Pre and Post Dredging Coral Health Monitoring

Towed Camera Video Surveys

11/08/16

Level 31, 12 Creek St
Brisbane QLD 4000
Australia

301310-09660-00-EN-REP-0003

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Project No: 301310-09660-00-EN-REP-0003 – Pre and Post Dredging Coral Health Monitoring: Towed Camera Video Surveys

Rev	Description	Author	Review	Advisian Approval	Date
0	For Client Use	S Neale	J Kennedy	J Kennedy	11/08/16

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1 Introduction

The Amrun Project (formerly South of Embley) involves the construction and operation of a bauxite mine and associated processing and port facilities to be located near Boyd Point on the western side of Cape York Peninsula. The Amrun Project is being developed and operated by Rio Tinto Weipa Pty Ltd, a wholly-owned subsidiary of Rio Tinto Aluminium Limited. A detailed description of the project is provided in the Queensland EIS (RTA 2011), The Queensland SEIS (RTA 2012), and the Commonwealth EIS (RTA 2013).

The Amrun Project requires the construction and operation of a new Port facility located between Boyd Point and Pera Head. The marine works will include the construction of a jetty, wharf and ship loaders, which required capital dredging of berth pocket and approach and departure channel. Dredging was completed between 26 March and 09 April 2016. The campaign consisted of removal and disposal of approximately 202,416m^3 of material. Telemetered water quality monitoring completed during the campaign recorded no dredging related impacts.

The coral health monitoring program is designed to provide a quantitative measure of coral health (percent bleaching and/or mortality) which can be assessed against management triggers as outlined in the Coral Health Management Process. This process is detailed in Section 2.2 and Figure 13 of the South of Embley Project - Dredge Management Plan (DMP) – Port (Initial Capital Dredging) RTA (November, 2015).

This document outlines the results of the pre-dredging baseline towed video camera surveys and the two post-dredging towed video camera surveys (1 month post - May 2016 and 2 month post - June 2016) of monitoring sites I1, I2, I3, I4, R1 and R2.

2 Coral Heath Monitoring Methods

Coral monitoring surveys were completed as follows:

- Baseline survey was completed on 24th and 25th of February 2016 (Survey 1)
- 1 month post dredge surveys was completed on 19 May 2016 (Survey 2)
- 2 month post dredge survey was completed on 18 June 2016 (Survey 3)

All surveys were undertaken using a towed Delta Vision Industrial Colour Underwater Video Camera and Pro Package mounted facing down on a specialist frame. The video image was viewed live on screen and recorded directly onto a hard drive.

It is important to note the one month post coral surveys were originally scheduled for 9 May 2016, however surveys were delayed due to poor weather.

2.1 Site Selection

As per the requirements set out in the approved DMP (RTA, November 2015), six coral monitoring locations were surveyed - I1, I2, I3, I4, R1 and R2. As per DMP, at each site areas of highest coral cover were targeted for towed video transect survey as close as possible to the water quality monitoring sites.

During the pre-dredging survey, several test towed video transects were undertaken by the team using the towed video to determine an appropriate area of seafloor to commence surveys at each of the six locations. The depauperate patchy nature of the coral community at each site meant that once an area of relatively high coral cover at least 150m long and on a similar depth contour was found, this area was targeted for transect survey. The most appropriate way to survey this patchy community was to run the transects in a line along a similar depth contour aligned with the prevailing current and wind. Having determined the area with relatively high coral cover, four transects 30m long and approximately 10m apart were run along a contour between 3-6m deep depending on the particular monitoring location depth characteristics. Transects were recorded using a towed video system with camera oriented to face the seabed.

These same sites were surveyed during the 1 month and 2 month post dredging surveys. The sites and indicative locations of transects are provided in Figure 2-1. The start and end points of the sites and each transect were recorded to GPS along with the track taken by the vessel (Table 2-1).

Table 2-1 Start and end GPS points (WGS 84 UTM Zone 54) of the towed video transects at each monitoring site

Site	Transect	Depth (m)	Start		End	
			Easting	Northing	Easting	Northing
I1	1	3-6	568814	8572971	568798	8572993
	2		568792	8573001	568776	8573023
	3		568770	8573031	568754	8573053
	4		568748	8573061	568732	8573083
I2	1	3-6	565028	8568467	565057	8568476
	2		565066	8568479	565095	8568487
	3		565105	8568490	565134	8568499
	4		565143	8568502	565172	8568510
I3	1	3-6	562691	8567106	562680	8567084
	2		562675	8567075	562664	8567053
	3		562660	8567045	562649	8567023
	4		562644	8567014	562633	8566992
I4	1	3-6	562875	8562704	562849	8562696
	2		562839	8562692	562813	8562683
	3		562804	8562680	562778	8562671
	4		562768	8562668	562742	8562659
R1	1	3-6	572415	8575092	572398	8575069
	2		572392	8575061	572375	8575038
	3		572369	8575029	572352	8575006
	4		572346	8574998	572329	8574975
R2	1	3-6	564966	8552472	564950	8552455
	2		564943	8552448	564927	8552431
	3		564921	8552424	564905	8552407
	4		564898	8552400	564882	8552383

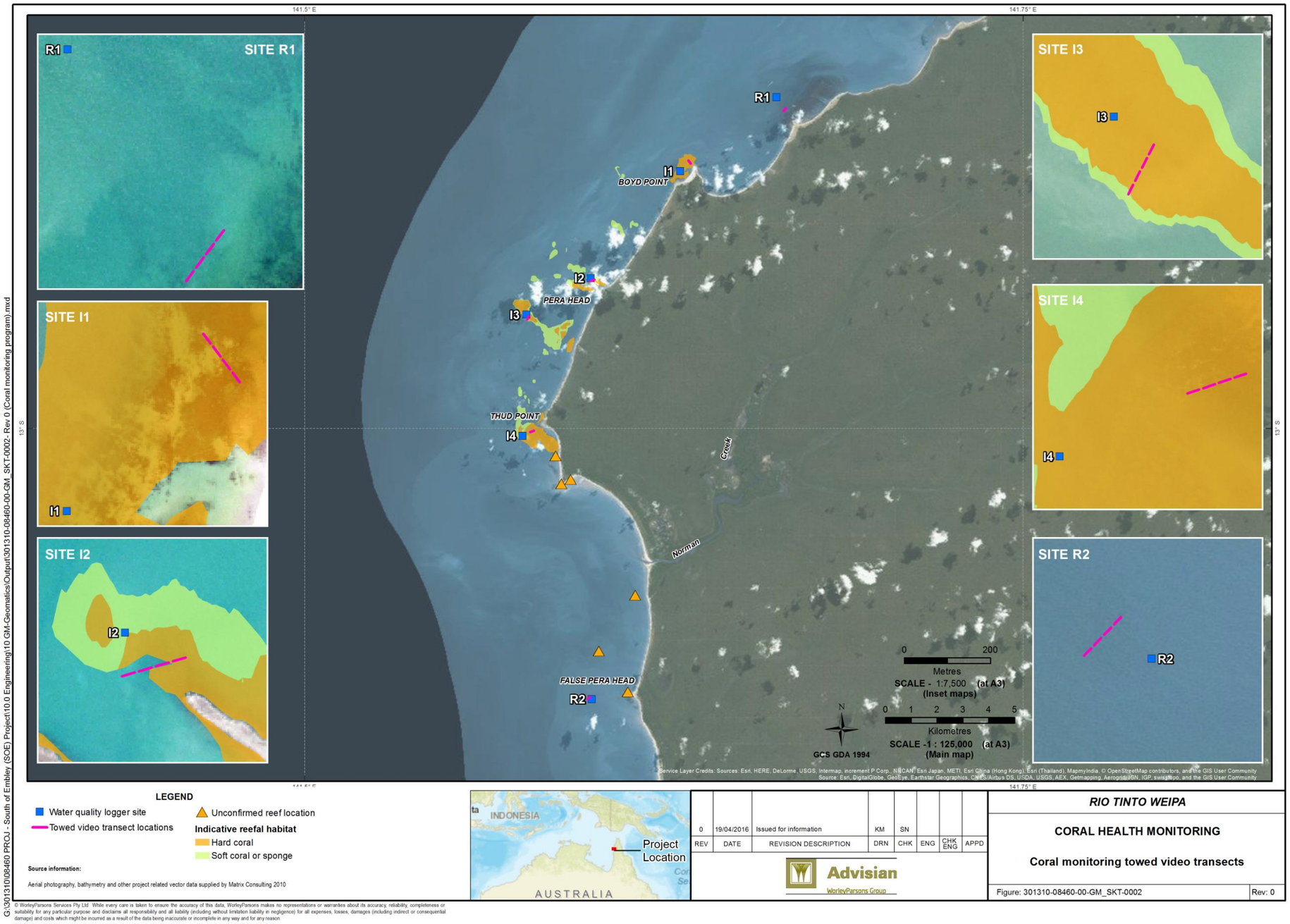


Figure 2-1 Coral monitoring sites and towed video transects

2.2 Image Capture and Analysis

At each monitoring location, the video was reviewed at the end of the fourth transect by the technical lead to ensure the image quality was acceptable. If the images were not acceptable the process was repeated along the same transect path.

2.2.1 Data Analysis

The method of analysis was based on two Standard Operational Procedures used by the Australian Institute of Marine Science (AIMS).

- *Australian Institute of Marine Science Standard Operational Procedure Number 2 - Surveys of Benthic Reef Communities Using Underwater Video* (AIMS 2004)[1]
- *Australian Institute of Marine Science Standard Operational Procedure Number 10 - Surveys of Benthic Reef Communities Using Underwater Digital Photography and Counts of Juvenile Corals* (AIMS 2008)[1]

The AIMS method was considered best practise and is the basis of analysis used by the AIMS Long Term Monitoring Program since 1992. The method used is summarised below.

For each transect, 40 captured images were analysed using the publicly available Reef Monitoring program (Reefmon)[2] developed by AIMS. This program superimposes five fixed points on each captured image and the benthic category under each point entered into the AIMS Reefmon program. This equates to 200 points sampled along each 30m transect. The program allows for each point to be zoomed into allowing for better categorisation of the benthic category under the point. A screen shot of the Reefmon data input program is provided in Figure 2-2.

The fixed points superimposed on each screen are numbered in the flowing order; top left=1, top right=2, centre=3, bottom left=4, bottom right=5.

All the data is then stored in an Oracle database and linked to an Access database. Percentage cover data for all benthic organisms at all levels of resolution (broad group, growth form, family, genus and species) can then be calculated from this data.

[1] http://www.aims.gov.au/docs/research/monitoring/reef/sops.html

[2] http://data.aims.gov.au/reef-page-plots/reefmon.zip

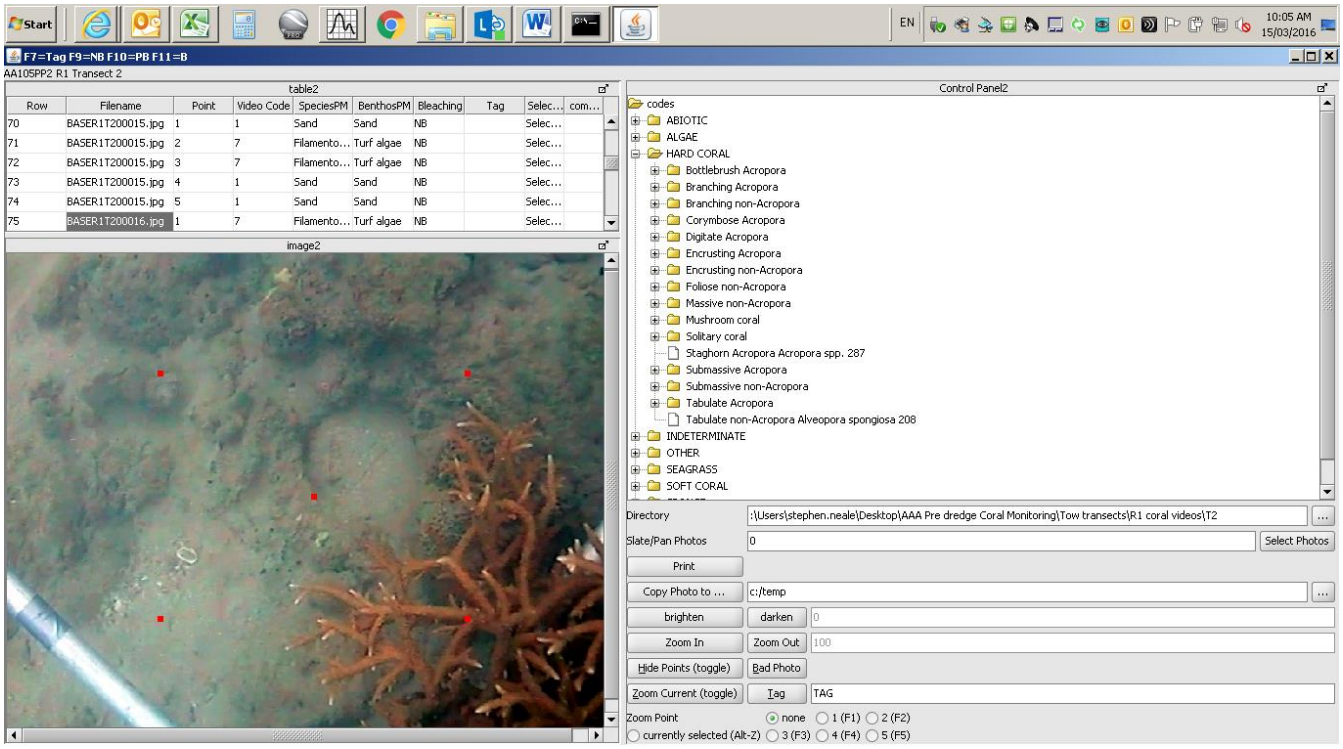


Figure 2-2 Screen shot of the AIMS Reefmon data entry screen showing five fixed points superimposed onto a captured still from site R1

2.2.2 Data QAQC

For each survey trip, forty images were chosen across all sites which represent of range of benthic groups encountered during the analysis. These images were analysed by both experienced analysts (Steve Neale and Cathie Page) independently; the results are presented in Table 2-2. The percentage cover estimates for the hard coral cover differed by only 0.5% between observers for the pre dredge and 2 month post dredging QAQC images – bolded in Table 2-2.

This 0.5% difference represents a difference between observers for this group of approximately 2.3% for a hard coral cover of 21.5% (pre dredging) and 2.2% for a hard coral cover of 22.5% (2 month post dredging). The largest differences between observers were in characterising the four broad categories, turf algae, macroalgae, sponge and sand. Reviewing the results indicated that the majority of the differences between observers were due to two issues; the point falling on a border of two different benthic groups (for example on the border between sand and turf algae on hard substrate or on the border between sponge and turf algae) and the interpretation between macroalge (fleshy structure) and turf algae (filamentous structure and encrusting like).

Table 2-2 Percentage cover results between observers for each broad benthic group for each survey

Benthic Group	pre dredging Survey 1			1 month post dredging Survey 2			2 month post dredging Survey 3		
	CP	SN	Difference	CP	SN	Difference	CP	SN	Difference
Indeterminate	2	1.5	-0.5	0	0	0.0	0.0	0	0.0
Hard Coral	**21**	**21.5**	**0.5**	**12.5**	**12.5**	**0.0**	**22.5**	**22**	**-0.5**
Macro Algae	9	10	1.0	15.5	18.5	3.0	12	12	0.0
Other	0	0	0.0	2	2	0.0	0	0	0.0
Sand	28.5	30	1.5	36	34	-2.0	27.5	28.5	1.0
Sponge	9	10.5	1.5	3.5	2.5	-1.0	8	8	0.0
Soft Coral	2.5	2.5	0.0	0	0	0.0	0.0	0	0.0
Turf Algae	28	24	-4.0	30.5	30.5	0.0	30	29.5	-0.5

SN = Stephen Neale, CP=Cathie Page

3 Image Analysis Results

The results of the image analysis for the three surveys are represented as a series of box plots or tabulated statistical summaries broken into three different categories:

1. Site specific percentage covers of the broad benthic categories for each survey which includes Hard Coral, Soft Coral, Macroalgae, Sponges, Turf Algae, Sand, Other (e.g. Zooanthids, Ascidians and anemones), and Indeterminate are presented in Appendix A and Figure 3-1.

2. Percentage covers of hard coral cover for reference and concern sites (pooled) are presented in Table 3-1and Figure 3-2.

3. Percentage covers of each hard coral growth form for all reference and concern sites for all surveys are provided in Appendix B

Photographic examples of the typical benthic community encountered at each site are provided in Appendix C

Box plot description: The line within the box represents the mean percentage cover, the extent of box represents plus or minus the Standard Error (SE) and the whiskers represent plus or minus 2 standard deviations from the mean. The percentage cover values presented in the following sections are presented ±SE.

During survey 1, the mean hard coral percentage cover was highest at Site R2 (23.6±4.5%) and lowest at site I1 (4.4±1.0%; Appendix A and Figure 3-1). During survey 2, the mean hard coral percentage cover was highest at Site R2 (23.0±1.8%) and lowest at site I1 (2.8±1.6%). During survey 3, the mean hard coral percentage cover was highest at Site R2 (24.5±1.4%) and lowest at site I1 (2.8±1.0%). During all surveys the seafloor at all sites was dominated by sand, turf algae or macroalgae or combinations of these three groups.

The mean hard coral percentage cover at concern sites (pooled) was consistent across all surveys ranging from 9.3±1.4% during survey 2 to 10.7±2.2% during survey 3 (Table 3-1 and Figure 3-2). The mean hard coral percentage cover at reference sites (pooled) was approximately twice the cover observed at the concern sites and also consistent across all surveys ranging from 18.1±2.2% during survey 2 to 20.3±1.8% during survey 3.

The growth forms of the hard coral community differed at each site but were primarily dominated by encrusting, foliose and massive growth forms, which is typical of inshore reefs. Branching Acropora colonies were occasionally found at sites I3 and R2 (Appendix B).

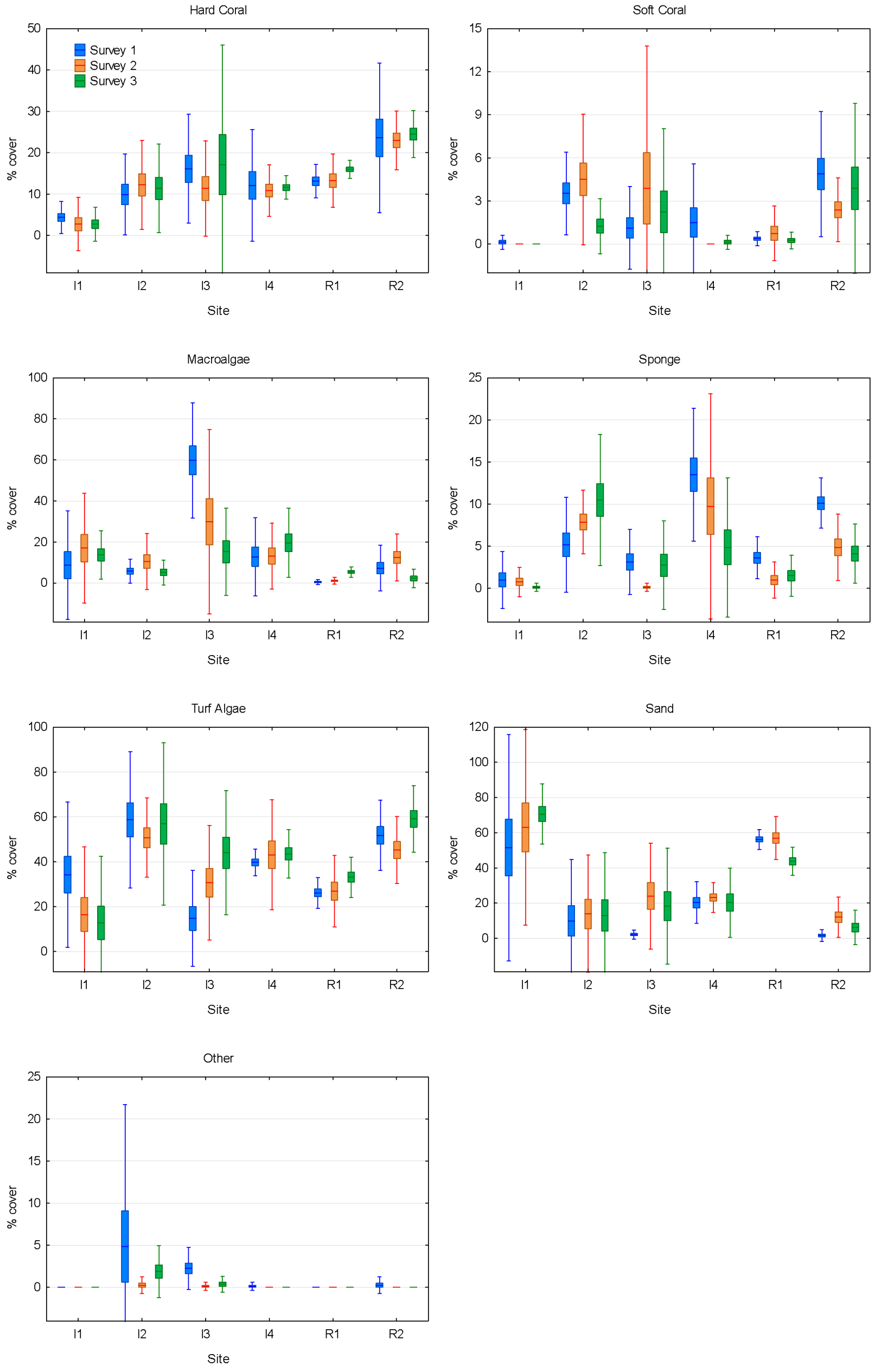


Figure 3-1 Percentage cover of the broad benthic groups at each site for each survey

Table 3-1 Hard coral cover at concern and reference sites (pooled) during each survey

Survey	Description	n	Mean	Min	Max	Std.Dev.	Standard Error
1	Concern	16	10.6	2.5	22.5	6.5	1.6
1	Reference	8	18.4	11.5	34.5	8.3	2.9
2	Concern	16	9.3	0.5	18.5	5.7	1.4
2	Reference	8	18.1	11.0	26.0	6.1	2.2
3	Concern	16	10.7	0.0	38.5	8.8	2.2
3	Reference	8	20.3	15.0	28.0	5.0	1.8

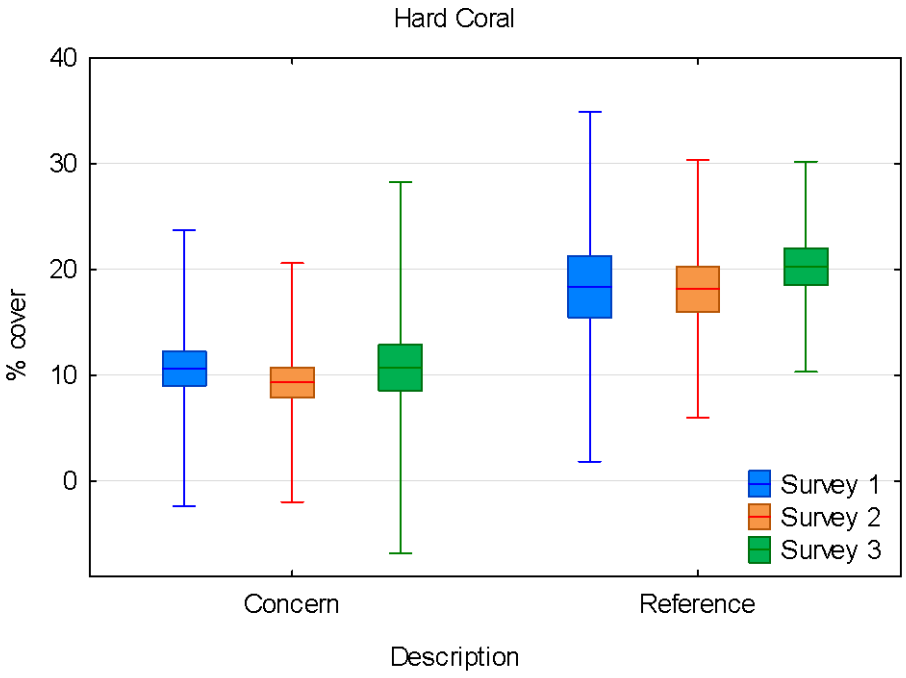


Figure 3-2 Percentage cover of the broad benthic groups for reference and concern sites (pooled) during each survey

3.1.1 Coral Health

Hard and soft coral bleaching was observed during all surveys and at all sites (Appendix D and Figure 3-4), peaking during survey 2. The percentage cover of hard and soft coral bleaching during each survey when data from all reference and concern sites are pooled is provided in Table 3-2 and Figure 3-5. Refer to previous section for box plot description.

During survey 1, the highest mean hard coral bleaching of 2.0±0.9% and soft coral bleaching of 2.8±0.5% was recorded at reference site R2 where the highest coral cover was also observed. The remaining sites recorded between 0% and 0.8% mean hard and soft coral bleaching. Examples of the hard and soft coral bleaching observed at reference site R2 are provided in Figure 3-3.

Hard and soft coral bleaching was generally higher at all sites during survey 2. The highest mean hard coral bleaching of 14.3±1.2% was recorded at reference site R2 which represented over 50% of all coral observed. The mean soft coral bleaching of 4.3±1.1% was recorded at concern site I2.

During survey 3, hard and soft coral bleaching returned to the levels recorded during survey 1, the highest mean hard coral and soft coral bleaching of 2.4±0.2% and 1.0±1.5%, respectively was recorded at Reference Site R2. At all remaining sites the mean percentage hard and soft coral bleaching was below 2%.

When the site data is pooled into concern and reference sites, the highest mean hard coral bleaching of 10.6±1.5% and 3.9±0.8% occurred at reference and concern sites, respectively, during survey 2. During this survey the percentage cover of bleached corals was consistent across both reference and concern sites representing approximately half of all hard corals recorded.

During all surveys no unusual amounts of sediment on coral, coral disease or obvious coral mucous was observed.

Figure 3-3 Examples of bleached hard and soft corals from Reference Site 2 (R2). Top left – *Porites* spp. Top Right small bleached and non-bleached soft coral colonies. Bottom left -bleached *Turbinaria* spp. Corals, Bottom Right – bleached Turbinaria spp. Adjacent to non-bleached *Turbinaria* spp.

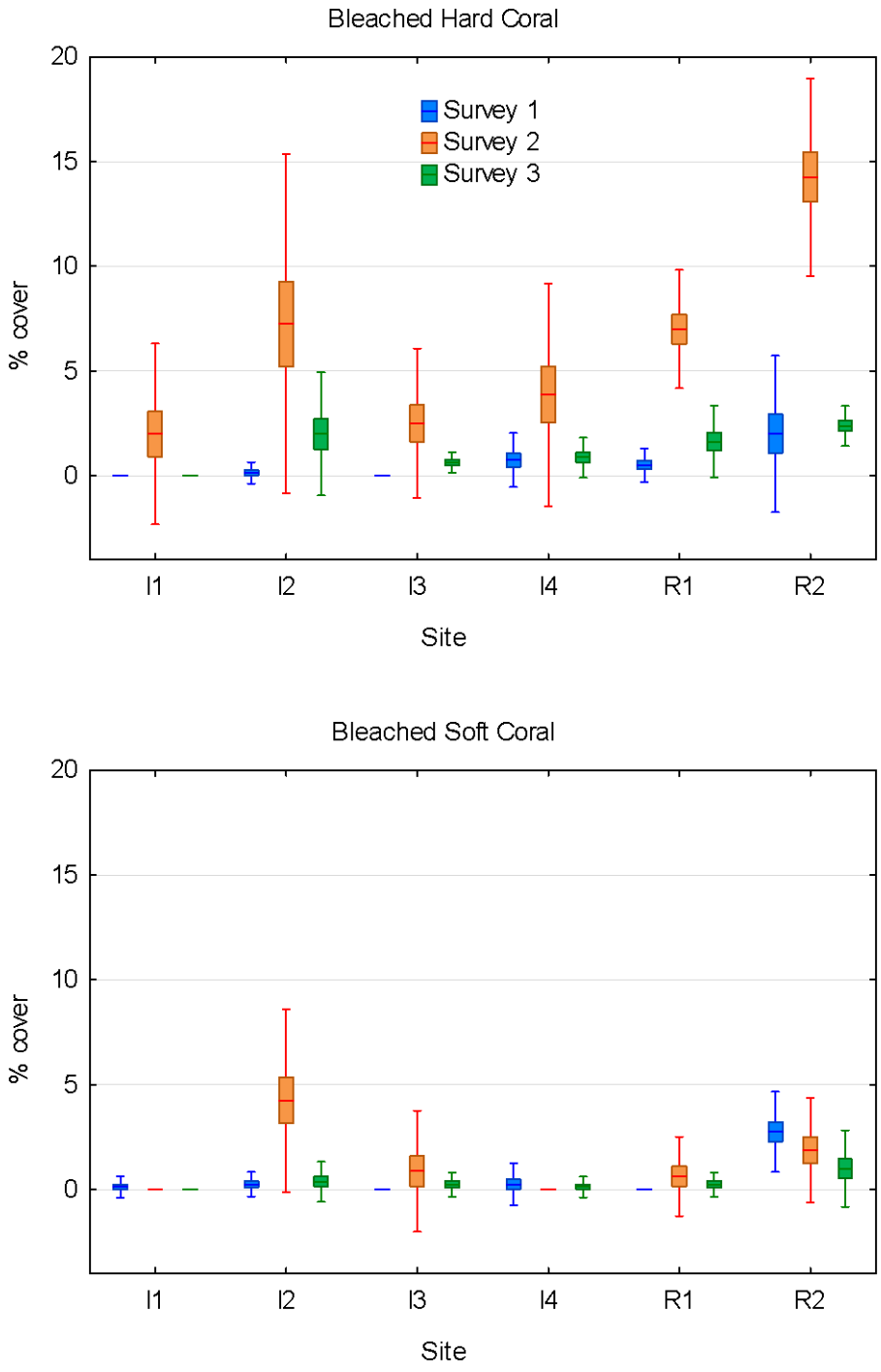


Figure 3-4 Percentage cover of bleached hard and soft corals at each site for each survey

Table 3-2 Hard and soft coral bleaching data for reference and concern sites (pooled) during each survey

Benthic Group	Survey	Site	n	Mean	Min	Max	Std.Dev.	Standard Error
Hard Coral	1	Concern	16	0.2	0.0	1.5	0.4	0.1
Soft Coral	1	Concern	16	0.2	0.0	1.0	0.3	0.1
Hard Coral	1	Reference	8	1.3	0.0	4.5	1.5	0.5
Soft Coral	1	Reference	8	1.4	0.0	4.0	1.6	0.6
Hard Coral	2	Concern	16	3.9	0.0	11.0	3.3	0.8
Soft Coral	2	Concern	16	1.3	0.0	6.0	2.2	0.5
Hard Coral	2	Reference	8	10.6	5.0	17.5	4.3	1.5
Soft Coral	2	Reference	8	1.3	0.0	3.5	1.2	0.4
Hard Coral	3	Concern	16	0.9	0.0	3.5	1.0	0.3
Soft Coral	3	Concern	16	0.2	0.0	1.0	0.3	0.1
Hard Coral	3	Reference	8	2.0	0.5	3.0	0.8	0.3
Soft Coral	3	Reference	8	0.6	0.0	2.0	0.7	0.3

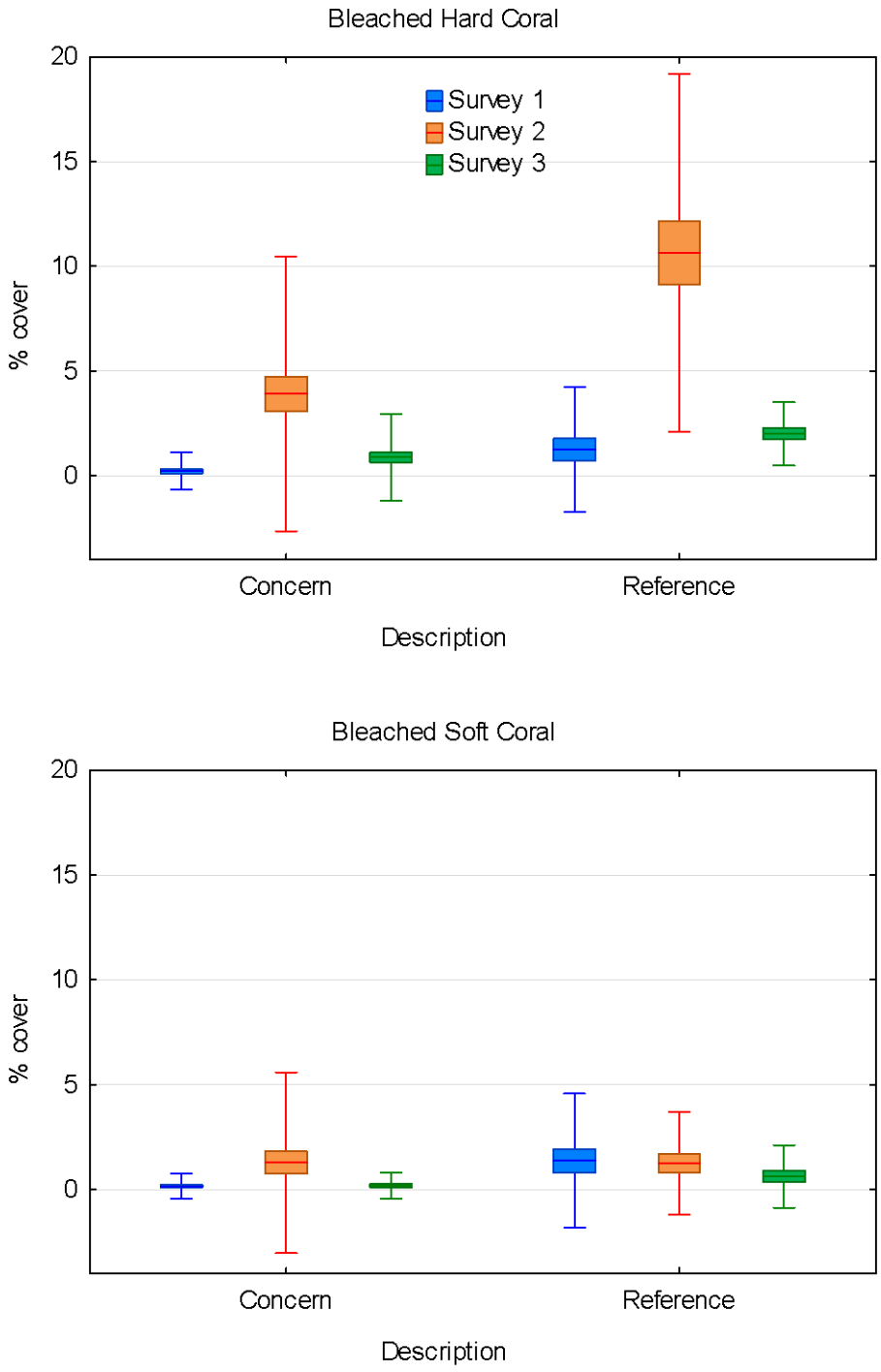


Figure 3-5 Hard and soft coral bleaching percentage cover for each survey when data is pooled at the concern and reference level

3.1.2 Power analysis of pre dredging data

The results of the power analysis on the pre dredging data are detailed in the *Baseline Coral Health Monitoring Report* (301310-09660-EN-REP-0002). The aim of the power analysis was to confirm that statistical power is sufficient to detect a 10% change in coral cover between sites and between the baseline and subsequent sampling trips. The results showed that a 10% change in coral cover would be considered to be a large effect size. The power to detect an effect this size with the sampling design is 1.00, which is the highest possible probability of detecting an effect if one is actually present.

3.1.3 Statistical analysis

An Analysis of Variance (ANOVA) using a linear mixed effect model in Minitab 17 was performed on the percentage cover data from all surveys for the benthic group - Hard Coral. The analysis examined the significance of three factors:

- Survey number
- Site
- Transect (nested within Site)

Prior to the analysis the hard coral percentage cover data was transformed. The result of the analysis is provided in Table 3-3. Significant interactions ($p<0.05$) are bolded in this table.

There was a significant difference in hard coral cover between sites ($P=0.000$) but no significant difference was found for the interaction between Site and Survey number for hard coral cover ($p>0.05$). This suggests that there has been no statistically detectable change in hard coral cover across sites over time. In addition the linear model used had reasonably high adjusted r-squared values (>40%) which provides confidence that the model captures a substantial proportion of local environmental variability.

Table 3-3 Summary results of the statistical analysis of changes in hard coral cover over time

Factor	Degrees of freedom	Adjusted Sum of Squares	Adjusted Mean Square	F-Value	P-Value
Survey	2	0.003284	0.001642	0.52	0.602
Reef	5	0.262847	0.052569	17.77	**0.000**
Transect (Reef)	18	0.053239	0.002958	0.93	0.554
Survey x Reef	10	0.008956	0.000896	0.28	0.982
Error	36	0.114751	0.003188		
Total	71	0.443076			

4 Conclusion

Hard coral cover on four 30m long towed video transects at each of four concern sites and two reference sites was measured prior to dredging (February 2016), approximately one month post dredging (May 2016) and approximately two months after dredging (June 2016). Analysis of the results found no statistical difference (or change) in the hard coral cover at each site across the three surveys. Coral bleaching was evident during all surveys and peaked during the May 2016 survey; predominately at the reference sites where hard coral cover was the highest.

The dominant hard corals found at each site were form the genera Turbinaria spp and Porites spp and from the Faviidae family; all are typically found in turbid inshore environments. The growth forms of the hard coral community differed at each site but were primarily dominated by encrusting, foliose and massive growth forms, also typical of growth forms found at inshore reefs

Visual signs of stress such as excessive mucous were not observed on coral colonies at any site during any survey. Small amounts of sediment were observed on *Turbinaria* spp. corals (refer to Figure 3-3 lower right image) which is typical for species with a cup (or foliose) shaped growth form. No amounts of sediment on coral colonies with other growth forms (encrusting, massive or branching) was observed on the video transects at any site during any survey.

The dredging operations did not appear to cause any loss of hard coral cover at sites of concern nor cause any sedimentation related stress. The temporal (February 2016 to June 2016) and spatial (all sites of concern and reference sites) scale of the coral bleaching recorded make it highly unlikely that the bleaching was in any way caused or exacerbated by the dredge related activities. The bleaching appears to be related to the wider sustained elevations of sea temperatures observed across northern tropical waters between February and April 2016 (BOM 2016); which was responsible for wide scale coral bleaching observed in the Northern GBR.

5 References

AIMS (2004). Australian Institute of Marine Science Standard Operational Procedure Number 2 - Surveys of Benthic Reef Communities Using Underwater Video.

AIMS (2008). Australian Institute of Marine Science Standard Operational Procedure Number 10 - Surveys of Benthic Reef Communities Using Underwater Digital Photography and Counts of Juvenile Corals.

BOM (2016). Bureau of Metrology ENSO Wrap-Up archive – Current State of the Pacific and Indian Ocean sea surface temperatures (weekly and monthly), available online at: http://www.bom.gov.au/climate/enso/wrap-up/archive.shtml

Appendix A: Survey and Site Benthic Group Data statistical summary

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard Error
Hard Coral	1	I1	4	4.4	2.5	7.0	1.9	1.0
Soft Coral	1	I1	4	0.1	0.0	0.5	0.3	0.1
Macroalgae	1	I1	4	8.8	0.0	28.5	13.3	6.6
Sponge	1	I1	4	1.0	0.0	3.5	1.7	0.8
Turf algae	1	I1	4	34.3	19.5	55.0	16.2	8.1
Sand	1	I1	4	51.5	5.5	74.0	32.2	16.1
Other	1	I1	4	0.0	0.0	0.0	0.0	0.0
Indeterminate	1	I1	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	1	I2	4	9.9	5.0	14.4	4.9	2.4
Soft Coral	1	I2	4	3.5	2.1	5.0	1.4	0.7
Macroalgae	1	I2	4	5.8	1.5	7.7	2.9	1.5
Sponge	1	I2	4	5.2	3.0	9.0	2.8	1.4
Turf algae	1	I2	4	58.7	42.0	77.0	15.2	7.6
Sand	1	I2	4	9.9	0.0	36.0	17.4	8.7
Other	1	I2	4	4.9	0.0	17.4	8.4	4.2
Indeterminate	1	I2	4	2.0	0.0	3.6	1.6	0.8
Hard Coral	1	I3	4	16.1	9.5	22.5	6.6	3.3

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard Error
Soft Coral	1	I3	4	1.1	0.0	3.0	1.4	0.7
Macroalgae	1	I3	4	59.8	44.5	74.5	14.1	7.0
Sponge	1	I3	4	3.1	2.0	6.0	1.9	1.0
Turf algae	1	I3	4	14.8	4.0	29.0	10.7	5.3
Sand	1	I3	4	2.1	1.0	4.0	1.3	0.7
Other	1	I3	4	2.3	0.5	3.5	1.3	0.6
Indeterminate	1	I3	4	0.8	0.0	1.5	0.9	0.4
Hard Coral	1	I4	4	12.1	7.0	21.5	6.7	3.4
Soft Coral	1	I4	4	1.5	0.0	4.5	2.0	1.0
Macroalgae	1	I4	4	12.8	7.0	27.0	9.5	4.8
Sponge	1	I4	4	13.5	9.0	18.5	3.9	2.0
Turf algae	1	I4	4	39.8	37.5	44.0	3.0	1.5
Sand	1	I4	4	20.3	14.0	28.0	5.9	3.0
Other	1	I4	4	0.1	0.0	0.5	0.3	0.1
Indeterminate	1	I4	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	1	R1	4	13.1	11.5	16.0	2.0	1.0
Soft Coral	1	R1	4	0.4	0.0	0.5	0.3	0.1
Macroalgae	1	R1	4	0.5	0.0	1.0	0.6	0.3
Sponge	1	R1	4	3.6	2.0	5.0	1.3	0.6
Turf algae	1	R1	4	26.1	23.0	31.0	3.4	1.7

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard Error
Sand	1	R1	4	56.1	53.5	60.0	2.9	1.4
Other	1	R1	4	0.0	0.0	0.0	0.0	0.0
Indeterminate	1	R1	4	0.1	0.0	0.5	0.3	0.1
Hard Coral	1	R2	4	23.6	15.0	34.5	9.0	4.5
Soft Coral	1	R2	4	4.9	2.0	7.0	2.2	1.1
Macroalgae	1	R2	4	7.3	2.0	13.0	5.6	2.8
Sponge	1	R2	4	10.1	8.5	12.0	1.5	0.7
Turf algae	1	R2	4	51.8	44.5	58.5	7.8	3.9
Sand	1	R2	4	1.6	0.0	3.5	1.7	0.8
Other	1	R2	4	0.3	0.0	1.0	0.5	0.3
Indeterminate	1	R2	4	0.5	0.0	1.0	0.6	0.3
Hard Coral	2	I1	4	2.8	0.5	7.5	3.2	1.6
Soft Coral	2	I1	4	0.0	0.0	0.0	0.0	0.0
Macroalgae	2	I1	4	17.0	1.5	33.5	13.4	6.7
Sponge	2	I1	4	0.8	0.0	2.0	0.9	0.4
Turf algae	2	I1	4	16.5	0.0	36.0	15.1	7.5
Sand	2	I1	4	63.0	38.5	97.5	27.8	13.9
Other	2	I1	4	0.0	0.0	0.0	0.0	0.0
Indeterminate	2	I1	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	2	I2	4	12.3	5.0	17.0	5.4	2.7

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard Error
Soft Coral	2	I2	4	4.5	1.5	6.5	2.3	1.1
Macroalgae	2	I2	4	10.5	2.0	16.5	6.8	3.4
Sponge	2	I2	4	7.9	6.0	9.5	1.9	0.9
Turf algae	2	I2	4	50.8	42.0	63.0	8.8	4.4
Sand	2	I2	4	13.9	2.0	37.5	16.7	8.4
Other	2	I2	4	0.3	0.0	1.0	0.5	0.3
Indeterminate	2	I2	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	2	I3	4	11.4	6.0	18.5	5.8	2.9
Soft Coral	2	I3	4	3.9	0.5	11.0	5.0	2.5
Macroalgae	2	I3	4	29.9	14.0	63.0	22.5	11.3
Sponge	2	I3	4	0.1	0.0	0.5	0.3	0.1
Turf algae	2	I3	4	30.6	16.0	46.5	12.8	6.4
Sand	2	I3	4	24.0	6.0	42.5	15.1	7.5
Other	2	I3	4	0.1	0.0	0.5	0.3	0.1
Indeterminate	2	I3	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	2	I4	4	10.9	7.5	15.0	3.1	1.5
Soft Coral	2	I4	4	0.0	0.0	0.0	0.0	0.0
Macroalgae	2	I4	4	13.1	2.5	20.0	8.0	4.0
Sponge	2	I4	4	9.8	3.0	19.0	6.7	3.3
Turf algae	2	I4	4	43.1	29.5	59.0	12.3	6.1

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard Error
Sand	2	I4	4	23.1	18.5	28.0	4.2	2.1
Other	2	I4	4	0.0	0.0	0.0	0.0	0.0
Indeterminate	2	I4	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	2	R1	4	13.3	11.0	18.0	3.2	1.6
Soft Coral	2	R1	4	0.8	0.0	2.0	1.0	0.5
Macroalgae	2	R1	4	1.1	0.0	2.0	0.9	0.4
Sponge	2	R1	4	1.0	0.0	2.5	1.1	0.5
Turf algae	2	R1	4	26.9	16.5	35.5	8.0	4.0
Sand	2	R1	4	57.0	49.5	64.5	6.1	3.1
Other	2	R1	4	0.0	0.0	0.0	0.0	0.0
Indeterminate	2	R1	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	2	R2	4	23.0	18.0	26.0	3.6	1.8
Soft Coral	2	R2	4	2.4	1.5	4.0	1.1	0.6
Macroalgae	2	R2	4	12.5	5.0	18.5	5.8	2.9
Sponge	2	R2	4	4.9	2.5	6.5	2.0	1.0
Turf algae	2	R2	4	45.3	35.0	52.0	7.5	3.8
Sand	2	R2	4	12.0	6.5	20.0	5.7	2.9
Other	2	R2	4	0.0	0.0	0.0	0.0	0.0
Indeterminate	2	R2	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	3	I1	4	2.8	0.0	5.0	2.1	1.0

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard Error
Soft Coral	3	I1	4	0.0	0.0	0.0	0.0	0.0
Macroalgae	3	I1	4	13.8	6.0	20.0	5.9	3.0
Sponge	3	I1	4	0.1	0.0	0.5	0.3	0.1
Turf algae	3	I1	4	12.8	1.5	34.5	14.8	7.4
Sand	3	I1	4	70.6	59.5	79.5	8.6	4.3
Other	3	I1	4	0.0	0.0	0.0	0.0	0.0
Indeterminate	3	I1	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	3	I2	4	11.4	5.0	16.5	5.3	2.7
Soft Coral	3	I2	4	1.3	0.0	2.0	1.0	0.5
Macroalgae	3	I2	4	5.1	1.5	8.5	3.0	1.5
Sponge	3	I2	4	10.5	5.5	15.0	3.9	1.9
Turf algae	3	I2	4	56.9	31.5	71.0	18.1	9.0
Sand	3	I2	4	13.0	1.5	39.5	17.8	8.9
Other	3	I2	4	1.9	0.5	4.0	1.5	0.8
Indeterminate	3	I2	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	3	I3	4	17.1	8.0	38.5	14.5	7.2
Soft Coral	3	I3	4	2.3	0.0	6.5	2.9	1.5
Macroalgae	3	I3	4	15.3	7.5	31.0	10.7	5.3
Sponge	3	I3	4	2.8	0.0	5.0	2.6	1.3
Turf algae	3	I3	4	44.0	30.0	61.5	13.8	6.9

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard Error
Sand	3	I3	4	18.3	6.0	42.5	16.4	8.2
Other	3	I3	4	0.4	0.0	1.0	0.5	0.2
Indeterminate	3	I3	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	3	I4	4	11.6	10.0	13.5	1.4	0.7
Soft Coral	3	I4	4	0.1	0.0	0.5	0.3	0.1
Macroalgae	3	I4	4	19.6	11.0	30.5	8.4	4.2
Sponge	3	I4	4	4.9	2.0	11.0	4.1	2.1
Turf algae	3	I4	4	43.5	36.5	49.5	5.4	2.7
Sand	3	I4	4	20.3	13.0	34.5	9.8	4.9
Other	3	I4	4	0.0	0.0	0.0	0.0	0.0
Indeterminate	3	I4	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	3	R1	4	16.0	15.0	17.5	1.1	0.5
Soft Coral	3	R1	4	0.3	0.0	0.5	0.3	0.1
Macroalgae	3	R1	4	5.4	4.0	7.0	1.3	0.6
Sponge	3	R1	4	1.5	0.5	3.0	1.2	0.6
Turf algae	3	R1	4	33.1	29.0	39.5	4.5	2.2
Sand	3	R1	4	43.8	38.0	47.0	4.0	2.0
Other	3	R1	4	0.0	0.0	0.0	0.0	0.0
Indeterminate	3	R1	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	3	R2	4	24.5	21.5	28.0	2.9	1.4

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard Error
Soft Coral	3	R2	4	3.9	1.0	8.0	3.0	1.5
Macroalgae	3	R2	4	2.3	0.5	5.5	2.2	1.1
Sponge	3	R2	4	4.1	2.0	6.0	1.8	0.9
Turf algae	3	R2	4	59.1	50.5	66.5	7.4	3.7
Sand	3	R2	4	6.1	1.5	13.0	4.9	2.4
Other	3	R2	4	0.0	0.0	0.0	0.0	0.0
Indeterminate	3	R2	4	0.0	0.0	0.0	0.0	0.0

Appendix B: Survey and Site Hard Coral Growth Form data statistical summary

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard
Branching Acropora	1	I1	4	0.1	0.0	0.5	0.3	0.1
Branching non-Acropora	1	I1	4	0.5	0.0	1.5	0.7	0.4
Encrusting non-Acropora	1	I1	4	1.9	0.5	3.5	1.4	0.7
Foliose non-Acropora	1	I1	4	0.1	0.0	0.5	0.3	0.1
Massive non-Acropora	1	I1	4	1.8	0.0	3.0	1.3	0.7
Submassive non-Acropora	1	I1	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	1	I1	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	1	I2	4	0.3	0.0	0.5	0.3	0.1
Branching non-Acropora	1	I2	4	0.1	0.0	0.5	0.3	0.1
Encrusting non-Acropora	1	I2	4	3.9	1.5	6.0	2.5	1.2
Foliose non-Acropora	1	I2	4	3.4	2.5	4.5	0.9	0.4
Massive non-Acropora	1	I2	4	5.5	3.5	7.0	1.5	0.7
Submassive non-Acropora	1	I2	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	1	I2	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	1	I3	4	0.3	0.0	0.5	0.3	0.1
Branching non-Acropora	1	I3	4	0.1	0.0	0.5	0.3	0.1
Encrusting non-Acropora	1	I3	4	3.1	1.0	6.7	2.7	1.3
Foliose non-Acropora	1	I3	4	4.2	2.5	5.6	1.3	0.7

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard
Massive non-Acropora	1	I3	4	2.3	1.5	4.1	1.2	0.6
Submassive non-Acropora	1	I3	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	1	I3	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	1	I4	4	3.0	0.0	7.0	3.2	1.6
Branching non-Acropora	1	I4	4	0.3	0.0	0.5	0.3	0.1
Encrusting non-Acropora	1	I4	4	2.1	1.5	2.5	0.5	0.2
Foliose non-Acropora	1	I4	4	15.4	11.0	22.5	5.5	2.8
Massive non-Acropora	1	I4	4	2.9	0.0	9.0	4.1	2.1
Submassive non-Acropora	1	I4	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	1	I4	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	1	R1	4	3.0	0.0	7.0	3.0	1.5
Branching non-Acropora	1	R1	4	0.0	0.0	0.0	0.0	0.0
Encrusting non-Acropora	1	R1	4	2.9	1.0	4.5	1.5	0.7
Foliose non-Acropora	1	R1	4	6.6	3.0	10.5	3.1	1.5
Massive non-Acropora	1	R1	4	3.6	0.5	8.0	3.3	1.6
Submassive non-Acropora	1	R1	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	1	R1	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	1	R2	4	1.3	0.0	3.5	1.6	0.8
Branching non-Acropora	1	R2	4	0.0	0.0	0.0	0.0	0.0
Encrusting non-Acropora	1	R2	4	4.4	2.5	9.0	3.1	1.6

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard
Foliose non-Acropora	1	R2	4	2.6	0.5	4.0	1.5	0.8
Massive non-Acropora	1	R2	4	3.9	1.0	6.5	2.3	1.1
Submassive non-Acropora	1	R2	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	1	R2	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	2	I1	4	0.0	0.0	0.0	0.0	0.0
Branching non-Acropora	2	I1	4	0.0	0.0	0.0	0.0	0.0
Encrusting non-Acropora	2	I1	4	0.5	0.0	2.0	1.0	0.5
Foliose non-Acropora	2	I1	4	0.3	0.0	0.5	0.3	0.1
Massive non-Acropora	2	I1	4	2.0	0.5	5.5	2.4	1.2
Submassive non-Acropora	2	I1	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	2	I1	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	2	I2	4	0.0	0.0	0.0	0.0	0.0
Branching non-Acropora	2	I2	4	0.3	0.0	1.0	0.5	0.3
Encrusting non-Acropora	2	I2	4	4.5	1.5	11.5	4.7	2.4
Foliose non-Acropora	2	I2	4	2.8	1.5	4.0	1.0	0.5
Massive non-Acropora	2	I2	4	5.8	3.5	8.0	1.8	0.9
Submassive non-Acropora	2	I2	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	2	I2	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	2	I3	4	0.0	0.0	0.0	0.0	0.0
Branching non-Acropora	2	I3	4	0.0	0.0	0.0	0.0	0.0

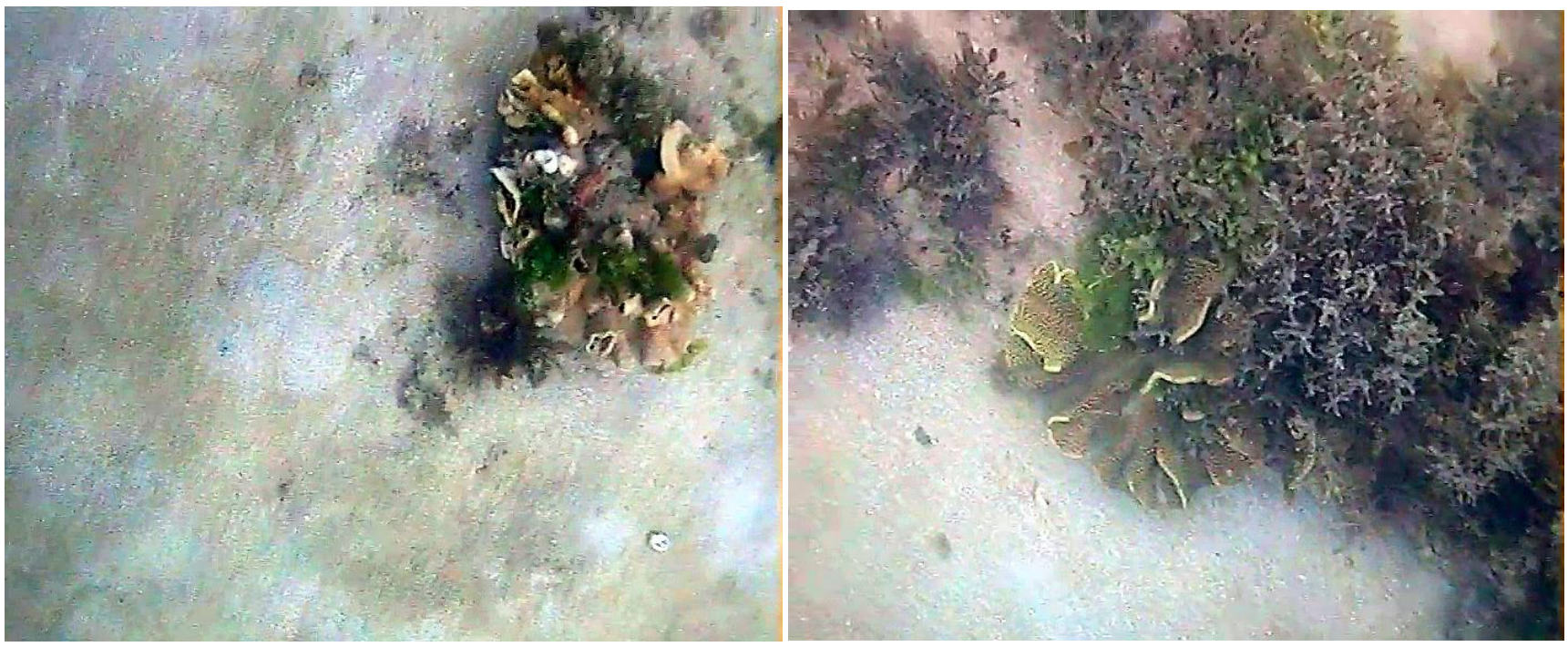
Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard
Encrusting non-Acropora	2	I3	4	5.4	1.5	8.5	3.2	1.6
Foliose non-Acropora	2	I3	4	4.4	1.5	8.0	3.0	1.5
Massive non-Acropora	2	I3	4	2.5	0.5	4.0	1.6	0.8
Submassive non-Acropora	2	I3	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	2	I3	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	2	I4	4	0.3	0.0	0.5	0.3	0.1
Branching non-Acropora	2	I4	4	0.0	0.0	0.0	0.0	0.0
Encrusting non-Acropora	2	I4	4	3.3	1.5	5.5	2.1	1.0
Foliose non-Acropora	2	I4	4	16.4	13.5	18.5	2.1	1.0
Massive non-Acropora	2	I4	4	3.1	1.5	5.5	1.7	0.9
Submassive non-Acropora	2	I4	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	2	I4	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	2	R1	4	0.1	0.0	0.5	0.3	0.1
Branching non-Acropora	2	R1	4	0.1	0.0	0.5	0.3	0.1
Encrusting non-Acropora	2	R1	4	1.5	1.0	2.5	0.7	0.4
Foliose non-Acropora	2	R1	4	5.6	2.0	9.5	3.7	1.8
Massive non-Acropora	2	R1	4	2.6	1.5	3.5	0.9	0.4
Submassive non-Acropora	2	R1	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	2	R1	4	1.4	0.0	5.5	2.8	1.4
Branching Acropora	2	R2	4	0.0	0.0	0.0	0.0	0.0

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard
Branching non-Acropora	2	R2	4	2.1	0.0	6.5	3.0	1.5
Encrusting non-Acropora	2	R2	4	3.0	2.0	4.0	0.8	0.4
Foliose non-Acropora	2	R2	4	2.3	1.5	4.0	1.2	0.6
Massive non-Acropora	2	R2	4	3.5	3.0	5.0	1.0	0.5
Submassive non-Acropora	2	R2	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	2	R2	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	3	I1	4	0.0	0.0	0.0	0.0	0.0
Branching non-Acropora	3	I1	4	0.0	0.0	0.0	0.0	0.0
Encrusting non-Acropora	3	I1	4	1.4	0.0	2.5	1.1	0.6
Foliose non-Acropora	3	I1	4	1.0	0.0	3.0	1.4	0.7
Massive non-Acropora	3	I1	4	0.4	0.0	1.5	0.8	0.4
Submassive non-Acropora	3	I1	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	3	I1	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	3	I2	4	0.0	0.0	0.0	0.0	0.0
Branching non-Acropora	3	I2	4	0.3	0.0	0.5	0.3	0.1
Encrusting non-Acropora	3	I2	4	4.5	0.0	10.0	4.6	2.3
Foliose non-Acropora	3	I2	4	7.0	2.5	11.5	4.4	2.2
Massive non-Acropora	3	I2	4	4.3	3.0	5.5	1.2	0.6
Submassive non-Acropora	3	I2	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	3	I2	4	0.0	0.0	0.0	0.0	0.0

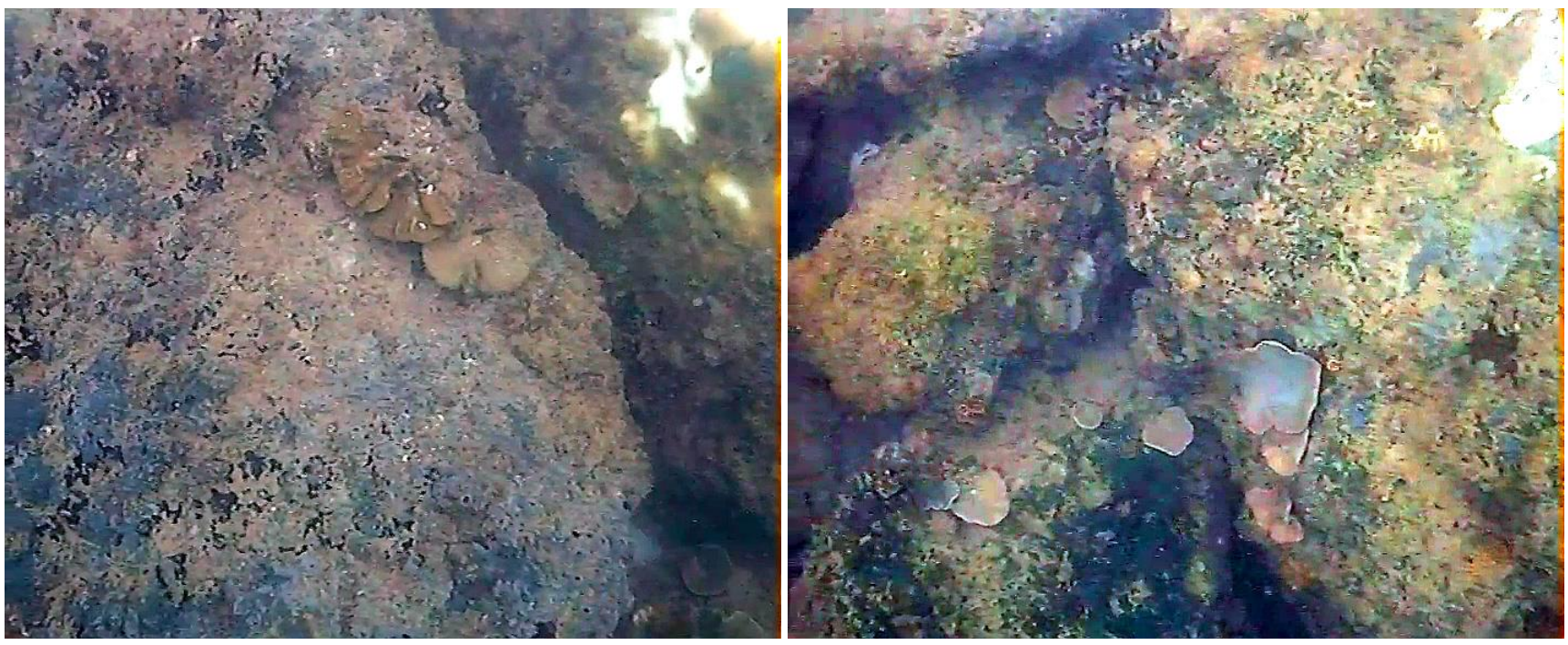
Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard
Branching Acropora	3	I3	4	0.3	0.0	0.5	0.3	0.1
Branching non-Acropora	3	I3	4	0.0	0.0	0.0	0.0	0.0
Encrusting non-Acropora	3	I3	4	3.5	2.0	7.5	2.7	1.3
Foliose non-Acropora	3	I3	4	5.4	1.5	8.5	3.2	1.6
Massive non-Acropora	3	I3	4	2.3	1.0	4.5	1.6	0.8
Submassive non-Acropora	3	I3	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	3	I3	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	3	I4	4	0.5	0.0	1.0	0.6	0.3
Branching non-Acropora	3	I4	4	0.0	0.0	0.0	0.0	0.0
Encrusting non-Acropora	3	I4	4	2.4	0.0	7.0	3.1	1.6
Foliose non-Acropora	3	I4	4	17.8	11.5	24.0	5.2	2.6
Massive non-Acropora	3	I4	4	3.8	1.0	6.5	2.3	1.2
Submassive non-Acropora	3	I4	4	0.1	0.0	0.5	0.3	0.1
Tabulate Acropora	3	I4	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	3	R1	4	1.6	0.0	3.5	1.7	0.8
Branching non-Acropora	3	R1	4	0.0	0.0	0.0	0.0	0.0
Encrusting non-Acropora	3	R1	4	6.9	0.5	23.0	10.8	5.4
Foliose non-Acropora	3	R1	4	6.4	2.0	11.5	4.1	2.0
Massive non-Acropora	3	R1	4	2.3	1.5	3.0	0.6	0.3
Submassive non-Acropora	3	R1	4	0.0	0.0	0.0	0.0	0.0

Benthic Group	Survey	Site	n	Mean	Min	Max	Std. Dev	Standard
Tabulate Acropora	3	R1	4	0.0	0.0	0.0	0.0	0.0
Branching Acropora	3	R2	4	0.0	0.0	0.0	0.0	0.0
Branching non-Acropora	3	R2	4	0.9	0.0	2.0	0.9	0.4
Encrusting non-Acropora	3	R2	4	5.4	1.5	10.0	3.7	1.9
Foliose non-Acropora	3	R2	4	1.6	0.0	4.0	1.8	0.9
Massive non-Acropora	3	R2	4	3.8	2.0	8.0	2.9	1.4
Submassive non-Acropora	3	R2	4	0.0	0.0	0.0	0.0	0.0
Tabulate Acropora	3	R2	4	0.0	0.0	0.0	0.0	0.0

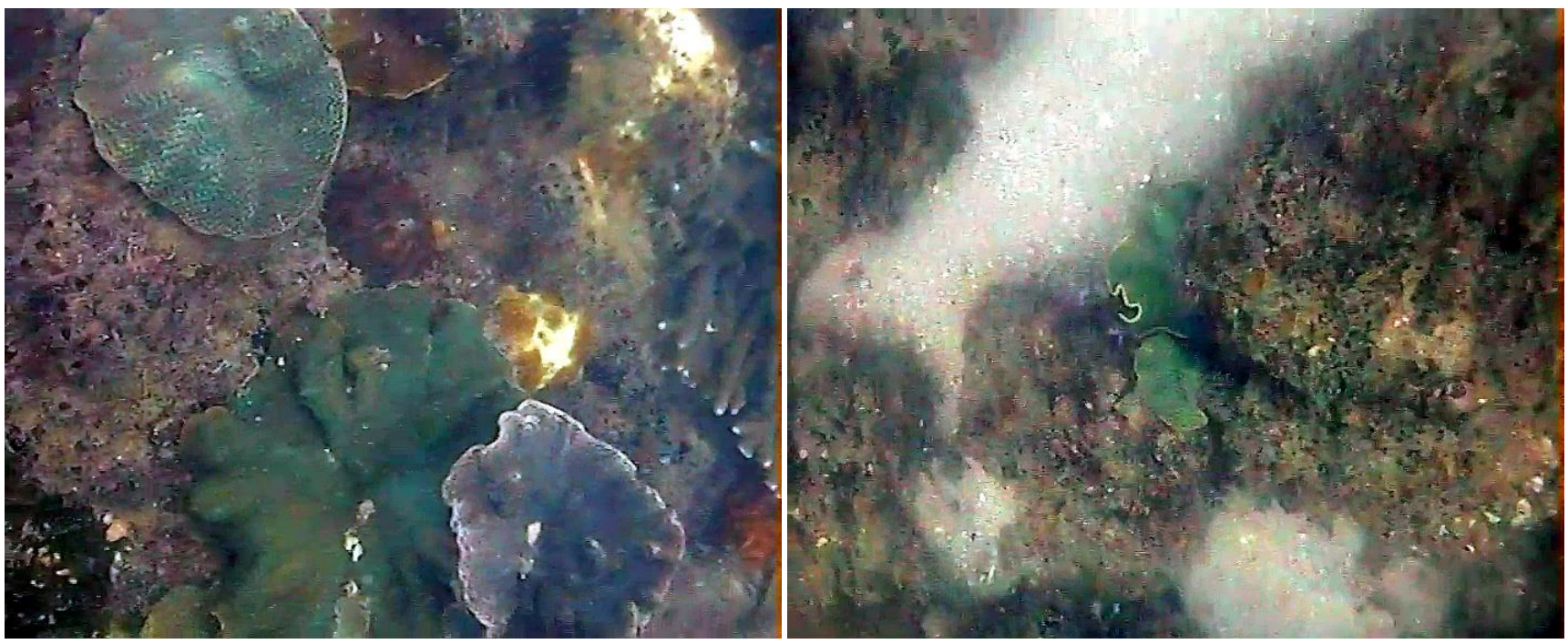
Appendix C: Examples of the typical benthic community at each site



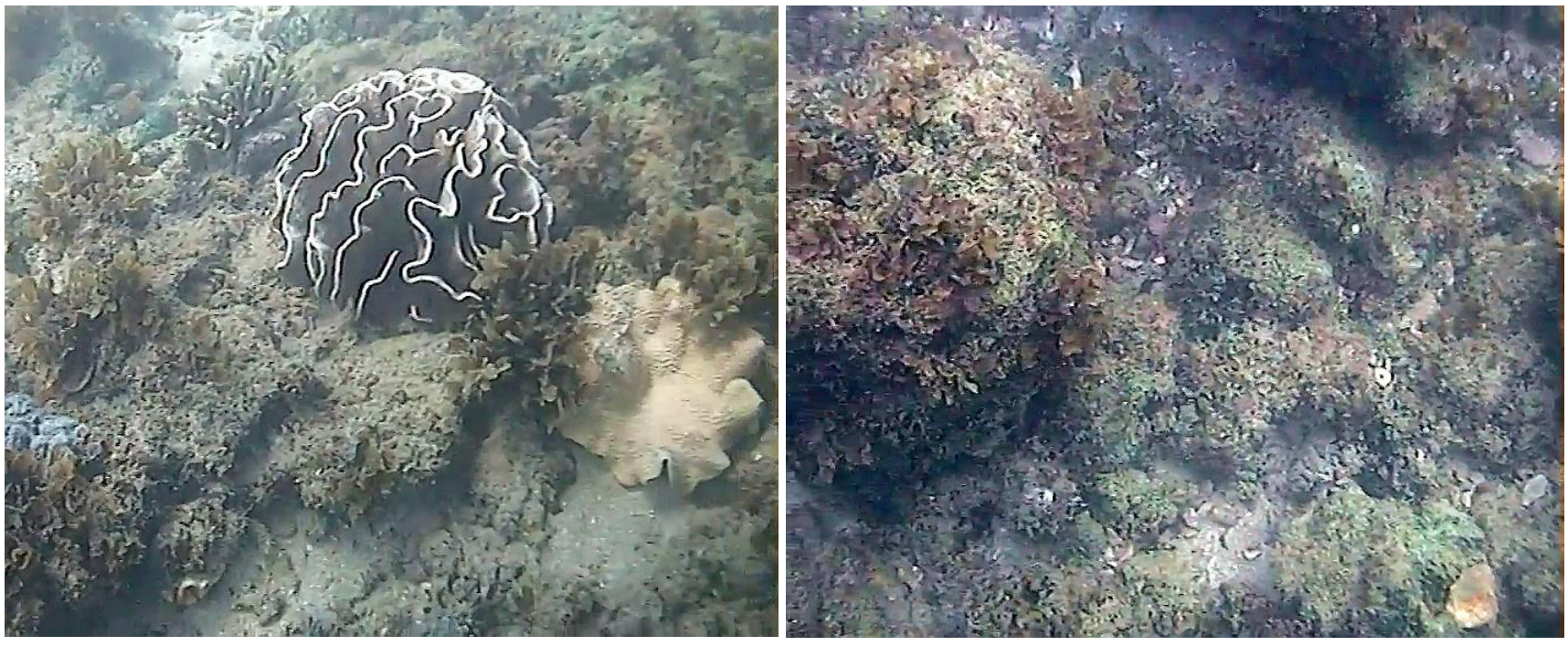
Typical benthic community found at Concern **Site I1** – large patches of sand with occasional hard corals and macroalgae



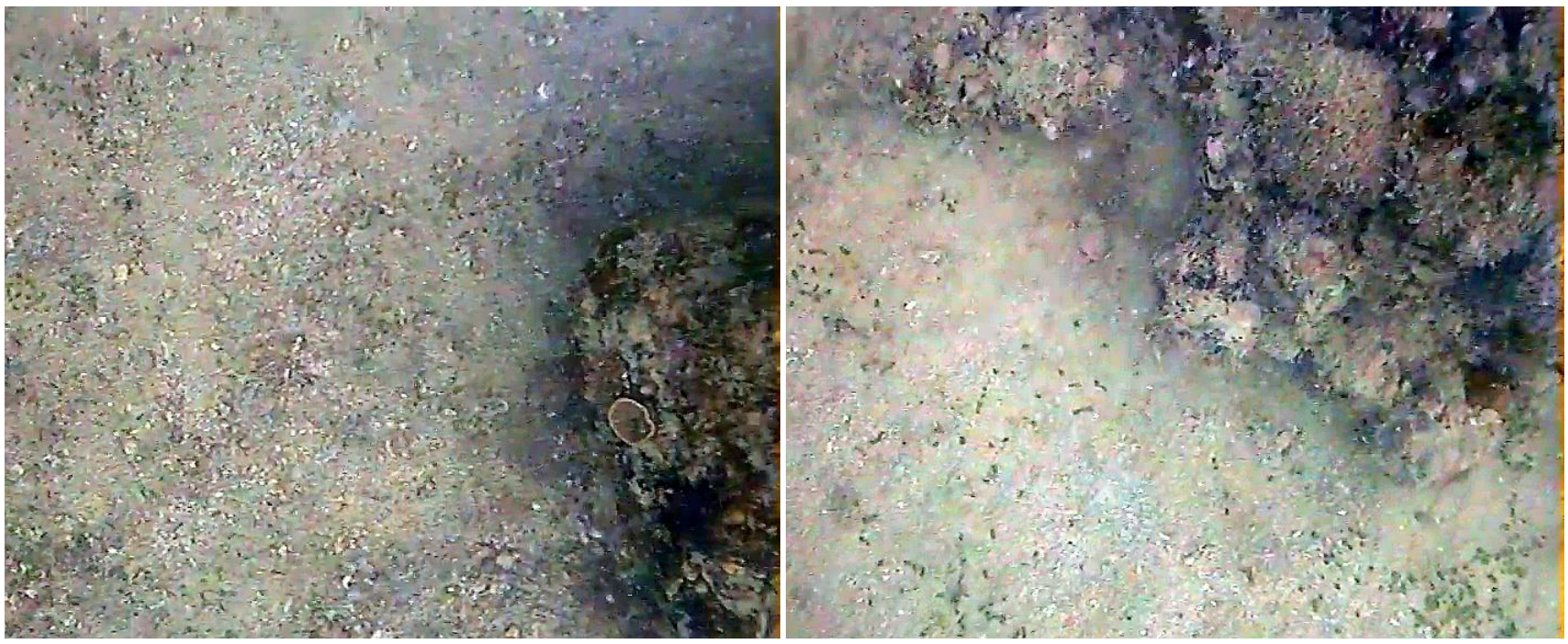
Typical benthic community found at Concern **Site I2** – large boulders covered in turf algae, sponges and macroalgae with occasional hard corals



Typical benthic community found at Concern **Site I3** – undulating hard substrate covered in turf algae, sponge, hard corals and macroalgae, occasional patches of sand in the channels between hard substrate.



Typical benthic community found at Concern **Site I4** – low relief undulating hard substrate covered in turf algae, sponge, hard corals and macroalgae, occasional patches of sand in the channels between hard substrate.



Typical benthic community found at Concern **Site R1** – large patches of sand with occasional hard corals and macroalgae growing on small patches of low relief hard substrate

Typical benthic community found at Concern **Site R2** – low relief undulating hard substrate covered in turf algae, sponge, hard corals and macroalgae, occasional patches of sand in the channels between hard substrate. Some areas of high hard coral cover.

Appendix D: Survey and Site bleached coral data statistical summary

Benthic Group	Survey	Site	n	Mean	Min	Max	Std.Dev.	Standard Error
Hard Coral	1	I1	4	0.0	0.0	0.0	0.0	0.0
Soft Coral	1	I1	4	0.1	0.0	0.5	0.3	0.1
Hard Coral	1	I2	4	0.1	0.0	0.5	0.3	0.1
Soft Coral	1	I2	4	0.3	0.0	0.5	0.3	0.1
Hard Coral	1	I3	4	0.0	0.0	0.0	0.0	0.0
Soft Coral	1	I3	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	1	I4	4	0.8	0.0	1.5	0.6	0.3
Soft Coral	1	I4	4	0.3	0.0	1.0	0.5	0.3
Hard Coral	1	R1	4	0.5	0.0	1.0	0.4	0.2
Soft Coral	1	R1	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	1	R2	4	2.0	0.0	4.5	1.9	0.9
Soft Coral	1	R2	4	2.8	2.0	4.0	1.0	0.5
Hard Coral	2	I1	4	2.0	0.0	5.0	2.2	1.1
Soft Coral	2	I1	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	2	I2	4	7.3	1.5	11.0	4.1	2.0
Soft Coral	2	I2	4	4.3	1.5	6.0	2.2	1.1

Benthic Group	Survey	Site	n	Mean	Min	Max	Std.Dev.	Standard Error
Hard Coral	2	I3	4	2.5	0.0	4.0	1.8	0.9
Soft Coral	2	I3	4	0.9	0.0	3.0	1.4	0.7
Hard Coral	2	I4	4	3.9	1.0	7.0	2.7	1.3
Soft Coral	2	I4	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	2	R1	4	7.0	5.0	8.0	1.4	0.7
Soft Coral	2	R1	4	0.6	0.0	2.0	0.9	0.5
Hard Coral	2	R2	4	14.3	12.5	17.5	2.4	1.2
Soft Coral	2	R2	4	1.9	0.5	3.5	1.3	0.6
Hard Coral	3	I1	4	0.0	0.0	0.0	0.0	0.0
Soft Coral	3	I1	4	0.0	0.0	0.0	0.0	0.0
Hard Coral	3	I2	4	2.0	0.0	3.5	1.5	0.7
Soft Coral	3	I2	4	0.4	0.0	1.0	0.5	0.2
Hard Coral	3	I3	4	0.6	0.5	1.0	0.3	0.1
Soft Coral	3	I3	4	0.3	0.0	0.5	0.3	0.1
Hard Coral	3	I4	4	0.9	0.5	1.5	0.5	0.2
Soft Coral	3	I4	4	0.1	0.0	0.5	0.3	0.1
Hard Coral	3	R1	4	1.6	0.5	2.5	0.9	0.4
Soft Coral	3	R1	4	0.3	0.0	0.5	0.3	0.1
Hard Coral	3	R2	4	2.4	2.0	3.0	0.5	0.2

Benthic Group	Survey	Site	n	Mean	Min	Max	Std.Dev.	Standard Error
Soft Coral	3	R2	4	1.0	0.0	2.0	0.9	0.5