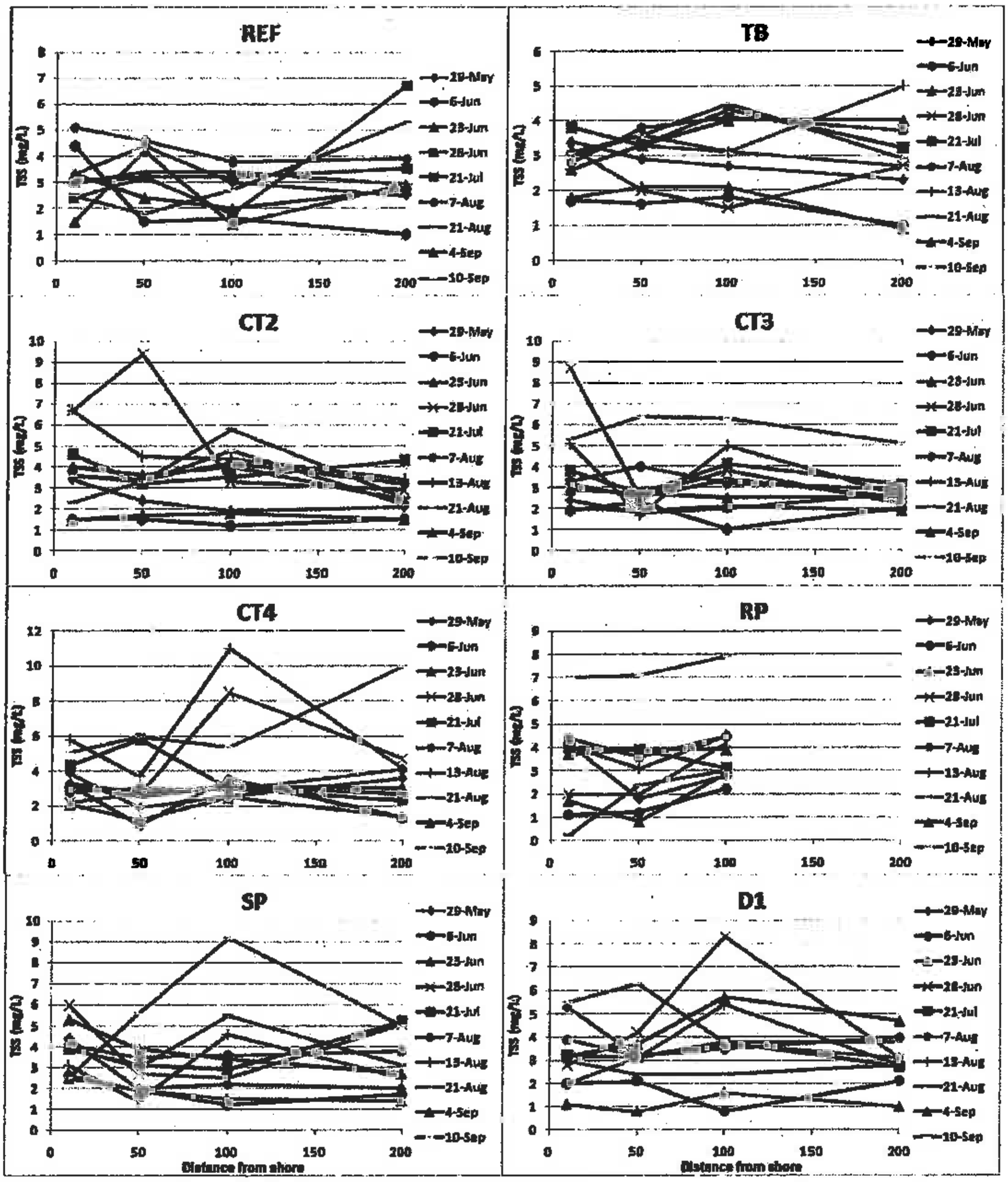


Figure 7. Variation in median Secchi depth on the Reference, Impact Risk and Impact transects since the pre-construction baseline (inner sites only, 10 and 50m from the Embankment). Occasions where the Secchi disk was still visible on the bottom have been omitted from the plot. Bars indicate minimum and maximum records recorded in each monitoring period.

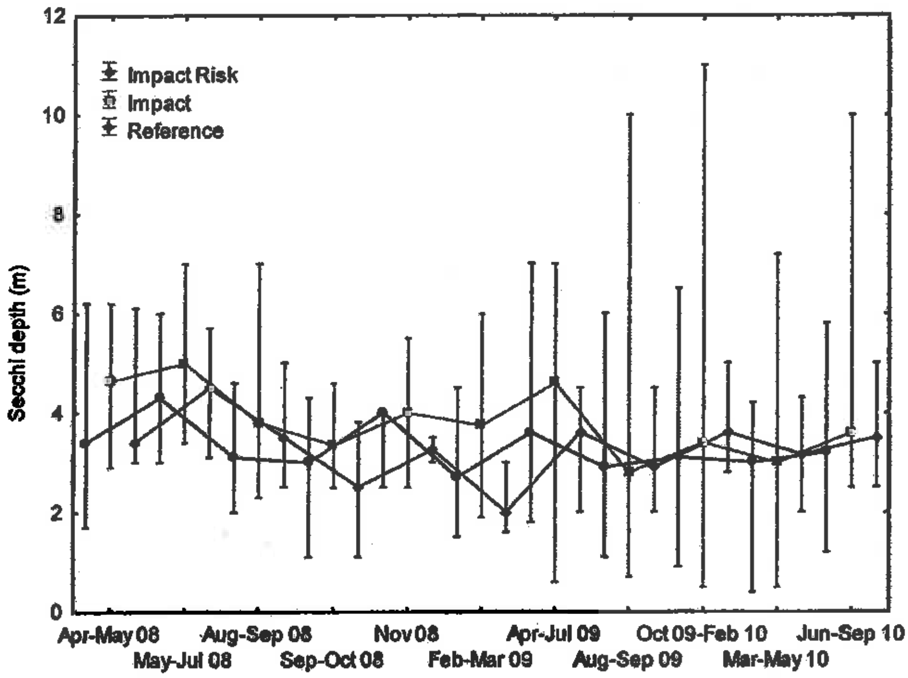


Figure 8. Variation in median surface NTU on the Reference, Impact Risk and Impact transects since the pre-construction baseline (inner sites only, 10 and 50m from the Embankment). Bars indicate minimum and maximum records recorded in each monitoring period. The spike in NTU on the Impact transects in the September 2009 survey was due to the presence of a turbid plume on the SP and RP transects.

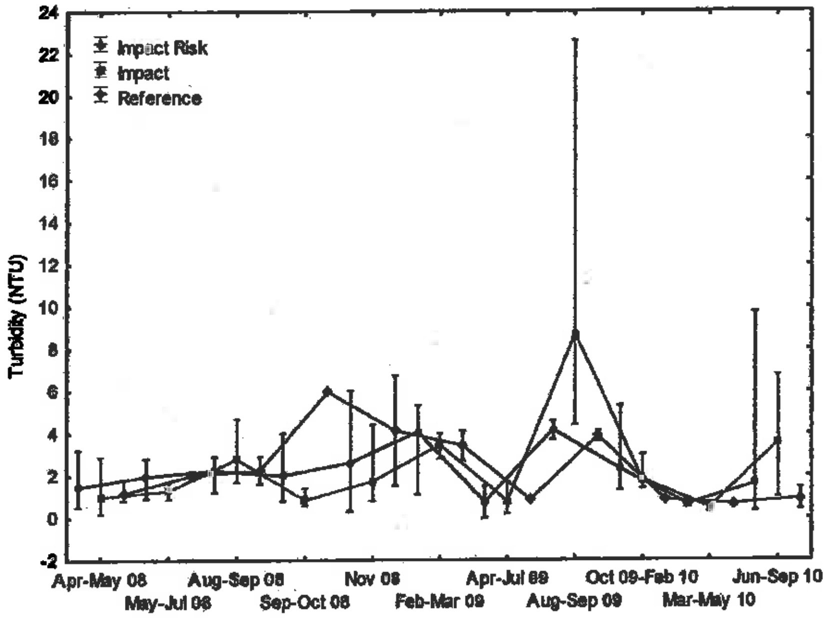
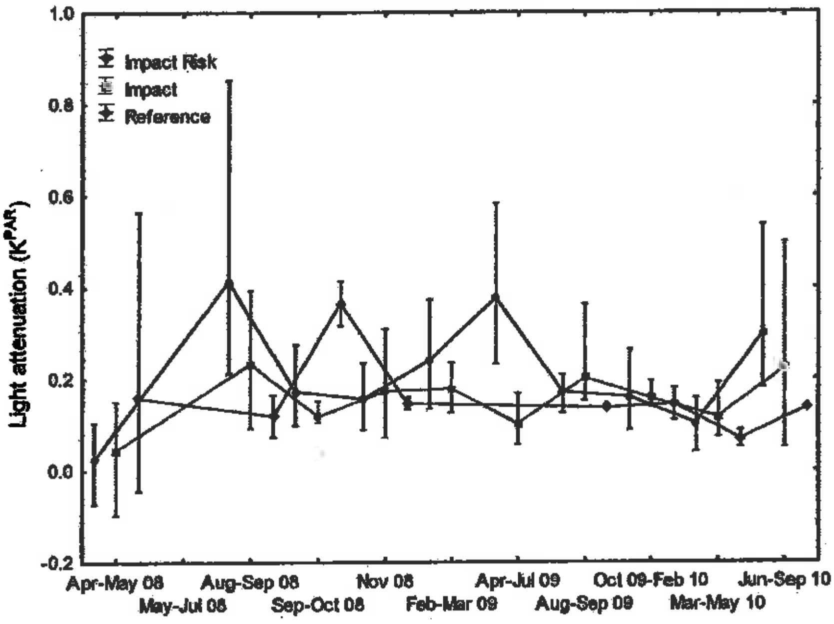


Figure 9. Variation in median light attenuation coefficients recorded on the Reference, Impact Risk and Impact transects since the pre-construction baseline. Bars indicate minimum and maximum records recorded in each monitoring period.



3.2 Sediment quality

Table 3 summarises the September 2010 particle size and total Fe results, and compares them to those of the July 2008 preconstruction baseline. There are no indications of consistently increasing fine sediment or iron content on any transect.

Figure 10 shows the proportion of fine sediment at the Impact (ST3) Impact Risk (CT3-200) and Reference (REF-300) sites. The proportion of fine sediment at the new ST3 Impact site closely matches that of the Reference and Impact Risk sites. The original Impact site, RP-100, was characterised by a much higher proportion of fine sediment than any of the currently monitored sites, possibly because it was closer to shore within the zone of mine-derived sedimentation. Since the last monitoring period the proportion of fine sediment has increased slightly at the Impact Risk site and remained stable at the Reference and Impact sites. Sediment Iron content has remained stable at all sites.

The position of the sediment surface at the reef crest coral monitoring sites is variable over time and shows no consistent trend (Figure 11). Since the previous measurement in February 2010 there has been a marked increase in mean sediment height at the Impact site. This was due to a large change (+50 mm) at subsite ST3-C. As there were no obvious signs of recent deposition at this subsite it is inferred that this 50 mm change is due to localised bioturbation rather than large scale deposition.

Table 3. Summary sediment assay results for September 2010. Percent fines (clay and silt) and total Fe values from the July 2008 preconstruction baseline are provided for comparison.

Site	% clay/silt (<0.075mm) Jul-08	% clay/silt (<0.075mm) Sep-10	% sand (0.075-2mm) Sep-10	% gravel (>2mm) Sep-10	Fe g/kg Jul-08	Fe g/kg Sep-10
REF-10	39	25	71	4	7.13	5.23
REF-50	24	15	83	2	4.73	3.64
REF-100	13	16	80	4	2.48	3.51
REF-200	8	8	85	7	2.29	2.27
REF-300C	13	7	79	14	1.88	1.54
REF-300E	17	18	69	13	5.16 (Sep 08)	3.1
REF-300W	10	12	80	9	1.46	2.02
TB-10	23	5	94	1	14.5	6.5
TB-50	23	7	91	2	9.23	7.76
TB-100	13	11	88	1	1.81	4.94
TB-200	17	19	75	6	2.91	2.44
CT2-10	58	28	71	1	3.8	7.44
CT2-50	19	30	63	8	3.27	4.44
CT2-100	10	17	59	23	2.38	2.83
CT2-200	10	23	68	10	1.71	2.63
CT3-10	73	30	69	1	11.3	10.1
CT3-50	31	27	67	6	5.59	4.18
CT3-100	12	19	74	7	1.99	3.33
CT3-200C	8	13	71	15	1.78	1.89
CT3-200E	14	23	71	6	3.22	2.91
CT3-200W	9	28	61	12	3.44	3.7
CT4-10	52	no sample	no sample	no sample	13.7	no sample
CT4-50	31	21	69	10	5.15	3.29
CT4-100	66	45	46	10	6.3	9.24
RP-100W	35	no sample	no sample	no sample	6.65	no sample
RP-100W1	56	no sample	no sample	no sample	9.54 (Sep 08)	no sample
RP-100W2	83	37	59	3	8.47 (Sep 08)	6.51
SP-10	43	40	60	0	12	8.8
SP-50	64	no sample	no sample	no sample	6.7	no sample
ST3-A	28 (Sep 09)	25	68	7	3.66 (Sep 09)	4.21
ST3-B	23 (Sep 09)	24	68	8	3.19 (Sep 09)	3.66
ST3-C	23 (Sep 09)	28	61	11	2.73 (Sep 09)	3.46

Figure 10. Variation in the mean proportion of fine sediment (<0.075mm) at the Reference (REF-300), Impact Risk (CT3-200) and Impact (ST3) coral monitoring sites since the first baseline survey (April 2008 for Reference and Impact Risk sites, September 2009 for the new ST3 Impact site). The original RP-100 Impact monitoring site was affected by the Embankment subsidence in April 2009 and was replaced by ST3 in September 2009. Bars indicate minimum and maximum records recorded in each monitoring period.

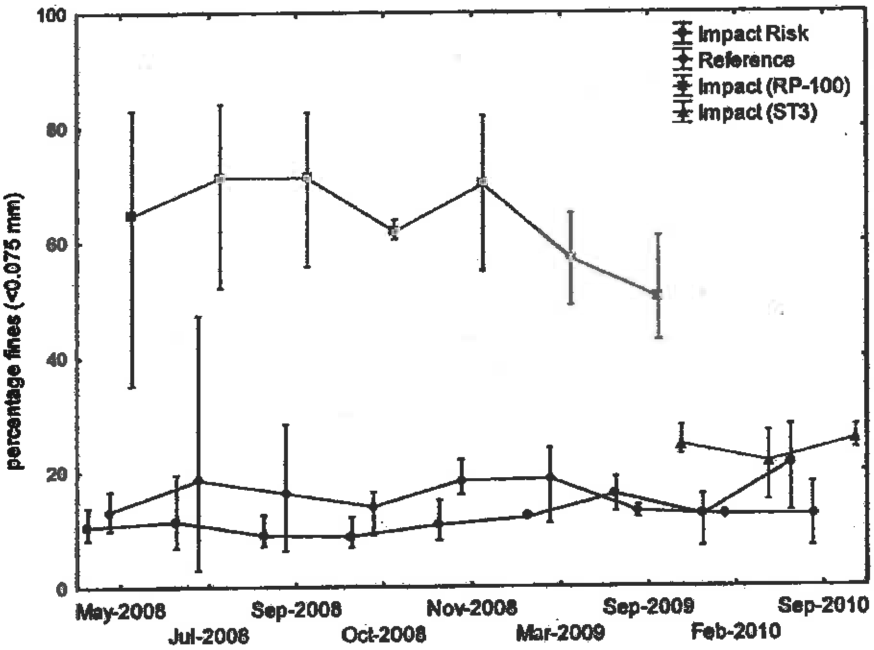
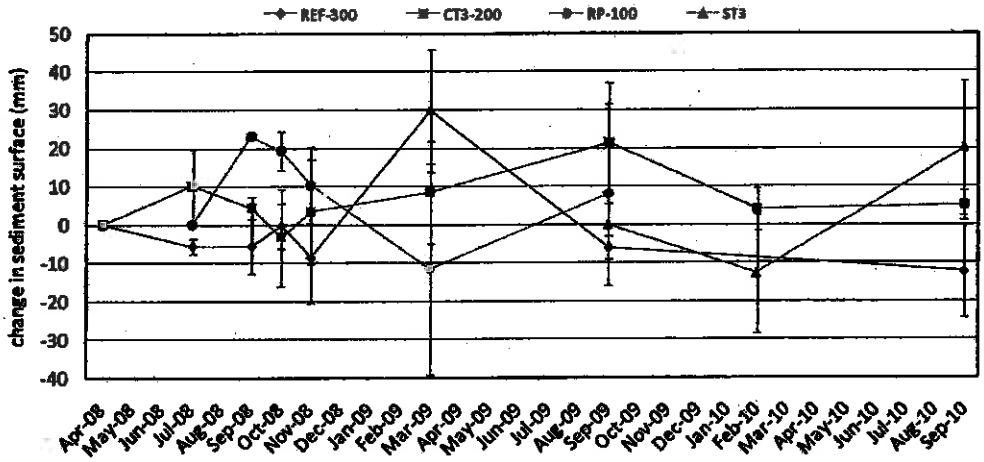


Figure 11. Mean change in the position of the sediment surface at the three coral monitoring sites since the first baseline survey in April 2008. The original impact site, RP-10, was replaced by ST3 in September 2009. Values represent the means of the three subsites at each site, plotted in mm ± standard error of the mean.

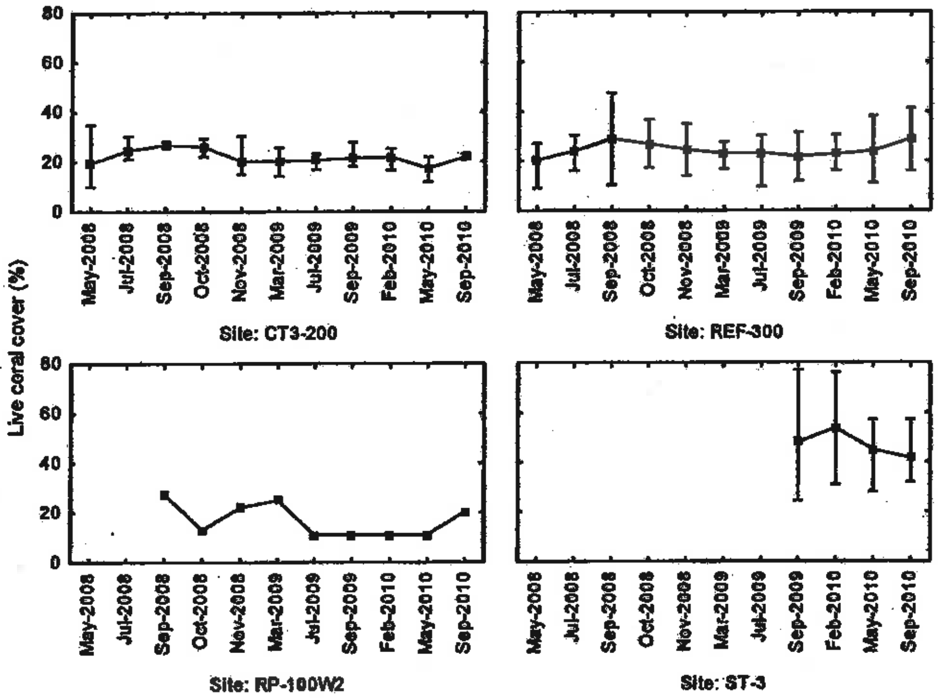


3.3 Coral

3.3.1 Quadrat monitoring

Live coral cover calculated from the quadrat photographs showed only minor variation since the previous (Remotely Operated Vehicle) survey in May 2010. Coral cover differs by no more than 9% from baseline level at any site.

Figure 12. Mean live coral cover in the quadrats at the coral monitoring sites. The y-axis indicates the percentage of the substrate covered by live coral. Data points at sites CT3-200, REF-300 and ST3 are the means of three subsites. Error bars indicate 95% confidence intervals for gross mortality values of individual colonies within sites. RP-100W2 is a single subsite.



3.3.1 Individual colony monitoring

Mean gross coral mortality—the change in partial coral mortality at a site relative to its baseline—increased at the Reference and Impact sites but decreased at the Impact Risk site (Figure 13). Mean gross coral mortality is now 15.2% at ST3, 7.6% at RP-100W2, 2.6% at CT3-200 and 20.5% at REF-300.

Mortality at the Reference site continued to increase steadily, while mortality at the Impact site ST-3 increased relatively sharply (by 6.6%) since the previous survey in May 2010 (). The ongoing mortality at the Reference site () prompted an investigation into potential causes During the September 2010 survey. No obvious or unusual agents of mortality were observed at the site. However, a survey of spot heights along the Reference transect showed the REF-300 monitoring site to be relatively shallow, rising to approximately 0.3m above minesite datum (Figure 14). Landward of the REF-300 site, live coral cover remains relatively high until approximately 200m from shore, then decreases where the reef flat again rises shallower than 0.3m (Figure 15). This apparent relationship between depth and live coral cover provides a potential explanation for the ongoing mortality at REF-300 site, which is explored further in the discussion.

The two most significant mortality events at the Impact site since the previous survey were the loss of 57% of *Merulina* colony ST3-A_04 (Figure 15) and the loss of 52% of *Montipora* colony ST3-B_10 (Figure 16). No evidence of the cause of mortality could be detected in either case. Sediment and turf algae were present on the dead patches of both colonies, but this is normal for any bare substrate and does not necessarily implicate sedimentation or algal overgrowth in the mortality.

Additional slight reductions in live cover were observed on colonies ST3-A_06 (Figure 17) and ST3-C_01 (Figure 18), at the Impact site. These were perhaps more likely due to sedimentation, as in both cases existing fine sediment deposits appear to have enlarged. It is uncertain whether the sediment is mine-derived, as it does not have the typical red-brown colour associated with mine runoff (e.g. MScience 2010a).

Impact assessment

Net mortality—change in the rate of mortality at an Impact site relative to a Reference site—is the preferred parameter for Impact assessment in programs of this type (e.g. Stoddart et al. 2005). Net mortality is defined as average gross mortality at the Impact site (ST3) or Impact Risk site (CT3-200) minus average gross mortality at the Reference site (see Section 2.3.1). Ongoing coral mortality at the original Reference site (Figure 13) suggests that it is no longer appropriate as a Reference. Therefore the CT3-200 site, where the level of coral mortality has been stable throughout the monitoring program, will be used as a Reference site in this and future surveys.

Using CT3-200 as a Reference, net mortality in the September 2010 survey was 11.6% at the Impact site ST3. Net mortality at the informally monitored Impact site RP-100W2 was 4.3%, and net mortality at the original Reference site was 17.9% (note the ST3 and RP-100W2 values were calculated against change at the Reference site since September 2009 and September 2008 respectively, corresponding to the dates they were established).

The net mortality of 11.6% at ST3 remains well below the proposed criterion for distinguishing a significant impact of 30%. However, if mortality at this site continues to rise as it has through 2010, it could approach the trigger criteria. Coral mortality at this site should therefore be closely followed in future surveys. If mortality continues to increase in the next survey, potential causes will be investigated.

Figure 13. Mean gross mortality (change in mortality relative to the baseline) of the monitored coral colonies by site. Positive values indicate an increase in mortality relative to the baseline and negative values indicate a reduction in mortality relative to the baseline. Error bars indicate 95% confidence intervals for gross mortality values of individual colonies within sites.

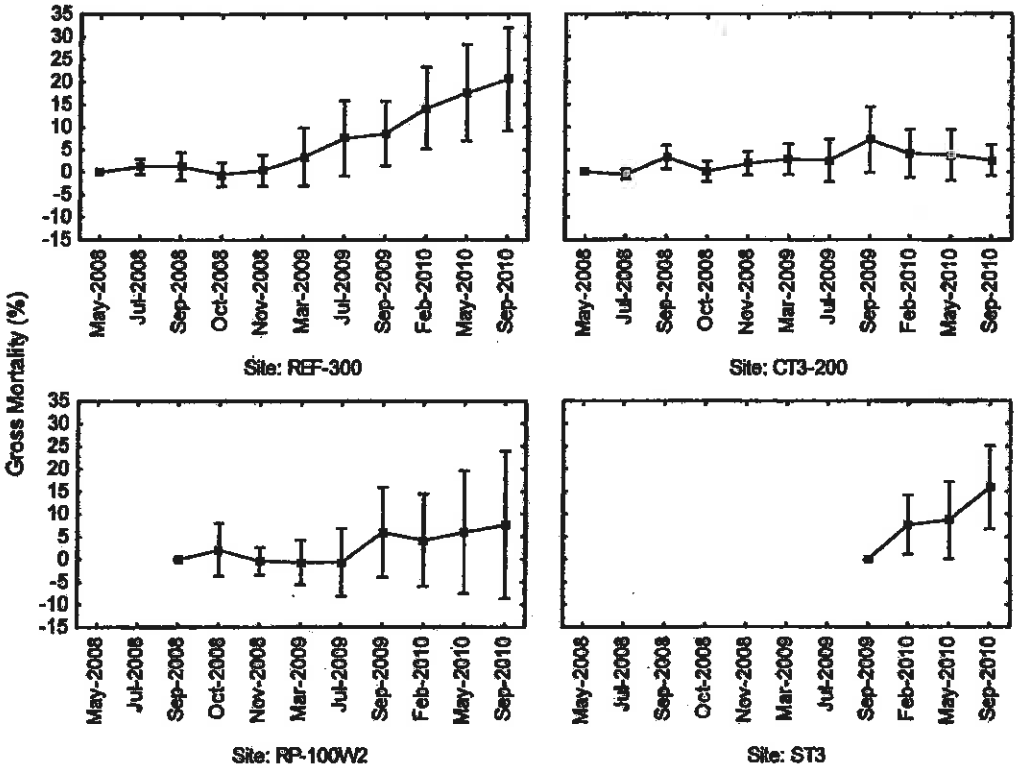


Figure 14. Schematic diagram showing the elevation of the reef flat, relative to the minesite datum, along the Reference (REF, red) and Impact Risk (CT3, blue) transects. Northeast is to the left and southwest to the right. The x-axis indicates distance from shore along the Reference (REF) transect. The CT3 transect has been superimposed from the 100m mark, based on the assumption that the current 'shore' (the toe of the Embankment) is approximately 90m seaward of the original shoreline. Vertical exaggeration is 25 times.

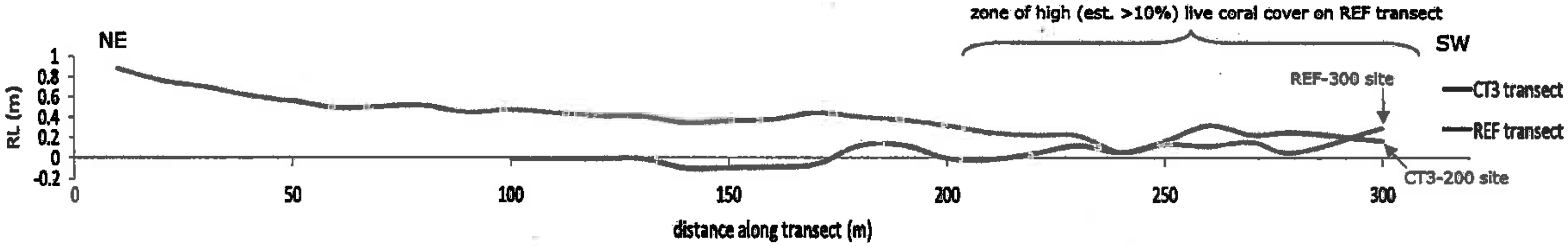


Figure 15. Partial mortality of 57% to *Merulina* colony ST3-A_04 between February 2010 (top) and September 2010 (bottom). The February image is shown here in preference to the image from the previous (May) survey, as the May image was taken from the ROV and is of lower quality.

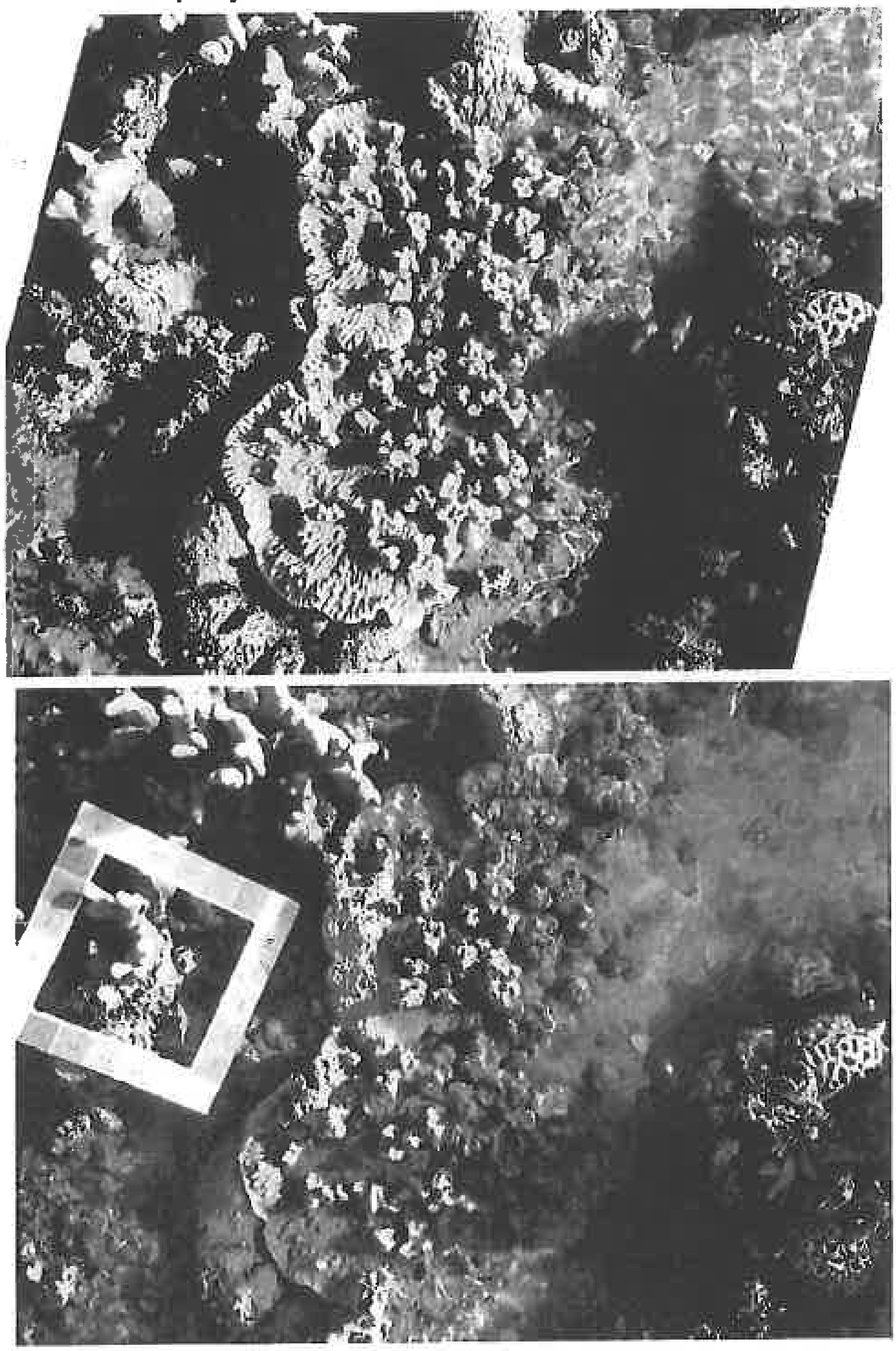


Figure 16. Partial mortality of 52% to *Montipora* colony ST3-B_10 between February 2010 (top) and September 2010 (bottom). The February image is shown here in preference to the image from the previous (May) survey, as the May image was taken from the ROV and is of lower quality.

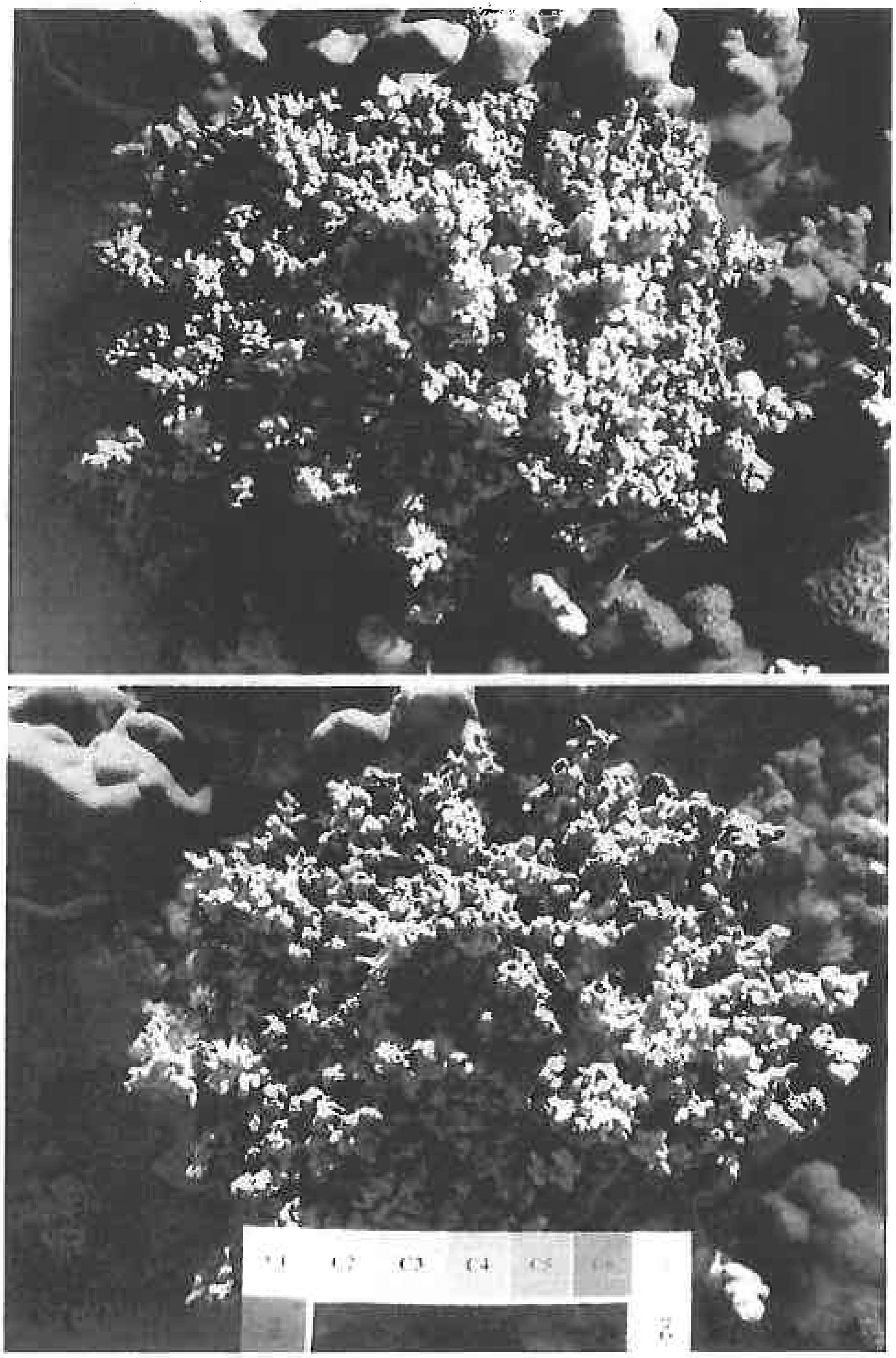
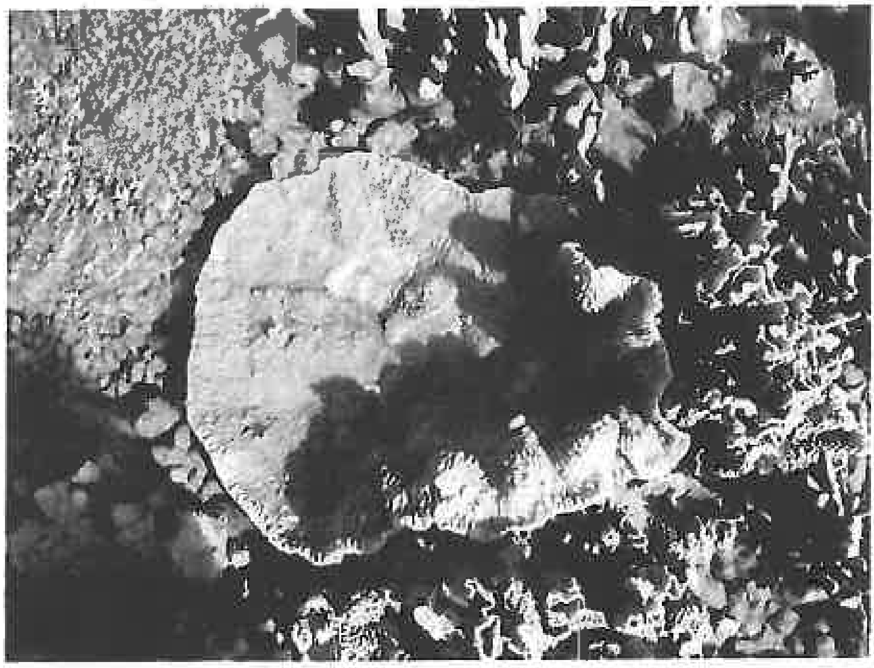
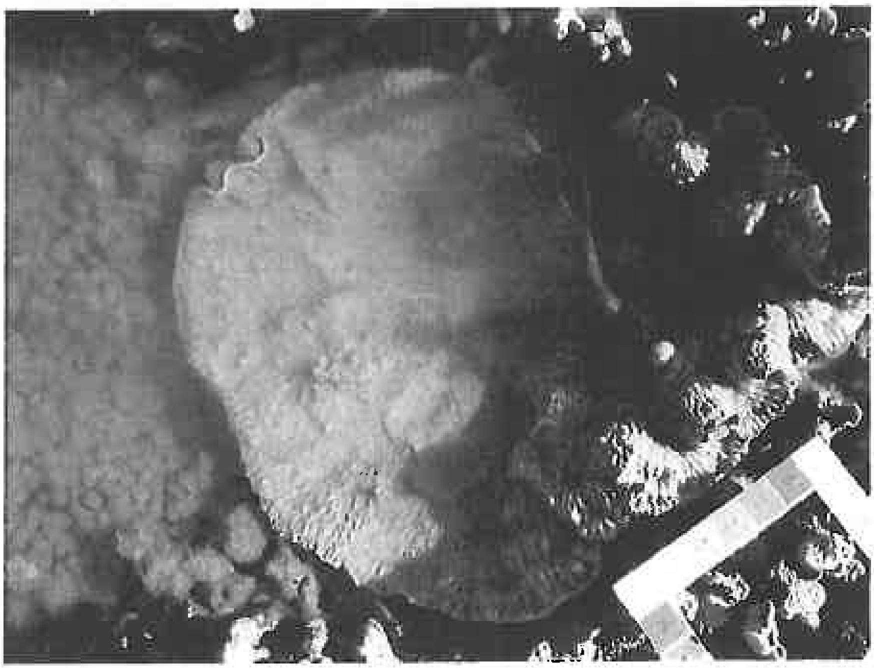


Figure 17. Slight increase in fine sediment deposition on *Goniopora* colony ST3A_06 between February (top) and September (bottom) 2010. The tissue below the sediment is presumed dead.

Figure 18. Slight increase in fine sediment deposition on *Merulina* colony ST3C_01 between February (top) and September (bottom) 2010. The tissue below the sediment is presumed dead. Note some growth has occurred around the margin of the colony, but probably not enough to offset the loss due to sedimentation.





4.0 DISCUSSION

4.1 WATER QUALITY

There was an apparent reduction in the frequency and intensity of sediment plumes observed in this survey period. This may be largely because the construction zone was less frequently inundated by the tide as the Embankment was built higher. However the limited amount of rainfall during this (dry season) survey has probably also assisted by minimising runoff plumes.

Sediment plumes occurring during this survey period were generally associated either with leakage through the walls of the Sediment Pond or runoff from the island after periods of heavy rainfall. As in previous surveys, plumes generally remained close to the Embankment and rarely reached even the closest of the coral Impact monitoring subsites, approximately 70 m from the embankment.

Water quality measurements including TSS and Secchi depth have remained relatively constant over the past 12 months, fluctuating around the baseline level. Light attenuation and NTU have risen slightly since the previous survey, possibly because the measurements in this survey were taken during a large spring tide.

4.2 SEDIMENT QUALITY

There has been little change in the measured sediment quality parameters at most sites. The proportion of fine sediment at the Impact Risk site CT3-200 was slightly elevated (approximately 10%) but this did not appear to cause any coral mortality at the site. At other sites the proportion of fines (silt and clay) is no higher than baseline levels, even at the sites closest to the Embankment. The proportion of fines has actually decreased at several of these sites, including CT2-10, CT3-10 and CT4-10. CT4-10 was affected by the Embankment subsidence, which removed fines and left coarse material behind. The reason for the change at CT2-10 and CT3-10 is not known.

4.3 CORAL

Ongoing coral mortality at the original Reference site is the main characteristic of the coral monitoring program to date. Mortality is not suspected to be mine-related because the site is distant from the construction and sediment plumes. An alternative hypothesis developed during the September field survey is that the decline in coral health at REF-300 is natural and is occurring simply because REF-300 has grown to a later stage of reef development than the other sites, and is approaching the maximum elevation at which corals can survive in this environment. Measurements taken during the September 2010 survey indicate that the REF-300 site is at least 10 cm higher than any other coral monitoring site (note ST3 and RP-100W2 were not measured directly but are known to be lower than CT3-200 from field observations). The greater height of the Reference site means it spends more time exposed to the air than the other sites, resulting in greater desiccation, ultraviolet radiation and heat stress, and also the potential risk of freshwater inundation if heavy rain occurs on a spring low tide. Although the difference in height between REF-300 and CT3-200 is only 10 cm, this is enough to cause several hours additional exposure at REF-300 than CT3-200 over the course of a year.

CT3-200 will be a more appropriate Reference site for future coral monitoring, although REF-300 remains a suitable Reference site for water and sediment quality.

The Impact site, ST3, has also undergone some recent coral mortality, some of which appears to result from sedimentation. It is not clear whether the sedimentation is natural or derived from the minesite. Further investigation will be required if mortality continues to increase in the next survey.

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APPENDIX A

Water Quality Data

*CODE = comprising descriptor (e.g. REF = reference transect) and distance from shore in metres, TSS = total suspended solids in mg/L, SECCHI= maximum depth at which Secchi disk was visible in m (BOTTOM?: 'B' indicates that the disk could be seen at the seafloor), NTU = turbidity in nephelometric turbidity units, ATTEN. = light attenuation coefficient of photosynthetically active radiation (PAR).

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
29/5/10	REF 10	REF	10	0.5	S	14:40	spring	ebb	REF	3.3	4	B		
29/5/10	REF 50	REF	50	0.5	S	14:42	spring	ebb	REF	4.4	4			
29/5/10	REF 100	REF	100	0.5	S	14:44	spring	ebb	REF	3	4			
29/5/10	REF 200	REF	200	0.5	S	14:46	spring	ebb	REF	2.5	4.2			
29/5/10	TB 10	TB	10	0.5	S	14:54	spring	ebb	INT	3.4	2.7	B		
29/5/10	TB 50	TB	50	0.5	S	14:52	spring	ebb	INT	2.9	3.3	B		
29/5/10	TB 100	TB	100	0.5	S	14:50	spring	ebb	INT	2.7	4	B		
29/5/10	TB 200	TB	200	0.5	S	14:48	spring	ebb	INT	2.3	4.2			
29/5/10	CT2 10	CT2	10	0.5	S	14:56	spring	ebb	INT	3.4	3.8			
29/5/10	CT2 50	CT2	50	0.5	S	14:58	spring	ebb	INT	2.4	4			
29/5/10	CT2 100	CT2	100	0.5	S	15:00	spring	ebb	INT	1.9	3.8			
29/5/10	CT2 200	CT2	200	0.5	S	15:02	spring	ebb	INT	2.1	4.2			
29/5/10	CT3 10	CT3	10	0.5	S	15:10	spring	ebb	INT	2.4	4			
29/5/10	CT3 50	CT3	50	0.5	S	15:08	spring	ebb	INT	1.8	4.5			
29/5/10	CT3 100	CT3	100	0.5	S	15:06	spring	ebb	INT	2	5.2			
29/5/10	CT3 200	CT3	200	0.5	S	15:04	spring	ebb	INT	2.7	4.7			
29/5/10	CT4 10	CT4	10	0.5	S	15:12	spring	ebb	INT	3.9	2.3	B		
29/5/10	CT4 50	CT4	50	0.5	S	15:14	spring	ebb	INT	1.9	4	B		
29/5/10	CT4 100	CT4	100	0.5	S	15:16	spring	ebb	INT	2.6	4.5	B		

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
29/5/10	CT4 200	CT4	200	0.5	S	15:18	spring	ebb	INT	3.6	5.1			
29/5/10	RP 20	RP	20	0.5	S	15:24	spring	ebb	IMP	4.2	4			
29/5/10	RP 50	RP	50	0.5	S	15:22	spring	ebb	IMP	1.8	5.1	B		
29/5/10	RP 100	RP	100	0.5	S	15:20	spring	ebb	IMP	2.8	5.5			
29/5/10	SP 10	SP	10	0.5	S	15:28	spring	ebb	IMP	4.4	4.1			
29/5/10	SP 50	SP	50	0.5	S	15:30	spring	ebb	IMP	2	5.1			
29/5/10	SP 100	SP	100	0.5	S	15:32	spring	ebb	IMP	2.2	5.1			
29/5/10	SP 200	SP	200	0.5	S	15:34	spring	ebb	IMP	2	6.1			
29/5/10	D1 10	D1	10	0.5	S	15:42	spring	ebb	IMP	5.3	3.1			
29/5/10	D1 50	D1	50	0.5	S	15:40	spring	ebb	IMP	3.2	3.1			
29/5/10	D1 100	D1	100	0.5	S	15:38	spring	ebb	IMP	3.7	6			
29/5/10	D1 200	D1	200	0.5	S	15:36	spring	ebb	IMP	3.1	5.1			
6/6/10	REF 10	REF	10	0.5	S	14:20	neap	flood	REF	4.4	3.5			
6/6/10	REF 50	REF	50	0.5	S	14:22	neap	flood	REF	1.5	4			
6/6/10	REF 100	REF	100	0.5	S	14:24	neap	flood	REF	1.6	4			
6/6/10	REF 200	REF	200	0.5	S	14:26	neap	flood	REF	1	4.5			
6/6/10	TB 10	TB	10	0.5	S	14:36	neap	flood	INT	1.7	2.5			
6/6/10	TB 50	TB	50	0.5	S	14:34	neap	flood	INT	1.6	2.5			
6/6/10	TB 100	TB	100	0.5	S	14:32	neap	flood	INT	1.8	2.5			
6/6/10	TB 200	TB	200	0.5	S	14:30	neap	flood	INT	1	3.5			
6/6/10	CT2 10	CT2	10	0.5	S	14:38	neap	flood	INT	1.5	2.5			
6/6/10	CT2 50	CT2	50	0.5	S	14:40	neap	flood	INT	1.5	3.5			

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
6/6/10	CT2 100	CT2	100	0.5	S	14:42	neap	flood	INT	1.2	3.5			
6/6/10	CT2 200	CT2	200	0.5	S	14:44	neap	flood	INT	1.5	5.8			
6/6/10	CT3 10	CT3	10	0.5	S	14:52	neap	flood	INT	1.9	2.5			
6/6/10	CT3 50	CT3	50	0.5	S	14:50	neap	flood	INT	2.3	3.5			
6/6/10	CT3 100	CT3	100	0.5	S	14:48	neap	flood	INT	1	5			
6/6/10	CT3 200	CT3	200	0.5	S	14:46	neap	flood	INT	2	10			
6/6/10	CT4 10	CT4	10	0.5	S	14:54	neap	flood	INT	3.2	2.3			
6/6/10	CT4 50	CT4	50	0.5	S	14:56	neap	flood	INT	0.9	4.5			
6/6/10	CT4 100	CT4	100	0.5	S	14:58	neap	flood	INT	3.5	4.5			
6/6/10	CT4 200	CT4	200	0.5	S	15:00	neap	flood	INT	1.3	10			
6/6/10	RP 20	RP	20	0.5	S	15:06	neap	flood	IMP	1.1	4.5			
6/6/10	RP 50	RP	50	0.5	S	15:04	neap	flood	IMP	1.2	5			
6/6/10	RP 100	RP	100	0.5	S	15:02	neap	flood	IMP	2.2	10			
6/6/10	SP 10	SP	10	0.5	S	15:10	neap	flood	IMP	2.6	3.5			
6/6/10	SP 50	SP	50	0.5	S	15:12	neap	flood	IMP	1.9	5			
6/6/10	SP 100	SP	100	0.5	S	15:14	neap	flood	IMP	1.2	10			
6/6/10	SP 200	SP	200	0.5	S	15:16	neap	flood	IMP	1.7	10			
6/6/10	D1 10	D1	10	0.5	S	15:24	neap	flood	IMP	2	4			
6/6/10	D1 50	D1	50	0.5	S	15:22	neap	flood	IMP	2.1	10			
6/6/10	D1 100	D1	100	0.5	S	15:20	neap	flood	IMP	0.8	10			
6/6/10	D1 200	D1	200	0.5	S	15:18	neap	flood	IMP	2.1	10			
23/6/10	REF 10	REF	10	0.5	S	8:28	spring	ebb	REF	1.5	2.3	B		

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
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23/6/10	REF 200	REF	200	0.5	S	8:34	spring	ebb	REF	2.9	6.6			
23/6/10	TB 10	TB	10	0.5	S	8:43	spring	ebb	INT	1.8	3.2	B		
23/6/10	TB 50	TB	50	0.5	S	8:41	spring	ebb	INT	2.1	4.2	B		
23/6/10	TB 100	TB	100	0.5	S	8:39	spring	ebb	INT	2.1	5.1	B		
23/6/10	TB 200	TB	200	0.5	S	8:36	spring	ebb	INT	0.9	6	B		
23/6/10	CT2 10	CT2	10	0.5	S	8:46	spring	ebb	INT	1.5	4.7	B		
23/6/10	CT2 50	CT2	50	0.5	S	8:45	spring	ebb	INT	1.7	5.5			
23/6/10	CT2 100	CT2	100	0.5	S	8:47	spring	ebb	INT	1.8	5.5			
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23/6/10	CT3 10	CT3	10	0.5	S	8:52	spring	ebb	INT	2	5.2	B		
23/6/10	CT3 50	CT3	50	0.5	S	8:54	spring	ebb	INT	1.9	5			
23/6/10	CT3 100	CT3	100	0.5	S	8:56	spring	ebb	INT	2.1	6	B		
23/6/10	CT3 200	CT3	200	0.5	S	8:59	spring	ebb	INT	1.9	6.5	B		
23/6/10	CT4 10	CT4	10	0.5	S	9:02	spring	ebb	INT	2.1	4	B		
23/6/10	CT4 50	CT4	50	0.5	S	9:04	spring	ebb	INT	1.2	5.8			
23/6/10	CT4 100	CT4	100	0.5	S	9:06	spring	ebb	INT	2.5	6.5	B		
23/6/10	CT4 200	CT4	200	0.5	S	9:08	spring	ebb	INT	1.4	7			
23/6/10	RP 20	RP	20	0.5	S	9:12	spring	ebb	IMP	1.7	4	B		
23/6/10	RP 50	RP	50	0.5	S	9:14	spring	ebb	IMP	0.8	6.2	B		
23/6/10	RP 100	RP	100	0.5	S	9:17	spring	ebb	IMP	2.9	7.5			

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
23/6/10	SP 10	SP	10	0.5	S	9:20	spring	ebb	IMP	2.5	5.5			
23/6/10	SP 50	SP	50	0.5	S	9:22	spring	ebb	IMP	1.9	6.2			
23/6/10	SP 100	SP	100	0.5	S	9:24	spring	ebb	IMP	1.5	6.5			
23/6/10	SP 200	SP	200	0.5	S	9:27	spring	ebb	IMP	1.4	7			
23/6/10	D1 10	D1	10	0.5	S	9:31	spring	ebb	IMP	1.1	5.7			
23/6/10	D1 50	D1	50	0.5	S	9:33	spring	ebb	IMP	0.8	6.6			
23/6/10	D1 100	D1	100	0.5	S	9:36	spring	ebb	IMP	1.6	6.8			
23/6/10	D1 200	D1	200	0.5	S	9:39	spring	ebb	IMP	1	7.3			
28/6/10	REF 10	REF	10	0.5	S	15:15	spring	ebb	REF	2.4	4.5			
28/6/10	REF 50	REF	50	0.5	S	15:13	spring	ebb	REF	3.2	5			
28/6/10	REF 100	REF	100	0.5	S	15:11	spring	ebb	REF	1.8	5			
28/6/10	REF 200	REF	200	0.5	S	15:09	spring	ebb	REF	6.7	5			
28/6/10	TB 10	TB	10	0.5	S	14:59	spring	ebb	INT	3.2	2.9	B		
28/6/10	TB 50	TB	50	0.5	S	15:01	spring	ebb	INT	2	3.5			
28/6/10	TB 100	TB	100	0.5	S	15:03	spring	ebb	INT	1.5	4.2			
28/6/10	TB 200	TB	200	0.5	S	15:06	spring	ebb	INT	2.7	4			
28/6/10	CT2 10	CT2	10	0.5	S	14:56	spring	ebb	INT	6.7	3.9	B		
28/6/10	CT2 50	CT2	50	0.5	S	14:54	spring	ebb	INT	9.4	4.3			
28/6/10	CT2 100	CT2	100	0.5	S	14:52	spring	ebb	INT	3.3	4.5			
28/6/10	CT2 200	CT2	200	0.5	S	14:49	spring	ebb	INT	2.9	4.7			
28/6/10	CT3 10	CT3	10	0.5	S	14:38	spring	ebb	INT	8.7	3.4	B		
28/6/10	CT3 50	CT3	50	0.5	S	14:40	spring	ebb	INT	2.6	4.8			

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
28/6/10	CT3 100	CT3	100	0.5	S	14:43	spring	ebb	INT	3.8	5.1			
28/6/10	CT3 200	CT3	200	0.5	S	14:46	spring	ebb	INT	2.2	4.2			
28/6/10	CT4 10	CT4	10	0.5	S	14:35	spring	ebb	INT	2.2	4.3			
28/6/10	CT4 50	CT4	50	0.5	S	14:33	spring	ebb	INT	2.7	5			
28/6/10	CT4 100	CT4	100	0.5	S	14:31	spring	ebb	INT	8.5	5			
28/6/10	CT4 200	CT4	200	0.5	S	14:29	spring	ebb	INT	4.7	4.3			
28/6/10	RP 20	RP	20	0.5	S	14:21	spring	ebb	IMP	2	3.2	B		
28/6/10	RP 50	RP	50	0.5	S	14:23	spring	ebb	IMP	2	4.5			
28/6/10	RP 100	RP	100	0.5	S	14:26	spring	ebb	IMP	4.2	5.1			
28/6/10	SP 10	SP	10	0.5	S	14:19	spring	ebb	IMP	6	3.2			
28/6/10	SP 50	SP	50	0.5	S	14:16	spring	ebb	IMP	2.7	3.4			
28/6/10	SP 100	SP	100	0.5	S	14:14	spring	ebb	IMP	2.5	5.3			
28/6/10	SP 200	SP	200	0.5	S	14:11	spring	ebb	IMP	5.1	5.2			
28/6/10	D1 10	D1	10	0.5	S	14:00	spring	ebb	IMP	2.8	4			
28/6/10	D1 50	D1	50	0.5	S	14:03	spring	ebb	IMP	4.2	4.2			
28/6/10	D1 100	D1	100	0.5	S	14:05	spring	ebb	IMP	8.3	4.5			
28/6/10	D1 200	D1	200	0.5	S	14:08	spring	ebb	IMP	3.1	4.5			
21/7/10	REF 10	REF	10	0.5	S	8:35	neap	ebb	REF	3	3			
21/7/10	REF 50	REF	50	0.5	S	8:37	neap	ebb	REF	3.2	2.5			
21/7/10	REF 100	REF	100	0.5	S	8:39	neap	ebb	REF	3.2	2.8			
21/7/10	REF 200	REF	200	0.5	S	8:41	neap	ebb	REF	3.5	3.1			
21/7/10	TB 10	TB	10	0.5	S	8:50	neap	ebb	INT	3.8	2.3			

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
21/7/10	TB 50	TB	50	0.5	S	8:48	neap	ebb	INT	3.3	3.4			
21/7/10	TB 100	TB	100	0.5	S	8:46	neap	ebb	INT	4.3	3.3			
21/7/10	TB 200	TB	200	0.5	S	8:44	neap	ebb	INT	3.2	3.4			
21/7/10	CT2 10	CT2	10	0.5	S	8:52	neap	ebb	INT	4.6	2.6			
21/7/10	CT2 50	CT2	50	0.5	S	8:54	neap	ebb	INT	3.2	3			
21/7/10	CT2 100	CT2	100	0.5	S	8:56	neap	ebb	INT	3.5	3.1			
21/7/10	CT2 200	CT2	200	0.5	S	8:59	neap	ebb	INT	4.3	3.3			
21/7/10	CT3 10	CT3	10	0.5	S	9:08	neap	ebb	INT	3.8	3			
21/7/10	CT3 50	CT3	50	0.5	S	9:06	neap	ebb	INT	2.7	3			
21/7/10	CT3 100	CT3	100	0.5	S	9:04	neap	ebb	INT	4.1	3.1			
21/7/10	CT3 200	CT3	200	0.5	S	9:02	neap	ebb	INT	3.1	3.1			
21/7/10	CT4 10	CT4	10	0.5	S	9:10	neap	ebb	INT	4.3	2.2			
21/7/10	CT4 50	CT4	50	0.5	S	9:12	neap	ebb	INT	5.8	2.7			
21/7/10	CT4 100	CT4	100	0.5	S	9:14	neap	ebb	INT	3	3.3			
21/7/10	CT4 200	CT4	200	0.5	S	9:16	neap	ebb	INT	2.3	2.8			
21/7/10	RP 20	RP	20	0.5	S	9:22	neap	ebb	IMP	4	1.6			
21/7/10	RP 50	RP	50	0.5	S	9:21	neap	ebb	IMP	3.9	3			
21/7/10	RP 100	RP	100	0.5	S	9:19	neap	ebb	IMP	3.1	3.1			
21/7/10	SP 10	SP	10	0.5	S	9:25	neap	ebb	IMP	3.9	3			
21/7/10	SP 50	SP	50	0.5	S	9:27	neap	ebb	IMP	3.1	3.1			
21/7/10	SP 100	SP	100	0.5	S	9:29	neap	ebb	IMP	2.9	2.9			
21/7/10	SP 200	SP	200	0.5	S	9:31	neap	ebb	IMP	5.2	3.6			

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
21/7/10	D1 10	D1	10	0.5	S	9:39	neap	ebb	IMP	3.2	3.1			
21/7/10	D1 50	D1	50	0.5	S	9:37	neap	ebb	IMP	3.1	3.6			
21/7/10	D1 100	D1	100	0.5	S	9:35	neap	ebb	IMP	3.8	3.5			
21/7/10	D1 200	D1	200	0.5	S	9:33	neap	ebb	IMP	2.7	2.9			
7/8/10	REF 10	REF	10	0.5	S	12:34	spring	ebb	REF	5.1	3			
7/8/10	REF 50	REF	50	0.5	S	12:36	spring	ebb	REF	4.6	3.1			
7/8/10	REF 100	REF	100	0.5	S	12:38	spring	ebb	REF	3.8	3.2			
7/8/10	REF 200	REF	200	0.5	S	12:40	spring	ebb	REF	3.9	5.3			
7/8/10	TB 10	TB	10	0.5	S	12:50	spring	ebb	INT	2.8	1.9			
7/8/10	TB 50	TB	50	0.5	S	12:48	spring	ebb	INT	3.8	2.9			
7/8/10	TB 100	TB	100	0.5	S	12:46	spring	ebb	INT	4.1	3.8			
7/8/10	TB 200	TB	200	0.5	S	12:43	spring	ebb	INT	3.7	5			
7/8/10	CT2 10	CT2	10	0.5	S	12:52	spring	ebb	INT	3.6	3.4			
7/8/10	CT2 50	CT2	50	0.5	S	12:54	spring	ebb	INT	3.4	3.3			
7/8/10	CT2 100	CT2	100	0.5	S	12:56	spring	ebb	INT	4.2	3.6			
7/8/10	CT2 200	CT2	200	0.5	S	12:58	spring	ebb	INT	3.2	5			
7/8/10	CT3 10	CT3	10	0.5	S	13:07	spring	ebb	INT	3.3	3.4			
7/8/10	CT3 50	CT3	50	0.5	S	13:05	spring	ebb	INT	4	3.1			
7/8/10	CT3 100	CT3	100	0.5	S	13:03	spring	ebb	INT	3.2	6			
7/8/10	CT3 200	CT3	200	0.5	S	13:01	spring	ebb	INT	2.9	5.5			
7/8/10	CT4 10	CT4	10	0.5	S	13:10	spring	ebb	INT	2.8	2.9			
7/8/10	CT4 50	CT4	50	0.5	S	13:12	spring	ebb	INT	3	3.4			

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
7/8/10	CT4 100	CT4	100	0.5	S	13:15	spring	ebb	INT	2.9	4.7			
7/8/10	CT4 200	CT4	200	0.5	S	13:17	spring	ebb	INT	4.1	5.2			
7/8/10	RP 20	RP	20	0.5	S	13:24	spring	ebb	IMP	4.4	3.2			
7/8/10	RP 50	RP	50	0.5	S	13:22	spring	ebb	IMP	3.6	5.4			
7/8/10	RP 100	RP	100	0.5	S	13:20	spring	ebb	IMP	4.5	5.6			
7/8/10	SP 10	SP	10	0.5	S	13:26	spring	ebb	IMP	4.1	2.9			
7/8/10	SP 50	SP	50	0.5	S	13:28	spring	ebb	IMP	3.5	4.7			
7/8/10	SP 100	SP	100	0.5	S	13:30	spring	ebb	IMP	3.6	4.5			
7/8/10	SP 200	SP	200	0.5	S	13:32	spring	ebb	IMP	3.8	4.9			
7/8/10	D1 10	D1	10	0.5	S	13:40	spring	ebb	IMP	3.9	2.8			
7/8/10	D1 50	D1	50	0.5	S	13:38	spring	ebb	IMP	3.2	4.5			
7/8/10	D1 100	D1	100	0.5	S	13:36	spring	ebb	IMP	3.5	5.2			
7/8/10	D1 200	D1	200	0.5	S	13:34	spring	ebb	IMP	4	4.3			
13/8/10	TB 10	TB	10	0.5	S	16:03	spring	ebb	INT	2.6	2			
13/8/10	TB 50	TB	50	0.5	S	16:05	spring	ebb	INT	3.3	2.5			
13/8/10	TB 100	TB	100	0.5	S	16:07	spring	ebb	INT	3.1	2.5			
13/8/10	TB 200	TB	200	0.5	S	16:09	spring	ebb	INT	5	2.5			
13/8/10	CT2 10	CT2	10	0.5	S	16:01	spring	ebb	INT	6.7	2			
13/8/10	CT2 50	CT2	50	0.5	S	15:59	spring	ebb	INT	4.5	2.5			
13/8/10	CT2 100	CT2	100	0.5	S	15:57	spring	ebb	INT	4.4	2.5			
13/8/10	CT2 200	CT2	200	0.5	S	15:55	spring	ebb	INT	3.4	3			
13/8/10	CT3 10	CT3	10	0.5	S	15:47	spring	ebb	INT	5.1	2			

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
13/8/10	CT3 50	CT3	50	0.5	S	15:49	spring	ebb	INT	1.7	2.5			
13/8/10	CT3 100	CT3	100	0.5	S	15:57	spring	ebb	INT	5	2.5			
13/8/10	CT3 200	CT3	200	0.5	S	15:53	spring	ebb	INT	2.6	3			
13/8/10	CT4 10	CT4	10	0.5	S	15:45	spring	ebb	INT	5.8	2			
13/8/10	CT4 50	CT4	50	0.5	S	15:43	spring	ebb	INT	3.7	3			
13/8/10	CT4 100	CT4	100	0.5	S	15:41	spring	ebb	INT	11	2.5			
13/8/10	CT4 200	CT4	200	0.5	S	15:39	spring	ebb	INT	4.1	3			
13/8/10	RP 20	RP	20	0.5	S	15:33	spring	ebb	IMP	4.1	2.5			
13/8/10	RP 50	RP	50	0.5	S	15:35	spring	ebb	IMP	3.1	2.5			
13/8/10	RP 100	RP	100	0.5	S	15:37	spring	ebb	IMP	4.5	2.5			
13/8/10	SP 10	SP	10	0.5	S	15:31	spring	ebb	IMP	3.1	2.5			
13/8/10	SP 50	SP	50	0.5	S	15:27	spring	ebb	IMP	1.4	2.5			
13/8/10	SP 100	SP	100	0.5	S	15:25	spring	ebb	IMP	4.6	2.5			
13/8/10	SP 200	SP	200	0.5	S	15:23	spring	ebb	IMP	2.5	3.5			
13/8/10	D1 10	D1	10	0.5	S	15:15	spring	ebb	IMP	2	2.5			
13/8/10	D1 50	D1	50	0.5	S	15:17	spring	ebb	IMP	3.1	3			
13/8/10	D1 100	D1	100	0.5	S	15:19	spring	ebb	IMP	5.4	3			
13/8/10	D1 200	D1	200	0.5	S	15:21	spring	ebb	IMP	2.8	3.5			
21/8/10	REF 10	REF	10	0.5	S	12:05	spring	ebb	REF	3	3.2			
21/8/10	REF 50	REF	50	0.5	S	12:07	spring	ebb	REF	3.4	3			
21/8/10	REF 100	REF	100	0.5	S	12:10	spring	ebb	REF	3.4	4.1			
21/8/10	REF 200	REF	200	0.5	S	12:13	spring	ebb	REF	2.9	4.5			

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
21/8/10	TB 10	TB	10	0.5	S	12:22	spring	ebb	INT	3.1	2.5			
21/8/10	TB 50	TB	50	0.5	S	12:20	spring	ebb	INT	3.6	3			
21/8/10	TB 100	TB	100	0.5	S	12:18	spring	ebb	INT	3.1	4.2			
21/8/10	TB 200	TB	200	0.5	S	12:16	spring	ebb	INT	2.7	4.4			
21/8/10	CT2 10	CT2	10	0.5	S	12:25	spring	ebb	INT	2.3	3			
21/8/10	CT2 50	CT2	50	0.5	S	12:27	spring	ebb	INT	3.3	3.4			
21/8/10	CT2 100	CT2	100	0.5	S	12:30	spring	ebb	INT	5.8	4.1			
21/8/10	CT2 200	CT2	200	0.5	S	12:33	spring	ebb	INT	2.5	5			
21/8/10	CT3 10	CT3	10	0.5	S	12:42	spring	ebb	INT	3.2	3.1			
21/8/10	CT3 50	CT3	50	0.5	S	12:40	spring	ebb	INT	2.5	4.5			
21/8/10	CT3 100	CT3	100	0.5	S	12:38	spring	ebb	INT	3.4	5.3			
21/8/10	CT3 200	CT3	200	0.5	S	12:36	spring	ebb	INT	2.5	8			
21/8/10	CT4 10	CT4	10	0.5	S	12:45	spring	ebb	INT	3.2	2			
21/8/10	CT4 50	CT4	50	0.5	S	12:48	spring	ebb	INT	2.5	4.4			
21/8/10	CT4 100	CT4	100	0.5	S	12:51	spring	ebb	INT	3.1	4.4			
21/8/10	CT4 200	CT4	200	0.5	S	12:54	spring	ebb	INT	2.7	8.2			
21/8/10	RP 20	RP	20	0.5	S	13:02	spring	ebb	IMP	0.25	4.5			
21/8/10	RP 50	RP	50	0.5	S	13:00	spring	ebb	IMP	2.4	6.6			
21/8/10	RP 100	RP	100	0.5	S	12:57	spring	ebb	IMP	3	6			
21/8/10	SP 10	SP	10	0.5	S	13:04	spring	ebb	IMP	4	4.8			
21/8/10	SP 50	SP	50	0.5	S	13:06	spring	ebb	IMP	3	5			
21/8/10	SP 100	SP	100	0.5	S	13:09	spring	ebb	IMP	5.5	6.1			

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
21/8/10	SP 200	SP	200	0.5	S	13:12	spring	ebb	IMP	3.1	6.9			
21/8/10	D1 10	D1	10	0.5	S	13:22	spring	ebb	IMP	3	6.2			
21/8/10	D1 50	D1	50	0.5	S	13:20	spring	ebb	IMP	2.4	7			
21/8/10	D1 100	D1	100	0.5	S	13:17	spring	ebb	IMP	2.4	7			
21/8/10	D1 200	D1	200	0.5	S	13:15	spring	ebb	IMP	2.8	7			
4/9/10	REF 10	REF	10	0.5	S	8:48	neap	ebb	REF	3.3	3.5	B		
4/9/10	REF 50	REF	50	0.5	S	8:50	neap	ebb	REF	2.4	3.8			
4/9/10	REF 100	REF	100	0.5	S	8:52	neap	ebb	REF	2	3.8	B		
4/9/10	REF 200	REF	200	0.5	S	8:54	neap	ebb	REF	2.7	5.4			
4/9/10	TB 10	TB	10	0.5	S	9:02	neap	ebb	INT	2.6	2	B		
4/9/10	TB 50	TB	50	0.5	S	9:00	neap	ebb	INT	3.3	2.5	B		
4/9/10	TB 100	TB	100	0.5	S	8:58	neap	ebb	INT	4	3.6	B		
4/9/10	TB 200	TB	200	0.5	S	8:56	neap	ebb	INT	4	5			
4/9/10	CT2 10	CT2	10	0.5	S	9:05	neap	ebb	INT	4	4	B		
4/9/10	CT2 50	CT2	50	0.5	S	9:07	neap	ebb	INT	3.6	4	B		
4/9/10	CT2 100	CT2	100	0.5	S	9:09	neap	ebb	INT	4	4	B		
4/9/10	CT2 200	CT2	200	0.5	S	9:12	neap	ebb	INT	2.4	5.6			
4/9/10	CT3 10	CT3	10	0.5	S	9:20	neap	ebb	INT	2.9	3.8	B		
4/9/10	CT3 50	CT3	50	0.5	S	9:18	neap	ebb	INT	2.7	3.8	B		
4/9/10	CT3 100	CT3	100	0.5	S	9:16	neap	ebb	INT	2.5	3.8	B		
4/9/10	CT3 200	CT3	200	0.5	S	9:14	neap	ebb	INT	2.5	5.2			
4/9/10	CT4 10	CT4	10	0.5	S	9:23	neap	ebb	INT	3.3	2.4	B		

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
4/9/10	CT4 50	CT4	50	0.5	S	9:25	neap	ebb	INT	2.7	4	B		
4/9/10	CT4 100	CT4	100	0.5	S	9:27	neap	ebb	INT	3.1	3.8	B		
4/9/10	CT4 200	CT4	200	0.5	S	9:29	neap	ebb	INT	3	4.9			
4/9/10	RP 20	RP	20	0.5	S	9:35	neap	ebb	IMP	3.7	2	B		
4/9/10	RP 50	RP	50	0.5	S	9:33	neap	ebb	IMP	3.9	4.7	B		
4/9/10	RP 100	RP	100	0.5	S	9:31	neap	ebb	IMP	3.9	5.3			
4/9/10	SP 10	SP	10	0.5	S	9:37	neap	ebb	IMP	5.3	3.6			
4/9/10	SP 50	SP	50	0.5	S	9:39	neap	ebb	IMP	3.9	5.9			
4/9/10	SP 100	SP	100	0.5	S	9:41	neap	ebb	IMP	3.4	4.6			
4/9/10	SP 200	SP	200	0.5	S	9:43	neap	ebb	IMP	2.7	4.9			
4/9/10	D1 10	D1	10	0.5	S	9:51	neap	ebb	IMP	3.2	3.2			
4/9/10	D1 50	D1	50	0.5	S	9:49	neap	ebb	IMP	3.7	5.6			
4/9/10	D1 100	D1	100	0.5	S	9:47	neap	ebb	IMP	5.7	5.4			
4/9/10	D1 200	D1	200	0.5	S	9:45	neap	ebb	IMP	4.7	5.5			
10/9/10	REF 10	REF	10	0.5	S	13:47	spring	ebb	REF	2.5	3.7	B	0.4	0.32
10/9/10	REF 10	REF	10	3	B		spring	ebb	REF				0.0	
10/9/10	REF 50	REF	50	0.5	S	13:54	spring	ebb	REF	1.8	3.8		1.4	0.32
10/9/10	REF 50	REF	50	6	B		spring	ebb	REF				1.6	
10/9/10	REF 100	REF	100	0.5	S	14:00	spring	ebb	REF	2.7	4.1		0.2	0.28
10/9/10	REF 100	REF	100	6	B		spring	ebb	REF				0.9	
10/9/10	REF 200	REF	200	0.5	S	14:03	spring	ebb	REF	5.3	4.2		0.5	0.42
10/9/10	REF 200	REF	200	6	B		spring	ebb	REF				0.6	

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
10/9/10	TB 10	TB	10	0.5	S	14:20	spring	ebb	INT	3	3.5		1.2	0.48
10/9/10	TB 10	TB	10	4	B		spring	ebb	INT				0.8	
10/9/10	TB 50	TB	50	0.5	S	14:16	spring	ebb	INT	3.6	3.8		0.3	0.42
10/9/10	TB 50	TB	50	4.5	B		spring	ebb	INT				1.3	
10/9/10	TB 100	TB	100	0.5	S	14:12	spring	ebb	INT	4.5	3.9		0.2	0.45
10/9/10	TB 100	TB	100	5	B		spring	ebb	INT				0.5	
10/9/10	TB 200	TB	200	0.5	S	14:09	spring	ebb	INT	2.9	3.9		1.7	0.52
10/9/10	TB 200	TB	200	6	B		spring	ebb	INT				2.1	
10/9/10	CT2 10	CT2	10	0.5	S	14:26	spring	ebb	INT	3.6	3.8		1.1	0.61
10/9/10	CT2 10	CT2	10	5.5	B		spring	ebb	INT				1.7	
10/9/10	CT2 50	CT2	50	0.5	S	14:29	spring	ebb	INT	3.3	3.7		2.1	0.53
10/9/10	CT2 50	CT2	50	5	B		spring	ebb	INT				1.4	
10/9/10	CT2 100	CT2	100	0.5	S	14:34	spring	ebb	INT	4.8	3.9		0.7	0.51
10/9/10	CT2 100	CT2	100	5	B		spring	ebb	INT				1.1	
10/9/10	CT2 200	CT2	200	0.5	S	14:35	spring	ebb	INT	2.2	3.9		1.2	0.45
10/9/10	CT2 200	CT2	200	5.5	B		spring	ebb	INT				1.2	
10/9/10	CT3 10	CT3	10	0.5	S	14:56	spring	ebb	INT	5.3	3.4		2.0	0.84
10/9/10	CT3 10	CT3	10	4.5	B		spring	ebb	INT				2.7	
10/9/10	CT3 50	CT3	50	0.5	S	14:52	spring	ebb	INT	6.4	3.4		1.6	0.81
10/9/10	CT3 50	CT3	50	4.5	B		spring	ebb	INT				2.0	
10/9/10	CT3 100	CT3	100	0.5	S	14:46	spring	ebb	INT	6.3	3.5		1.6	0.71
10/9/10	CT3 100	CT3	100	5	B		spring	ebb	INT				2.2	

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
10/9/10	CT3 200	CT3	200	0.5	S	14:43	spring	ebb	INT	5.1	3.2		1.7	0.13
10/9/10	CT3 200	CT3	200	15	B		spring	ebb	INT				3.4	
10/9/10	CT4 10	CT4	10	0.5	S	15:00	spring	ebb	INT	5.1	1.2		9.7	1.24
10/9/10	CT4 10	CT4	10	3.2	B		spring	ebb	INT				1.8	
10/9/10	CT4 50	CT4	50	0.5	S	15:04	spring	ebb	INT	6	3.5		1.6	0.57
10/9/10	CT4 50	CT4	50	4.5	B		spring	ebb	INT				2.9	
10/9/10	CT4 100	CT4	100	0.5	S	15:06	spring	ebb	INT	5.4	3.3		1.9	0.98
10/9/10	CT4 100	CT4	100	5.5	B		spring	ebb	INT				4.0	
10/9/10	CT4 200	CT4	200	0.5	S	15:10	spring	ebb	INT	10	3.4		2.3	0.15
10/9/10	CT4 200	CT4	200	20	B		spring	ebb	INT				5.4	
10/9/10	RP-20	RP	20	0.5	S	15:24	spring	ebb	IMP	7	3.3		3.1	0.31
10/9/10	RP-20	RP	20	8	B		spring	ebb	IMP				3.8	
10/9/10	RP-50	RP	50	0.5	S	15:19	spring	ebb	IMP	7.1	3.5		1.0	0.12
10/9/10	RP-50	RP	50	20	B		spring	ebb	IMP				6.6	
10/9/10	RP-100	RP	100	0.5	S	15:16	spring	ebb	IMP	7.9	3.2		3.1	0.13
10/9/10	RP-100	RP	100	20	B		spring	ebb	IMP				3.7	
10/9/10	SP 10	SP	10	0.5	S	15:28	spring	ebb	IMP	2.5	3.1		6.0	1.15
10/9/10	SP 10	SP	10	3.5	B		spring	ebb	IMP				2.1	
10/9/10	SP 50	SP	50	0.5	S	15:30	spring	ebb	IMP	5.6	3.1		3.2	0.55
10/9/10	SP 50	SP	50	6	B		spring	ebb	IMP				3.3	
10/9/10	SP 100	SP	100	0.5	S	15:33	spring	ebb	IMP	9.2	3.4		1.7	0.12
10/9/10	SP 100	SP	100	20	B		spring	ebb	IMP				3.3	

DATE	CODE	SITE	DISTANCE	DEPTH	LEVEL	TIME	TIDE A	TIDE B	TYPE	TSS	SECCHI	BOTTOM	NTU	ATTEN.
10/9/10	SP 200	SP	200	0.5	S	15:37	spring	ebb	IMP	5	3.2		2.2	0.22
10/9/10	SP 200	SP	200	20	B		spring	ebb	IMP				4.4	
10/9/10	D1 10	D1	10	0.5	S	15:52	spring	ebb	IMP	5.5	2.6		6.8	0.66
10/9/10	D1 10	D1	10	2	B		spring	ebb	IMP				3.7	
10/9/10	D1 50	D1	50	0.5	S	15:48	spring	ebb	IMP	6.3	3.4		3.9	0.30
10/9/10	D1 50	D1	50	8	B		spring	ebb	IMP				2.8	
10/9/10	D1 100	D1	100	0.5	S	15:45	spring	ebb	IMP	3.8	3.6		1.3	0.09
10/9/10	D1 100	D1	100	20	B		spring	ebb	IMP				2.8	
10/9/10	D1 200	D1	200	0.5	S	15:40	spring	ebb	IMP	3.8	3.3		2.7	0.09
10/9/10	D1 200	D1	200	20	B		spring	ebb	IMP				3.8	

APPENDIX B

Coral Monitoring Data and Photographs

Quadrat coral colony data, September 2010

TRIP	MONTH	SITE	SUBSITE	TYPE	LIVE	FLORA	FAUNA	DEAD	ABIOTIC	UNKNOWN
MSA113-15	Sep-10	REF-300	REF-300C	Reference	16.2	0.0	0.0	0.0	83.8	1.0
MSA113-15	Sep-10	REF-300	REF-300E	Reference	41.4	0.0	0.0	0.0	57.6	1.0
MSA113-15	Sep-10	REF-300	REF-300W	Reference	29.5	3.2	2.1	0.0	65.3	5.3
MSA113-15	Sep-10	CT3-200	CT3-200C	Impact Risk	20.8	0.0	0.0	0.0	79.2	4.2
MSA113-15	Sep-10	CT3-200	CT3-200E	Impact Risk	22.1	0.0	0.0	0.0	77.9	5.3
MSA113-15	Sep-10	CT3-200	CT3-200W	Impact Risk	23.2	0.0	0.0	0.0	76.8	1.0
MSA113-15	Sep-10	RP-100W2	RP-100W2	Impact	20.4	0.0	2.0	0.0	77.6	2.0
MSA113-15	Sep-10	ST-3	ST3-A	Impact	32.0	1.0	0.0	0.0	67.0	0.0
MSA113-15	Sep-10	ST-3	ST3-B	Impact	57.1	0.0	0.0	0.0	42.9	2.0
MSA113-15	Sep-10	ST-3	ST3-C	Impact	35.6	0.0	0.0	0.0	64.4	14.9

Individual coral data, September 2010

TRIP	MONTH	SITE	SUBSITE	COLONY	ALGAE	BLEACHED	DEAD	FAUNA	HEALTHY	SEDIMENT	TOTAL
MSA113-15	Sep-10	REF-300	REF-300C	REF-300C_01	0	0	0	0	87.9	12.1	100
MSA113-15	Sep-10	REF-300	REF-300C	REF-300C_02	0	0	0	0	70.0	30.0	100
MSA113-15	Sep-10	REF-300	REF-300C	REF-300C_03	0	0	0	0	96.9	3.1	100
MSA113-15	Sep-10	REF-300	REF-300C	REF-300C_04	0	0	0	0	0.0	100.0	100
MSA113-15	Sep-10	REF-300	REF-300C	REF-300C_05	0	0	0	0	0.0	100.0	100
MSA113-15	Sep-10	REF-300	REF-300C	REF-300C_06	0	0	0	13.3	73.3	13.3	100
MSA113-15	Sep-10	REF-300	REF-300C	REF-300C_07	0	0	0	0	68.8	31.3	100
MSA113-15	Sep-10	REF-300	REF-300C	REF-300C_08	0	0	0	0	74.1	25.9	100
MSA113-15	Sep-10	REF-300	REF-300C	REF-300C_09	0	0	0	0	90.0	10.0	100
MSA113-15	Sep-10	REF-300	REF-300C	REF-300C_10	0	0	0	17.9	57.1	25.0	100
MSA113-15	Sep-10	REF-300	REF-300E	REF-300E_01	0	0	0	0	7.7	92.3	100
MSA113-15	Sep-10	REF-300	REF-300E	REF-300E_02	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	REF-300	REF-300E	REF-300E_03	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	REF-300	REF-300E	REF-300E_04	0	0	0	0	93.5	6.5	100
MSA113-15	Sep-10	REF-300	REF-300E	REF-300E_05	0	0	0	0	29.4	70.6	100
MSA113-15	Sep-10	REF-300	REF-300E	REF-300E_06	0	0	0	0	92.9	7.1	100
MSA113-15	Sep-10	REF-300	REF-300E	REF-300E_07	0	0	0	0	95.8	4.2	100
MSA113-15	Sep-10	REF-300	REF-300E	REF-300E_08	0	0	0	0	96.6	3.4	100
MSA113-15	Sep-10	REF-300	REF-300E	REF-300E_09	0	0	0	0	69.0	31.0	100
MSA113-15	Sep-10	REF-300	REF-300E	REF-300E_10	0	0	0	0	44.8	55.2	100
MSA113-15	Sep-10	REF-300	REF-300W	REF-300W_01	0	0	0	0	82.8	17.2	100
MSA113-15	Sep-10	REF-300	REF-300W	REF-300W_02	6.7	0	0	0	73.3	20.0	100

TRIP	MONTH	SITE	SUBSITE	COLONY	ALGAE	BLEACHED	DEAD	FAUNA	HEALTHY	SEDIMENT	TOTAL
MSA113-15	Sep-10	REF-300	REF-300W	REF-300W_03	0	0	0	0	90.3	9.7	100
MSA113-15	Sep-10	REF-300	REF-300W	REF-300W_04	0	0	0	0	82.8	17.2	100
MSA113-15	Sep-10	REF-300	REF-300W	REF-300W_05	0	0	0	3.7	85.2	11.1	100
MSA113-15	Sep-10	REF-300	REF-300W	REF-300W_06	0	0	0	0	85.3	14.7	100
MSA113-15	Sep-10	REF-300	REF-300W	REF-300W_07	0	0	0	0	54.8	45.2	100
MSA113-15	Sep-10	REF-300	REF-300W	REF-300W_08	0	0	0	0	84.6	15.4	100
MSA113-15	Sep-10	REF-300	REF-300W	REF-300W_09	0	0	0	0	11.1	88.9	100
MSA113-15	Sep-10	REF-300	REF-300W	REF-300W_10	0	0	0	0	72.4	27.6	100
MSA113-15	Sep-10	CT3-200	CT3-200C	CT3-200C_01	0	0	0	0	91.4	8.6	100
MSA113-15	Sep-10	CT3-200	CT3-200C	CT3-200C_02	0	0	0	0	93.1	6.9	100
MSA113-15	Sep-10	CT3-200	CT3-200C	CT3-200C_03	0	0	0	0	96.4	3.6	100
MSA113-15	Sep-10	CT3-200	CT3-200C	CT3-200C_04	0	0	0	0	96.9	3.1	100
MSA113-15	Sep-10	CT3-200	CT3-200C	CT3-200C_05	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	CT3-200	CT3-200C	CT3-200C_06	0	0	0	0	89.7	10.3	100
MSA113-15	Sep-10	CT3-200	CT3-200C	CT3-200C_07	0	0	0	0	44.8	55.2	100
MSA113-15	Sep-10	CT3-200	CT3-200C	CT3-200C_08	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	CT3-200	CT3-200C	CT3-200C_09	0	0	0	0	74.1	25.9	100
MSA113-15	Sep-10	CT3-200	CT3-200C	CT3-200C_10	0	0	0	0	80.0	20.0	100
MSA113-15	Sep-10	CT3-200	CT3-200E	CT3-200E_01	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	CT3-200	CT3-200E	CT3-200E_02	0	0	0	0	84.6	15.4	100
MSA113-15	Sep-10	CT3-200	CT3-200E	CT3-200E_03	0	0	0	0	82.4	17.6	100
MSA113-15	Sep-10	CT3-200	CT3-200E	CT3-200E_04	0	0	0	0	93.8	6.3	100
MSA113-15	Sep-10	CT3-200	CT3-200E	CT3-200E_05	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	CT3-200	CT3-200E	CT3-200E_06	0	0	0	0	61.3	38.7	100
MSA113-15	Sep-10	CT3-200	CT3-200E	CT3-200E_07	0	0	0	0	80.0	20.0	100
MSA113-15	Sep-10	CT3-200	CT3-200E	CT3-200E_08	0	0	0	0	72.4	27.6	100
MSA113-15	Sep-10	CT3-200	CT3-200E	CT3-200E_09	0	0	0	0	72.4	27.6	100
MSA113-15	Sep-10	CT3-200	CT3-200E	CT3-200E_10	0	0	0	0	84.4	15.6	100
MSA113-15	Sep-10	CT3-200	CT3-200W	CT3-200W_01	0	0	0	0	100.0	0.0	100

TRIP	MONTH	SITE	SUBSITE	COLONY	ALGAE	BLEACHED	DEAD	FAUNA	HEALTHY	SEDIMENT	TOTAL
MSA113-15	Sep-10	CT3-200	CT3-200W	CT3-200W_02	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	CT3-200	CT3-200W	CT3-200W_03	0	0	0	0	90.6	9.4	100
MSA113-15	Sep-10	CT3-200	CT3-200W	CT3-200W_04	0	0	0	0	75.9	24.1	100
MSA113-15	Sep-10	CT3-200	CT3-200W	CT3-200W_05	0	0	0	0	78.3	21.7	100
MSA113-15	Sep-10	CT3-200	CT3-200W	CT3-200W_06	0	0	0	0	90.9	9.1	100
MSA113-15	Sep-10	CT3-200	CT3-200W	CT3-200W_07	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	CT3-200	CT3-200W	CT3-200W_08	0	0	0	0	93.1	6.9	100
MSA113-15	Sep-10	CT3-200	CT3-200W	CT3-200W_09	0	0	0	0	96.2	3.8	100
MSA113-15	Sep-10	CT3-200	CT3-200W	CT3-200W_10	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	RP-100W2	RP-100W2	RP-100W2_01	0	0	0	0	35.5	64.5	100
MSA113-15	Sep-10	RP-100W2	RP-100W2	RP-100W2_02	0	0	0	0	82.8	17.2	100
MSA113-15	Sep-10	RP-100W2	RP-100W2	RP-100W2_03	0	0	0	0	93.1	6.9	100
MSA113-15	Sep-10	RP-100W2	RP-100W2	RP-100W2_04	0	0	0	0	96.2	3.8	100
MSA113-15	Sep-10	RP-100W2	RP-100W2	RP-100W2_05	0	0	0	0	96.7	3.3	100
MSA113-15	Sep-10	RP-100W2	RP-100W2	RP-100W2_06	0	0	0	0	92.6	7.4	100
MSA113-15	Sep-10	RP-100W2	RP-100W2	RP-100W2_07	0	0	0	0	87.5	12.5	100
MSA113-15	Sep-10	RP-100W2	RP-100W2	RP-100W2_08	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	RP-100W2	RP-100W2	RP-100W2_09	0	0	0	0	96.4	3.6	100
MSA113-15	Sep-10	RP-100W2	RP-100W2	RP-100W2_10	0	0	0	3.6	32.1	64.3	100
MSA113-15	Sep-10	ST3	ST3-A	ST3-A_01	0	0	0	0	90.3	9.7	100
MSA113-15	Sep-10	ST3	ST3-A	ST3-A_02	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	ST3	ST3-A	ST3-A_03	0	0	0	0	96.4	3.6	100
MSA113-15	Sep-10	ST3	ST3-A	ST3-A_04	0	0	0	0	42.9	57.1	100
MSA113-15	Sep-10	ST3	ST3-A	ST3-A_05	0	0	0	0	75.0	25.0	100
MSA113-15	Sep-10	ST3	ST3-A	ST3-A_06	0	0	0	0	48.4	51.6	100
MSA113-15	Sep-10	ST3	ST3-A	ST3-A_07	0	0	0	0	89.7	10.3	100
MSA113-15	Sep-10	ST3	ST3-A	ST3-A_08	0	0	0	0	96.9	3.1	100
MSA113-15	Sep-10	ST3	ST3-A	ST3-A_09	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	ST3	ST3-A	ST3-A_10	0	0	0	0	83.3	16.7	100

TRIP	MONTH	SITE	SUBSITE	COLONY	ALGAE	BLEACHED	DEAD	FAUNA	HEALTHY	SEDIMENT	TOTAL
MSA113-15	Sep-10	ST3	ST3-B	ST3-B_01	0	0	0	0	83.3	16.7	100
MSA113-15	Sep-10	ST3	ST3-B	ST3-B_02	0	0	0	6.1	84.8	9.1	100
MSA113-15	Sep-10	ST3	ST3-B	ST3-B_03	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	ST3	ST3-B	ST3-B_04	0	0	0	0	95.0	5.0	100
MSA113-15	Sep-10	ST3	ST3-B	ST3-B_05				Not found			
MSA113-15	Sep-10	ST3	ST3-B	ST3-B_06				Not found			
MSA113-15	Sep-10	ST3	ST3-B	ST3-B_07	0	0	0	15.6	78.1	6.3	100
MSA113-15	Sep-10	ST3	ST3-B	ST3-B_08	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	ST3	ST3-B	ST3-B_09	0	0	0	0	0.0	100.0	100
MSA113-15	Sep-10	ST3	ST3-B	ST3-B_10	0	0	0	0	48.3	51.7	100
MSA113-15	Sep-10	ST3	ST3-C	ST3-C_01	0	0	0	0	82.9	17.1	100
MSA113-15	Sep-10	ST3	ST3-C	ST3-C_02	0	0	0	0	43.3	56.7	100
MSA113-15	Sep-10	ST3	ST3-C	ST3-C_03	0	0	0	0	97.1	2.9	100
MSA113-15	Sep-10	ST3	ST3-C	ST3-C_04	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	ST3	ST3-C	ST3-C_05	0	0	0	5.6	69.4	25.0	100
MSA113-15	Sep-10	ST3	ST3-C	ST3-C_06	0	0	0	0	73.3	26.7	100
MSA113-15	Sep-10	ST3	ST3-C	ST3-C_07	0	0	0	7.1	85.7	7.1	100
MSA113-15	Sep-10	ST3	ST3-C	ST3-C_08	0	0	0	0	100.0	0.0	100
MSA113-15	Sep-10	ST3	ST3-C	ST3-C_09	0	0	0	0	87.5	12.5	100
MSA113-15	Sep-10	ST3	ST3-C	ST3-C_10	0	0	0	0	100.0	0.0	100

Next page: coral quadrat and individual colony photographs, September 2010. Colony locations are given as distance (m) and direction (degrees) from the central stake at each subsite. Stake coordinates are in Table 1.

ST3A-A

ST3A-B

ST3A-C

ST3A-D

A_1 *Turbinaria* 1.8@270

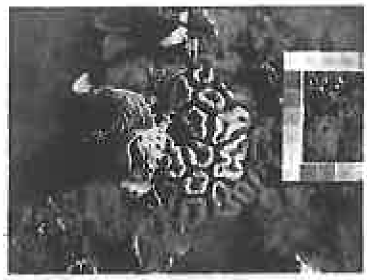
ST3A_2 *Porites* 0.5@270

ST3A_3 *Montipora* 2.0@350

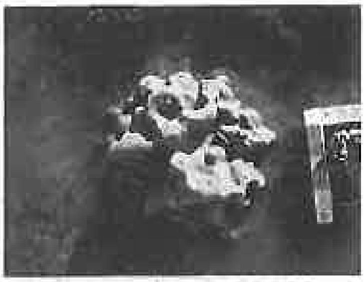
ST3A_4 *Meruiina* 3.0@350

ST3A_5 *Porites* 1.2@010

ST3A_6 *Goniopora* 0.5@080



ST3A_7 *Lobophyllia* 2.0@080



ST3A_8 *Porites* 2.0@100

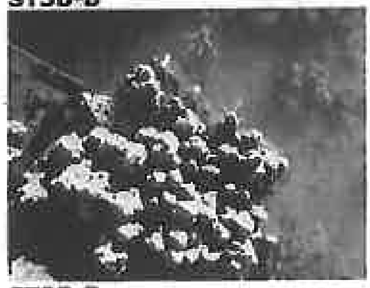
ST3A_9 *Montastrea* 1.0@110

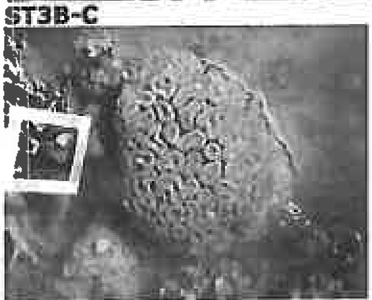
ST3A_10 *Merulina* 0.2@250


ST3B-A


ST3B-B


ST3B-C


ST3B-D


ST3B_1 *Lobophyllia* 2.0@270


ST3B_2 *Turbinaria* 1.5@270


ST3B_3 *Porites* 1.2@300


ST3B_4 *Porites* 1.5@020

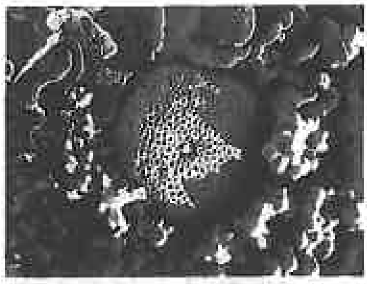
not found

ST3B_5 *Montipora* 4.0@130

wrong colony

ST3B_6 *Lobophyllia* 3.0@160

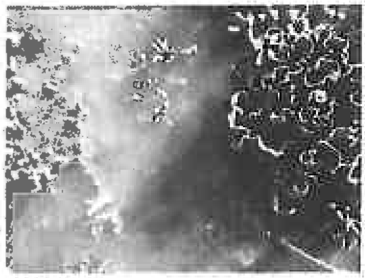
ST3B_7 *Turbinaria* 2.5@180



ST3B_8 *Favia* 3.0@200

ST3B_9 *Acropora* 1.8@220

ST3B_10 *Montipora* 1.50@250



ST3C-A

ST3C-B

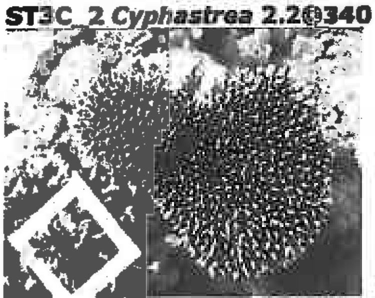
ST3C-C

ST3C-D

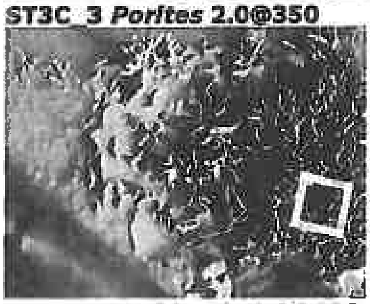
ST3C_1 *Merulina* 1.2@290

ST3C_2 *Cyphastrea* 2.2@340

ST3C_3 *Porites* 2.0@350



ST3C_4 *Acropora* 3.0@050



ST3C_5 *Turbinaria* 2.0@130

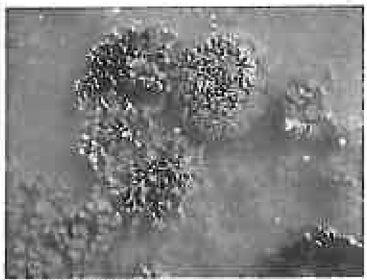
ST3C_6 *Turbinaria* 1.0@150

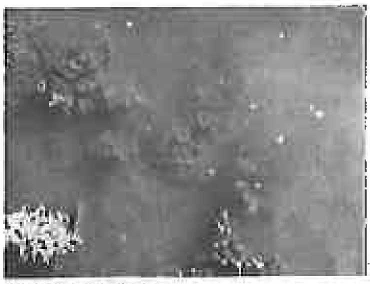
ST3C_7 *Acropora* 0.5@120

ST3C_8 *Pachyseris* 2.5@220

ST3C_9 *Favites* 3.5@270

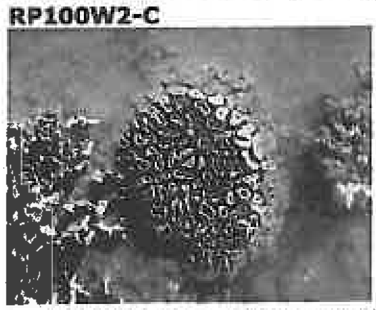
ST3C_10 *Pectinia* 0.5@250

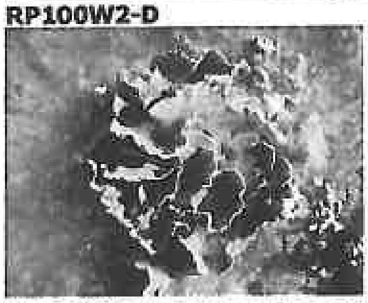

RP100W2-A


RP100W2-B


RP100W2-C


RP100W2-D


RP100W2-1 *Lobophyllia* 0.5@000


RP100W2-2 *Turbinaria* 2.0@000

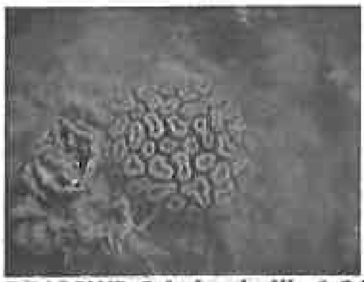

RP100W2-3 *Porites* 1.2@290


RP100E-4 *Porites* 0.5 @220

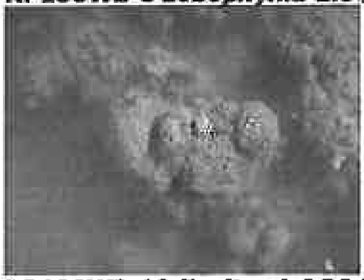

RP100W2-5 *Lobophyllia* 0.1@200


RP100W2-6 *Porites* 2.5@200


RP100W2-7 *Goniastrea* 2.0@160


RP100W2-8 *Lobophyllia* 1.8@170


RP100W2-9 *Acropora* 1.2@090


RP100W2-10 *Favites* 1.0@045

CT3-200C A

CT3-200C B

CT3-200C C

CT3-200C D

CT3-200C_1 *Goniastrea*1.2 @ 040

CT3-200C_2 *Porites* 1.1 @ 060

CT3-200C_3 *Favites* 0.6 @ 150

CT3-200C_4 *Lobophyllia* 0.7@150

CT3-200_5 *Favites* 0.6 @ 270

CT3-200C_6 *Favia* 1.2@120


CT3-200C_7 *Favia* 1.2 @ 260


CT3-200C_8 *Goniastrea*2.1 @ 290


CT3-200C_9 *Favites* 1.0 @ 340


CT3-200C_10 *Favia* 1.4 @ 040

CT3-200E A

CT3-200E B

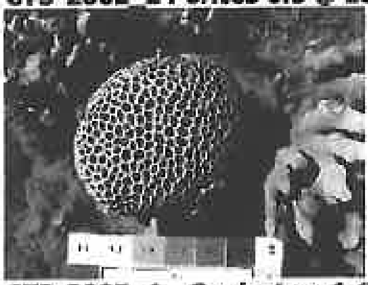
CT3-200E C

CT3-200E D

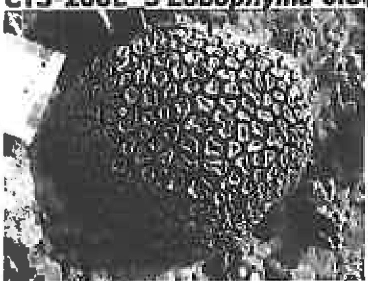
CT3-200E_1 *Turbinaria* 0.45@200

CT3-200E_2 *Porites* 0.5 @ 185

CT3-200E_3 *Lobophyllia* 0.8@160



CT3-200E_4 *Goniastrea* 1 @ 180



CT3-200E_5 *Lobophyllia* 1@100

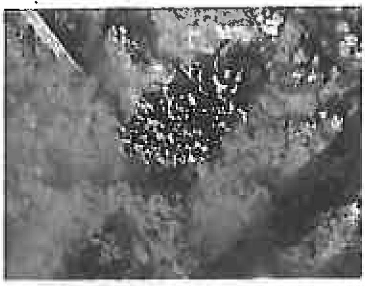
CT3-200E_6 *Lobophyllia* 1.3@110

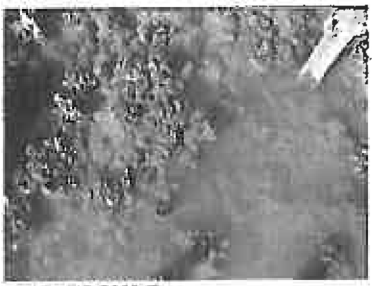
CT3-200E_7 *Favites* 1.3@100

CT3-200E_8 *Favia* 1.2@070

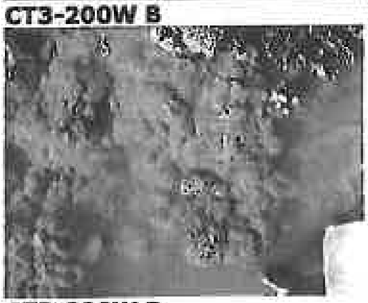
CT3-200E_9 *Goniastrea* 1.3@070

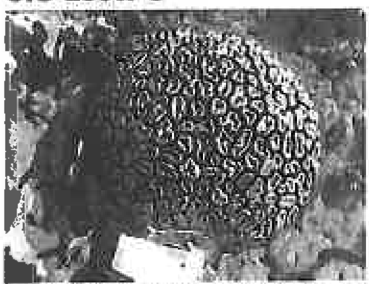
CT3-200E_10 *Favites* 1.3@090

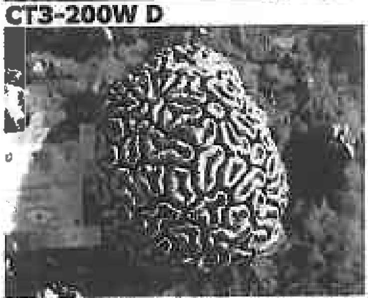

CT3-200W A


CT3-200W B


CT3-200W C


CT3-200W D


CT3-200W_1*Lobophyllia* 0.7@320


CT3-200W_2*Lobophyllia* 1.5@320


CT3-200W_3 *Favia* 2@010


CT3-200W_4 *Porites* 1.2@045


CT3-200W_5 *Turbinaria* 1.2@170


CT3-200W_6 *Favites* 1@200

CT3-200W_7 *Favites* 1.1@200

CT3-200W_8 *Astreopora*1.2@180

CT3-200W_9 *Favites* 0.9@290

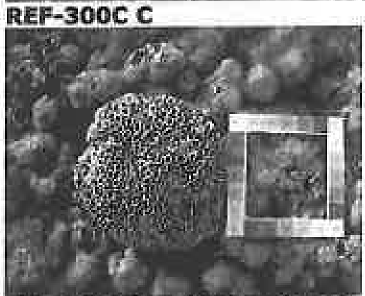
CT3-200W_10 *Goniastrea* 1.1@110

REF-300C A

REF-300C B

REF-300C C

REF-300C D

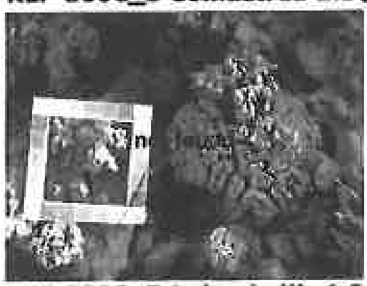


REF-300C_1 *Favia* 0.8@200

REF-300C_2 *Porites* 0.7@270

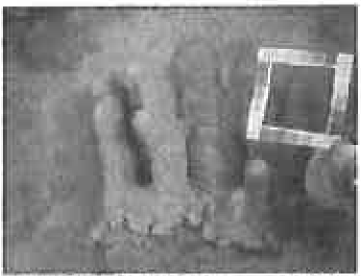
REF-300C_3 *Goniastrea* 2.5@100

REF-300C_4 *Euphyllia* 1@045



REF-300C_5 *Lobophyllia* 1.2@060

REF-300C_6 *Goniastrea* 1.5@150



REF-300C_7 *Galaxea* 2.0@250

REF-300C_8 *Cyphastrea* 1.2@270

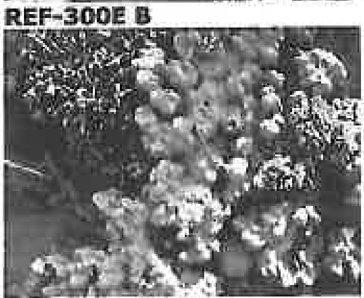
REF-300C_9 *Astreopora* 2.0@340

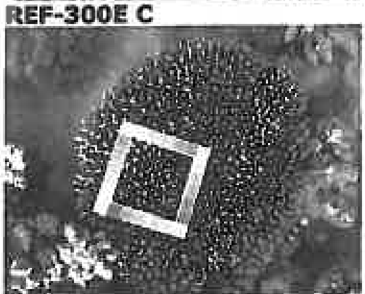
REF-300C_10 *Porites* 1.7@070


REF-300E A


REF-300E B


REF-300E C

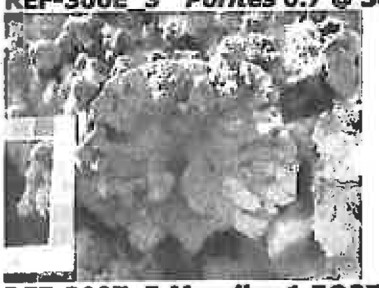

REF-300E D


REF-300E_1 *Acropora* 1.0@240

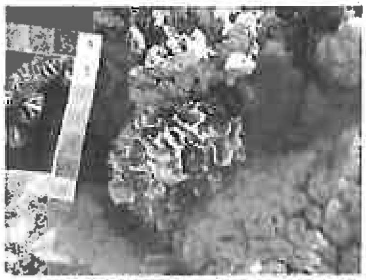

REF-300E_2 *Goniastrea* 1.1@250


REF-300E_3 *Porites* 0.7 @ 300

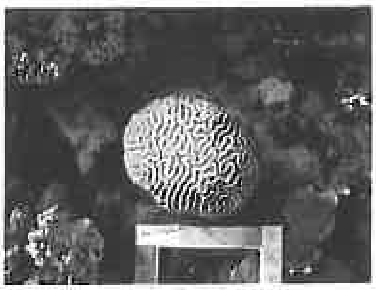

REF-300E_4 *Lobophyllia* 2.0@060


REF-300E_5 *Merulina* 1.5@270


REF-300E_6 *Astreopora* 0.4@300



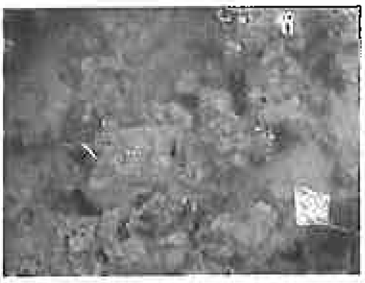
REF-300E_7 *Pectinia* 1.3@000



REF-300E_8 *Goniastrea* 1.8@030

REF-300E_9 *Acropora* 0.4@135

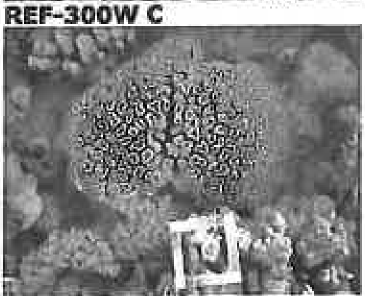
REF-300E_10 *Merulina* 2.0@090

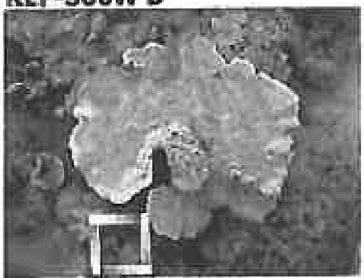

REF-300W A

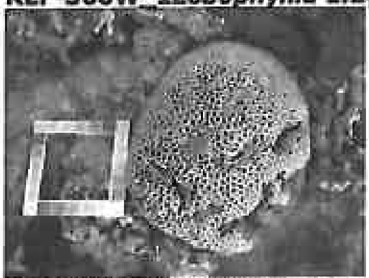

REF-300W B


REF-300W C


REF-300W D

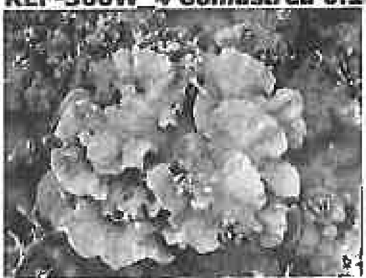

REF-300W_1*Lobophyllia* 1.2@120

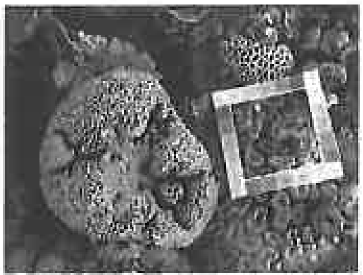

REF-300W_2 *Montipora* 1.5@090


REF-300W_3 *Favia* 1.2 @ 000

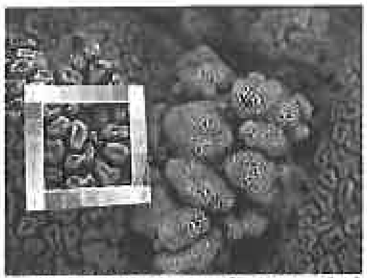

REF-300W_4 *Goniastrea* 0.15@120


REF-300W_5 *Podabacia* 0.7@000


REF-300W_6 *Turbinaria* 2.3@240



REF-300W_7 *Favia* 0.4@240



REF-300W_8 *Goniastrea* 1.1@120

REF-300W_9 *Pachyseris* 2.2@320

REF-300W_10 *Goniastrea* 0.9@320