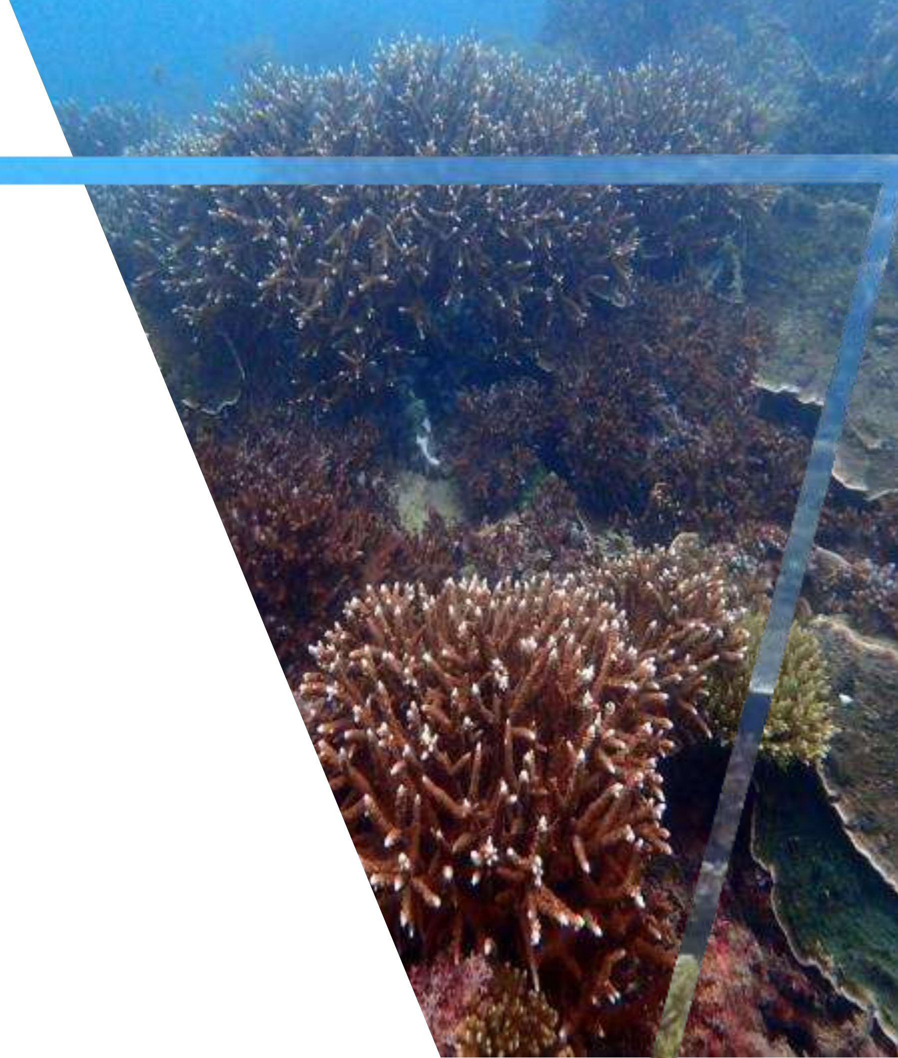

Port of Mackay and Hay Point Ambient Coral Monitoring

March 2015 - May 2016

13/09/16

Level 31, 12 Creek Street,
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301001-01923-00-EN-REP-0001

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Project No: 301001-01923-00-EN-REP-0001 – Port of Mackay and Hay Point Ambient Coral Monitoring: March 2015 - May 2016

Rev	Description	Author	Review	Advisian Approval	Date
0	Issued for use	T Ayling S Neale	B Boylson	B Boylson	13/09/16

Table of Contents

Table List

Figure List

Executive Summary

In recognition of the importance of gathering long term environmental data sets to inform future port management activity, NQBP commissioned Advisian (WorleyParsons Group) to develop and implement an ambient coral monitoring program for the Port of Mackay and Port of Hay Point regions.

The ambient coral monitoring program was designed with consideration of seasonality in order to identify potential environmental change that may be associated with seasonal conditions. Surveys were targeted before and after the wet season. Monitoring locations were identified with consideration of previous monitoring results. Fringing reefs were surveyed around four island locations; two near-shore islands close to the Port of Hay Point were incorporated (Round Top Island and Victor Islet), one inshore island (Slade Islet) 18 km north of the Port of Hay Point and directly adjacent to the Port of Mackay; and one offshore island location (Keswick/St Bees Island) located40 km NNE of the Port of Hay Point and 25km NE of the Port of Mackay

The major change recorded during the three ambient surveys undertaken between March 2015 and May 2016 was natural seasonal fluctuations in algal abundance. Algal growth is highest in spring when more nutrients are available and hence algal cover was highest during the pre-wet season survey in November 2015. These seasonal fluctuations were higher in the three inshore locations than on Keswick Island, where the changes in algal cover over the ambient surveys were not significant. That being said, whilst Keswick Island recorded low fluctuations of algal abundance, it also had the highest algae cover; the reasons for this are not clear however may be related to better average water clarity compared to the more turbid inshore locations.

The main change in hard coral communities during the ambient surveys was an increase in coral cover on Keswick Island driven by natural growth of the fast growing acroporid and pocilloporid coral groups. There was also a slight decrease in the cover of Turbinaria corals, primarily on Round Top Island where this coral group was most abundant. This decrease is potentially related to the levels of coral disease that were recorded on several colonies during the pre-wet season ambient survey. Although there were nominal fluctuations in soft coral cover during the ambient surveys these changes were not significant.

Algal cover (macroalge and turf algae) during the ambient surveys was higher than at any other time during the past 10 years and may be a sign of a possible shift toward more algal dominated reef communities on the inshore locations. Macroalge are an important food source for herbivorous fish and form an important habitat for number of other organisms; increases in macroalgae cover over time may be an indicator of overfishing of herbivorous fish or degradation of water quality via elevated nutrient and sediment inputs (Diaz-Pulido and McCook 2008). Increases in macroalgae abundance may also act to hinder recovery of coral cover on Round Top Island and Slade Islet, the locations that were most affected by Cyclone Ului and the subsequent smaller cyclone events in 2011 and 2014.

The significant increase in soft coral cover at Round Top Island over the ten years of survey appears to have been due to the natural growth of Sarcophyton and Sansibia soft coral colonies.

Soft coral cover did not increase at the other three locations over the same period and the reason for the increase on Round Top is not known.

Levels of *partial* bleaching were higher during the ambient surveys than at any time since the baseline survey in April 2006. Very few *totally* bleached colonies were observed during the ambient surveys. Minor to moderate coral bleaching was observed in the Mackay/Capricorn Management Area during extensive aerial and in water surveys undertaken in February and March 2016 (GBRMPA 2016a). The subsequent coral mortality associated with the preceding bleaching event on coral reefs in the Mackay/Capricorn Management Area measured in May/June 2016 was estimated at between 0 and 9.9% of all corals (GBRMPA 2016b). The average water temperatures in the summer of 2015 compared to the summer of 2016 did not differ markedly but were slightly higher on average. The highest summer maximum averages measured near coral monitoring locations in January 2015 ranged between 28.5°C to 29.15°C and in February 2016 ranged between 28.9°C to 29.22°C.

Although both sediment depths and percentage of corals with sediment were relatively high during the ambient surveys, the levels of coral damage were much lower than during most of the last ten years.

Levels of coral disease during the ambient surveys were relatively high, but were in line with levels recorded over the ten years spanned by the previous surveys. Less than 1% of hard corals were affected by disease on these locations at any one time and trends have been down or flat over this ten year period.

Ambient surveys of benthic communities should continue into the future to monitor the recovery of the benthic communities after the damage caused by cyclone Ului. The surveys provide sound baseline information for any impact monitoring that may be undertaken by NQBP in the future. Ambient benthic community data and ambient water quality information should be considered in combination, where possible, to look more closely at any local water quality drivers of benthic community change.

The sources of sediments in the marine environment which have small but significant impacts on individual coral colonies (and therefore the whole community) at the monitoring locations over time should be better quantified.

1 Introduction

1.1 Background

The Port of Hay Point is situated on the North Queensland coast approximately 40 kilometres by road south of Mackay. The port comprises two separate coal export terminals: Dalrymple Bay Coal Terminal (DBCT) which is leased from the Queensland Government by DBCT Management Pty Ltd and the Hay Point Coal Terminal (HPCT) which is owned by BHP Billiton Mitsubishi Alliance and operated by Hay Point Services. The Port of Mackay is located five kilometres north of the city of Mackay and comprises an artificial harbour formed by rock breakwaters. The port is a multi-cargo port, predominately facilitating the export of sugar and grain.

North Queensland Bulk Ports Corporation Limited (NQBP) is the port authority for both the Port of Hay Point and the Port of Mackay.

Coral monitoring has been undertaken previously for NQBP at key locations surrounding the Port of Hay Point and Mackay including Round Top Island, Victor Islet, Slade Islet and Keswick Island (Figure 1-1). These investigations were primarily focussed on the identification of potential impacts to corals associated with dredging projects and were completed before, during and after the 2006 capital dredging campaign at Hay Point, and before and after maintenance dredging in 2008 (Hay Point), 2010 (Hay Point) and 2013 (Mackay)

1.2 Objectives and program outline

In recognition of the importance of gathering long term environmental data sets to inform future port management activity, NQBP commissioned Advisian (WorleyParsons Group) to develop and implement an ambient period (coral monitoring program for the Port of Hay Point and the Port of Mackay.

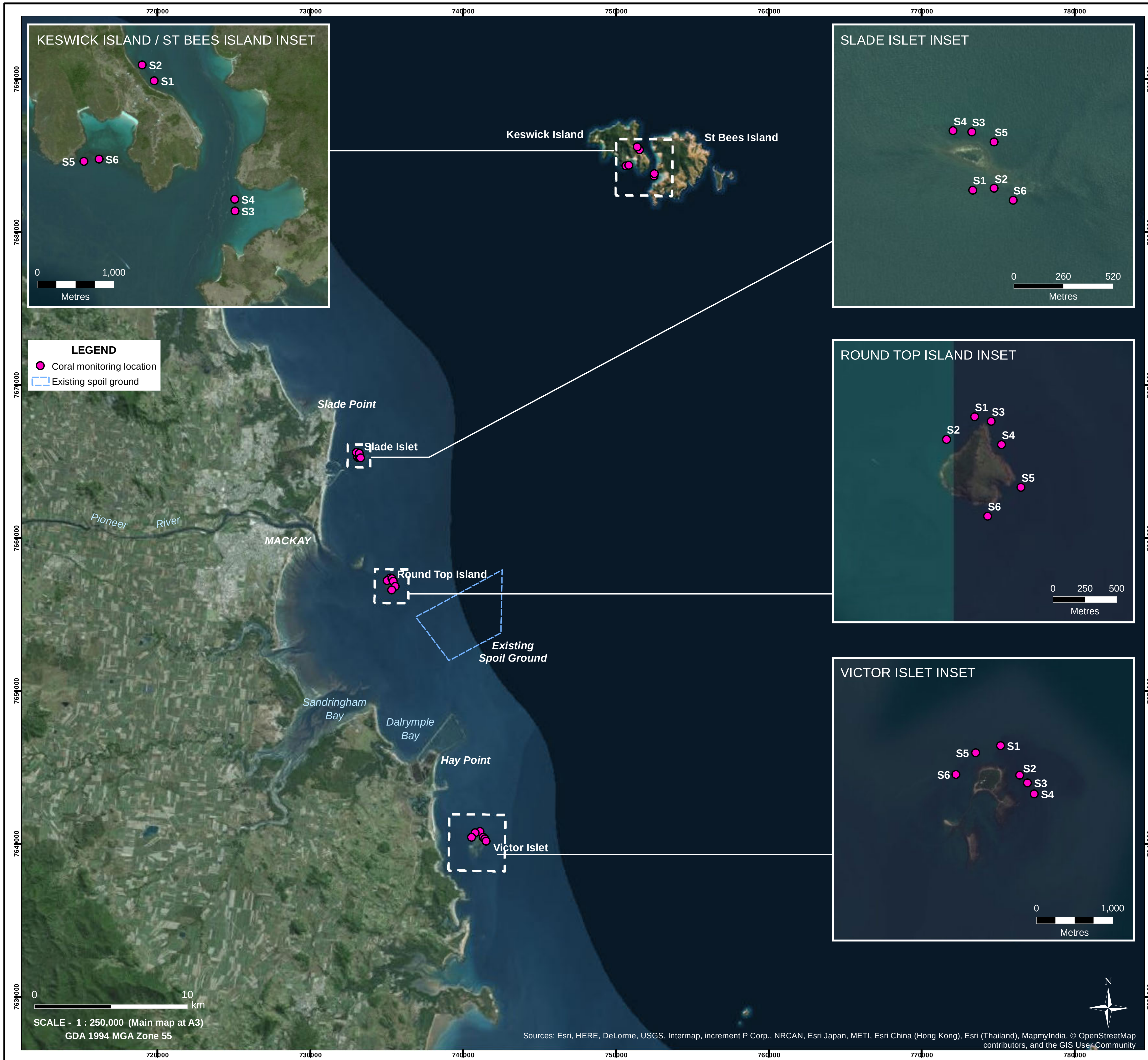
The ambient coral monitoring program was designed with consideration of seasonality in order to identify potential environmental change that may be associated with seasonal conditions. Surveys were targeted before and after the wet season.

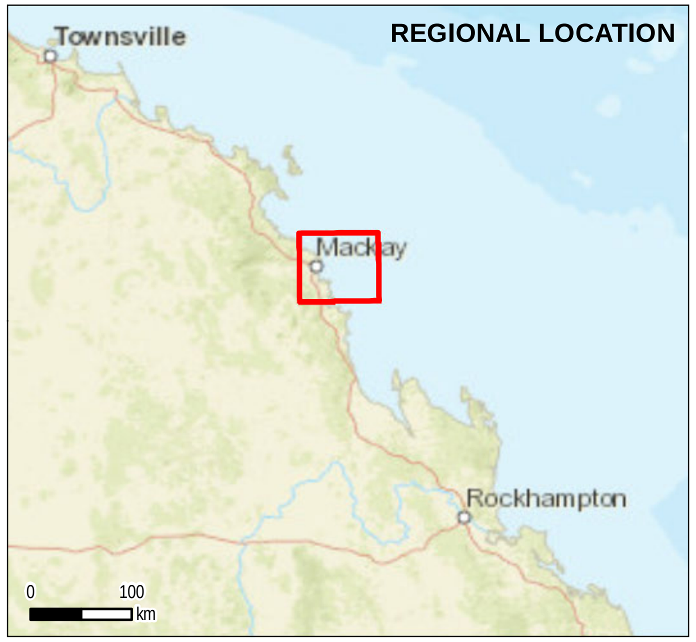
Monitoring locations were identified with consideration of previous monitoring results. Sites used for previous monitoring programs were relocated and/or repaired for use.

Coral monitoring surveys considered:

- Diversity and abundance of benthic communities;
- Percentage coral bleaching;
- Percentage coral mortality;
- Rates of sediment deposition on corals; and,
- Rates of coral recruitment.

This report describes the ambient coral monitoring program and results of its implementation during the 2015/2016 period, which included three ambient surveys at four locations. All surveys were carried out in accordance with the Great Barrier Reef Marine Park (GBRMP) Permit G14/36743.1 held by WorleyParsons Services.





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HAY POINT AMBIENT CORAL MONITORING: MARCH 2015 - MAY 2016

Figure 1-1
Coral monitoring locations

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2 Methods

2.1 Locations

Fringing reefs were surveyed around four island locations (Figure 1-1 and Table 2-1). Two near-shore islands close to the Port of Hay Point were incorporated (Round Top Island and Victor Islet), one inshore island (Slade Islet) 18 km north of the Port of Hay Point and directly adjacent to the Port of Mackay; and one offshore island location (Keswick/St Bees Island) located 40 km NNE of the Port of Hay Point and 25km NE of the Port of Mackay

Table 2-1 GPS coordinates of each monitoring site

Location	Ambient monitoring Site ID	Historical Site ID	Latitude	Longitude
Keswick Island	S1	Horseshoe site 1	-20.9150	149.4185
Keswick Island	S2	Horseshoe site2	-20.9132	149.4171
Keswick/St Bees Island	S3	Homestead 1	-20.9303	149.4280
Keswick/St Bees Island	S4	Homestead 2	-20.9290	149.4280
Keswick Island	S5	Basil/Arthur site 1	-20.9245	149.4102
Keswick Island	S6	Basil/Arthur site 2	-20.9243	149.4120
Slade Islet	S1	S1	-21.0989	149.2440
Slade Islet	S2	S2	-21.0988	149.2450
Slade Islet	S3	S3	-21.0962	149.2440
Slade Islet	S4	S4	-21.0961	149.2431
Slade Islet	S5	S5	-21.0966	149.2450
Slade Islet	S6	S6	-21.0994	149.2459
Round Top Island	S1	S1	-21.1699	149.2656
Round Top Island	S2	S2	-21.1715	149.2636
Round Top Island	S3	S3	-21.1702	149.2668
Round Top Island	S4	S4	-21.1719	149.2675
Round Top Island	S5	S5	-21.1749	149.2689
Round Top Island	S6	S6	-21.1769	149.2665
Victor Islet	S1	S1	-21.3189	149.3244
Victor Islet	S2	S2	-21.3223	149.3267
Victor Islet	S3	S3	-21.3232	149.3276
Victor Islet	S4	S4	-21.3246	149.3284
Victor Islet	S5	S5	-21.3197	149.3215
Victor Islet	S6	S6	-21.3223	149.3191

Six monitoring sites were previously established at each location at the start of the 2006 capital dredging monitoring program and these were maintained and utilised for several more monitoring programs since 2006 (Table 2-2). As described previously, monitoring sites were repaired and/or relocated for the ambient coral monitoring program. On Keswick Island two of the four Horseshoe Bay sites previously used were relocated to Homestead Bay on adjacent St Bees Island. Coral communities in Homestead Bay were rich Acropora dominated reefs and were included to increase the range of habitat types incorporated in the Keswick Island surveys.

Table 2-2 Historical summary of all coral surveys undertaken at the four survey locations

Survey Date	Round Top	Victor	Slade	Keswick
Apr 2006	X	X	X	X
Jul 2006	X	X	X	X
Sep 2006	X	X	X	X
Nov 2006	X	X	X	X
Apr 2007	X	X	X	X
May 2008	X	X	X	
Aug 2008	X	X	X	
Aug 2010	X	X	X	
Nov 2010	X	X	X	
Feb 2012	X	X	X	
Jul 2013	X		X	
Sep 2013	X		X	
Mar 2015*	X	X	X	X
Nov 2015*	X	X	X	X
May 2016*	X	X	X	X

X indicates locations that were included during each survey. * Surveys for which results are detailed in this report

2.2 Survey Period

This report provides a summary of coral conditions observed during three different surveys undertaken at four reef locations in the vicinity of the Port of Hay Point and Port of Mackay over the period April 2015 to May 2016. The three survey periods were post-wet season, from 20-25 March 2015, pre-wet season from 12-16 November 2015 and a second post-wet season survey from 2-6 May 2016. The survey periods were scheduled during periods where the long term forecast suggested light wind and this resulted in good in water conditions (underwater visibility) and more rapid, reliable surveys.

2.3 Benthic Line Intercept Surveys

Abundance surveys of the marine communities surrounding the islands were made at six sites around each island. At each site, cover of major benthic reef organisms was assessed using four 20 m, haphazardly positioned, line intercept transects, each run within a narrow depth band along about 50 m of reef. The depth range for the surveys at each site depended on the depth of the reef and the stratum where corals were most abundant, and ranged from -0.5 m to -7 m below Lowest

Astronomical Tide. The transects were permanently marked with 12 mm reinforcing rod stakes driven into the seabed at 5 m intervals.

As described previously a number of the sites were set up prior to capital dredging in 2006 and were repaired where necessary during the first of the three surveys reported here. The sites on Keswick Island had not been surveyed since 2007.

For each transect, survey tape was stretched tightly between the stakes close to the substratum. The intercept length was measured i.e. the length of tape with benthic organisms directly beneath it. Intercept lengths for all colonies of a species or benthic group along each transect were totalled and converted to a percentage cover measurement. The following organisms or groups of organisms were recorded:

- All algae;
- All sponges;
- All hard corals identified to genus level (or to growth form if more appropriate); and
- All soft corals.

These techniques have been used in many other surveys of fringing and offshore reefs in the Great Barrier Reef (GBR) region (Mapstone et al. 1989, Ayling and Ayling 1995, 2002, 2005).

The bleaching status of all coral intercepts was noted during these surveys in three categories:

1. Not bleached;
2. Partially bleached; and
3. Totally bleached.

2.4 Sediment Deposition on Corals

Depth of sediment deposition was measured on 20 hard coral colonies haphazardly selected within a metre of each transect. If sediment was present on the colony surface, the point of maximum sediment depth was measured in mm using a plastic ruler. Sediment usually only covered a portion of the colony surface and a single measurement of sediment depth was recorded where it was deepest.

2.5 Damaged, Diseased or Bleached Coral Colonies

Although line intercept transects give a good estimate of coral cover, the sample size of coral colonies immediately beneath the transect lines is not sufficient to encounter relatively rare events such as coral disease or sediment damage. As such, for a wider area (20 x 2 metre area centred on each transect line), the following parameters were also measured:

- Counts of the total number of coral colonies in each major coral group were recorded.

- Counts of bleached or partially bleached colonies were recorded for each of the major coral groups.
- Counts of all sediment damaged colonies were recorded for each of the major hard coral groups. Colonies were not recorded as sediment damaged if there was an actively growing edge encroaching into an old sediment-smothered dead patch.
- Counts of all diseased, partially dead or recently dead colonies were recorded for each of the major hard coral groups. As for sediment damage, if there was an actively growing edge reclaiming a disease-caused dead patch that colony was not recorded as diseased.

2.6 Coral Demography

To get an indication of levels of coral recruitment in the study locations, measures of coral demography were made during each of the surveys. The technique employed by the Australian Institute of Marine Science (AIMS) for inshore reef surveys was used (AIMS 2008). Using this technique small corals within 30 cm of the shoreward side of each transect were recorded in three size categories: 0-2 cm diameter; 2-5 cm diameter; 5-10 cm diameter. The genus of each young coral was recorded and numbers were summed from all four transects at each site.

2.7 Analysis

Analysis of Variance (ANOVA) techniques were used to determine the significance of any apparent changes in abundance of benthic organisms between successive benthic surveys. The design of the benthic abundance surveys was established to enable a repeated measures analysis of variance after subsequent surveys (Table 2-3).

Because the transects were fixed and the same parts of the benthic community were assessed during each survey, a more powerful repeated measures analysis is considered appropriate in this case. This analysis tested the significance of changes in a number of factors that may have influenced benthic abundance:

1. The first factor was the four locations i.e. to determine whether there were significant differences in benthic abundance among these locations.

2. The second factor was the six different sites surveyed at each location i.e. to determine whether there were significant differences in benthic abundance among the six sites within each location. Site is said to be nested within the location factor because site 1 at one location is not necessarily subject to the same influences as site 1 at the other locations i.e. what affects each site is unique to that site. Nested factors are indicated with brackets e.g. Site (Location) indicates that the site factor is nested within the location factor.

3. The third factor in the analysis design was time i.e. to determine whether there were any significant changes in benthic abundance between successive surveys at the same sites.

Interactions between the three factors were also determined in the analysis. The most important test in the design was the interaction between Location and Time (indicated as Location x Time). If benthic abundance changes are the same in each location then this interaction will not be significant but if benthic abundance decreases at one location and either does not change or increases at another location then the interaction may be significant. In this design, if coral cover decreased at certain sites due to a particular cause, but increased at other sites due to natural coral growth then the Time x Location interaction would likely be significant, even though the mean coral cover had not changed between the two surveys (as the increase at one site would cancel out the decrease at the other sites and mean coral cover would stay the same).

Changes in sediment depth on coral colonies were tested for each location using a two factor analysis of variance. As sediment depth is measured on a different random selection of corals during each survey, repeated measures analysis is not appropriate to apply. Two factor repeated measures analyses of variance were used to check the significance of changes in the density of damaged and diseased coral colonies in each location. In this case damaged and diseased colonies were assessed within the same transect area during each survey enabling the use of repeated measures analysis.

The significance of changes over the 14 months at all four locations (Keswick, Round Top, Slade and Victor) covered by the three surveys was tested with a series of ANOVAs (Table 2-3). Another series of analyses were used to establish the significance of any benthic or coral damage changes over all the surveys that have been consistently carried out at the three locations (Round Top, Slade and Victor) since April 2006 (Table 2-4).

Table 2-3 Repeated measures benthic cover ANOVA design for the three ambient surveys at four locations

Source of Variation	Degrees of freedom (df)	Denominator
Between Transects:		
Location	3	Site
Site (location)	20	error (transects)
Error (transects)	72	
Within Transects:		
Time	2	Site x Time
Location x Time	6	Site x Time
Site (location) x Time	40	error (transects x Time)
Error (transects x Time)	144	

Table 2-4 Repeated measures benthic cover ANOVA design for all surveys since 2006 at three locations

Source of Variation	Degrees of freedom (df)	Denominator
Between Transects:		
Location	2	Site
Site (location)	15	error (transects)
Error (transects)	54	
Within Transects:		
Time	12	Site x Time
Location x Time	24	Site x Time
Site (location) x Time	180	error (transects x Time)
Error (transects x Time)	648	

3 Results

3.1 Climatic Conditions March 2015 – May 2016

One of the key drivers of coral community health is the climatic conditions experienced by that community over time. Key climatic drivers of coral health include local and regional rainfall and river discharges into the nearshore environment, cyclonic conditions and sea water temperatures. The following section details the climatic conditions during the ambient monitoring period (November 2015 – May 2016) and compares these conditions to data collected since coral monitoring began in 2006. The Pioneer River which discharges into the nearshore environment inshore from Round Top Island is discussed here as an indicator of local riverine inputs.

3.1.1 Rainfall and River flows

The rainfall measured by the Bureau of Meteorology (BOM) at the Mackay Airport (BOM 2016a) is provided graphically in Figure 3-1 (upper graph). The Pioneer River discharge at Dumbleton Weir (located 16.6km from the mouth of the River) is presented using data provided by the Queensland Government Water Monitoring Information Portal (WIMP 2016) in Millions of Litres per day (ML/day) (Figure 3-1 - lower graph).

Large sustained rainfall events typically cause large river discharges. An example is the wet season of 2010-2011, where high sustained rainfall led to large sustained discharges from the Pioneer River during the entire wet season (several months). During this year nearly twice the mean rainfall was recorded; 2904mm compared to the mean rainfall of 1536mm (BOM 2016b). Additional rainfall in the catchment areas inland from Mackay contributed to the elevated river discharges. During the ambient monitoring period of 2015/16 the amount of rainfall recorded was less than previous years, subsequently the Pioneer River discharges into the nearshore marine environment were some of the lowest wet season flows recorded since 2006 and were very brief in duration (refer Figure 3-1).

The Port of Mackay and Hay Point Ambient Marine Water Quality Program (July 2014 to July 2015) (Waltham et al 2015) provides further context, noting that the 2014-2015 wet season can be considered a ‘failed wet season’ with values for rainfall within the 10^{th} percentile of the distribution of total annual wet season rainfall recorded in the region since 1910. The following wet season in 2015/2016, whilst more typical was still relatively short and resulted in a moderately high but short duration river discharges from the Pioneer River (Figure 3-1 - lower graph).

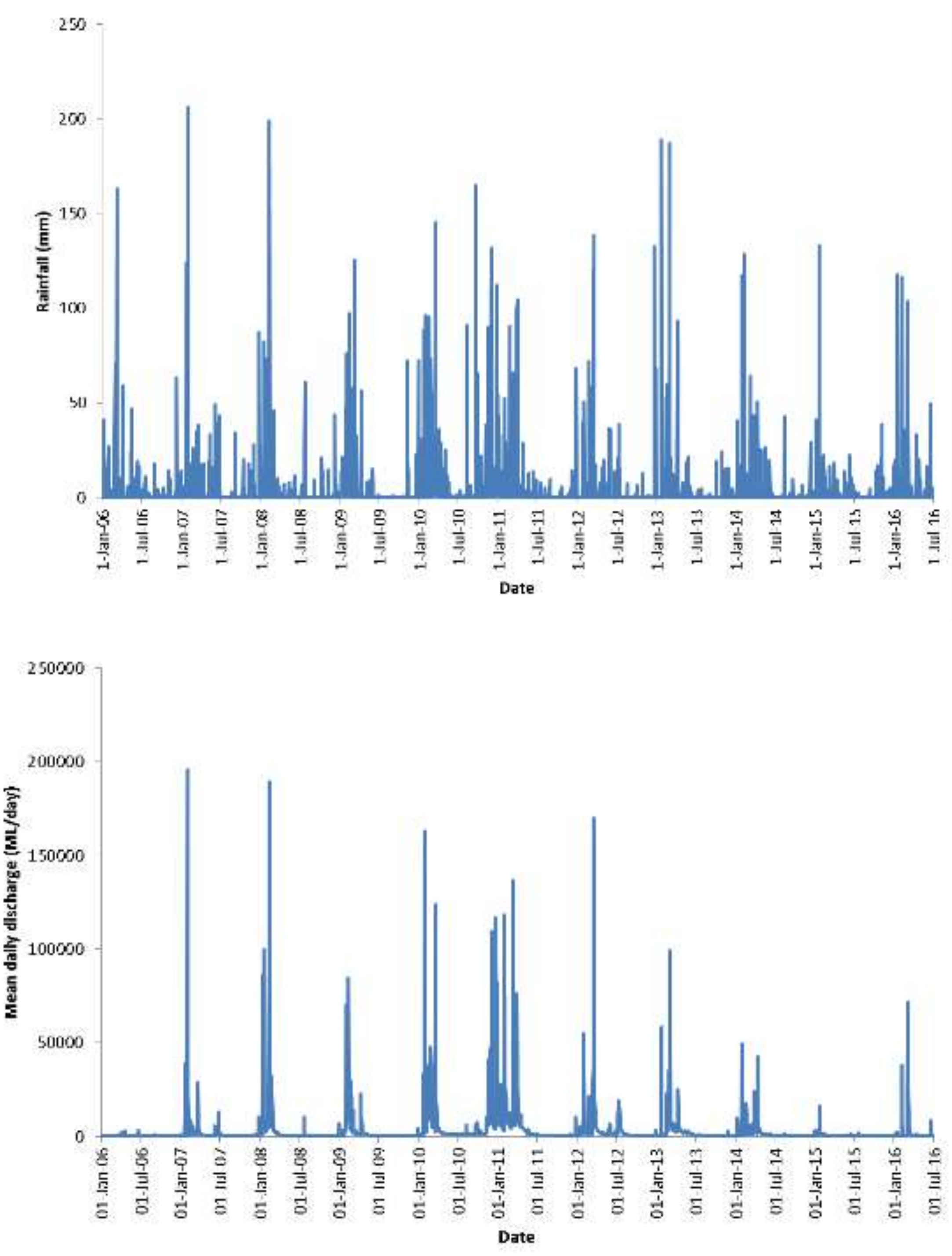


Figure 3-1 Top graph shows daily rainfall (measured at the Mackay Airport, lower graph shows the Pioneer River discharge at Dumbleton Weir

3.1.2 Cyclones

During the monitoring period only one cyclone passed in the vicinity of Mackay; cyclone Marcia. This severe tropical cyclone approached, and then eventually passed to the south of Mackay crossing the coast near Yeppoon (Figure 3-2). The rainfall recorded at Mackay Airport due to this cyclone was minor (<20mm) and exceptional damaging waves and winds did not occur in nearshore areas due to its passage.

More substantial rainfall occurred due to the passage of a low pressure system in March 2016 which resulted in nearly half a meter of rainfall (445mm) falling in the Mackay area that month. During this period, the Pioneer River discharge remained above 17000ML/day from 3 March to 9 March 2016 (Figure 3-1: lower graph). This level of discharge was still relatively minor compared to previous years.

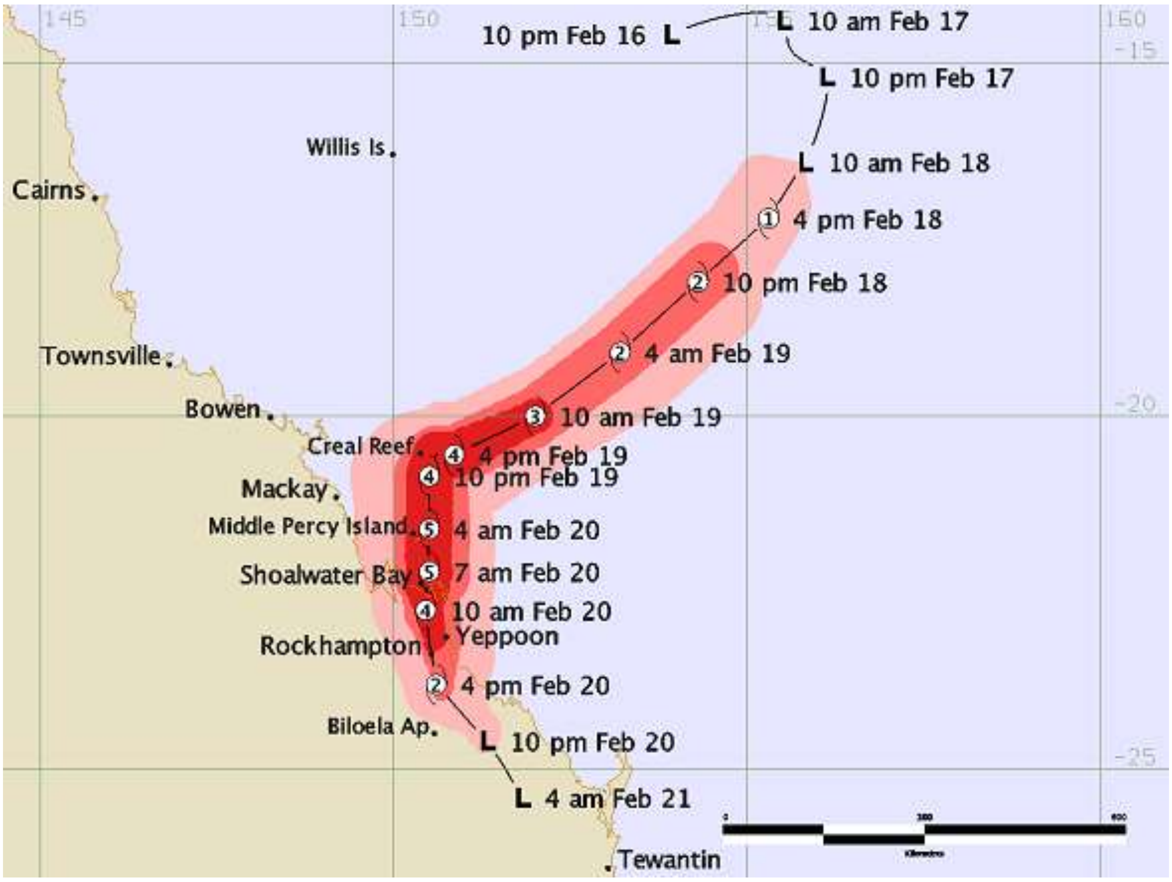


Figure 3-2 Track of severe tropical cyclone *Marcia* (source: BOM 2016c)

Prior to 2015 a number of cyclones passed close to Mackay leading to damaging winds and floods which may have impacted upon the benthic communities at all nearshore coral monitoring locations (Table 3-1); the most damaging cyclone was cyclone Ului. Severe Tropical cyclone Ului passed to just to the north of Mackay on 20 March 2010 (Figure 3-3). Cyclone Ului caused wide spread flooding in the Mackay region, and nearshore benthic communities suffered physical damage during the passage of this cyclone and subsequent deleterious impacts due to a sustained reduction in benthic light due to the associated flooding. Cyclone Ului appears to be the main cause of impacts to the benthic communities at the four monitoring locations surveyed in the last decade. A discussion of the impacts to benthic communities associated with this cyclone is presented in Section 4.2.

Table 3-1 Cyclones that influenced climatic conditions near Mackay since 2006

Tropical Cyclone	Date
Ului	20 March 2010
Yasi	30 January - 3 February 2011
Dylan	31 January 2014
Ita	13 April 2014
Marcia	20 Feb 2016

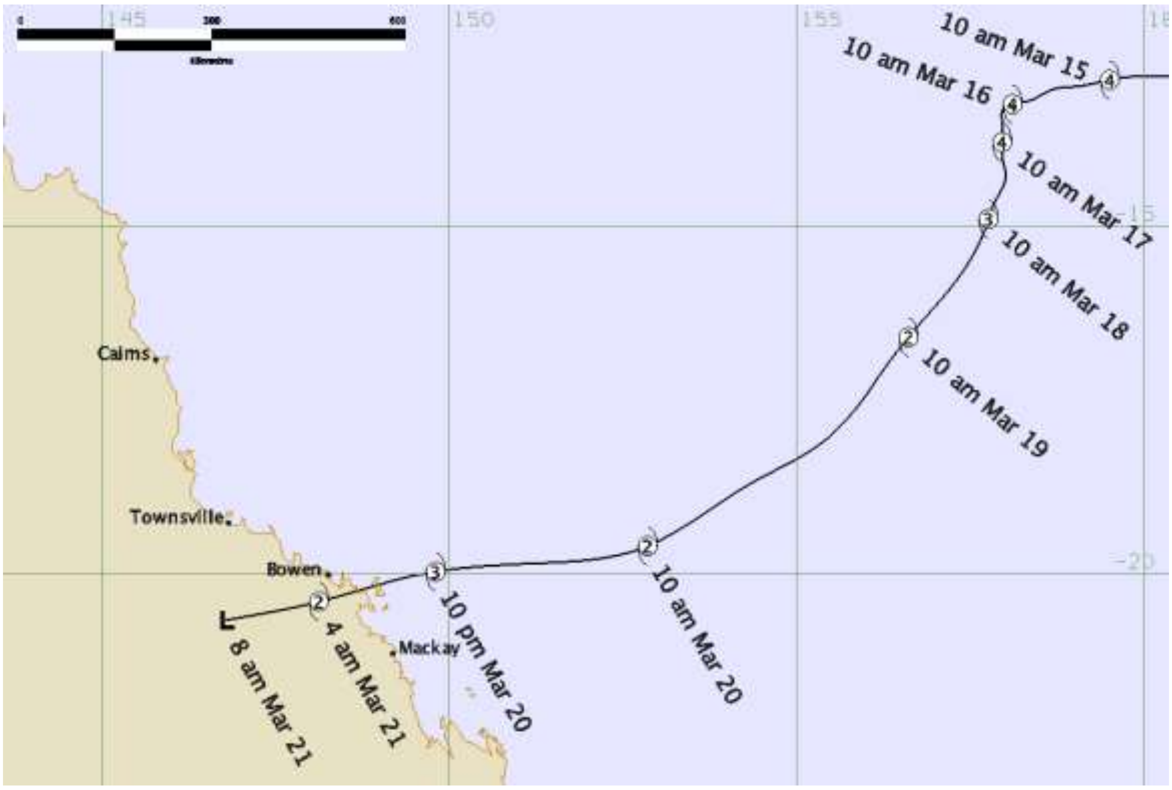


Figure 3-3 Track of severe tropical cyclone Ului (source: BOM 2016d)

3.1.3 Sea Water Temperatures

Sustained elevated sea water temperatures caused wide scale bleaching of coral communities in the Northern Sectors of the Great Barrier Reef during February to May, 2016. Sea temperature measurements are collected by TropWATER at a number of sites in the nearshore environment offshore from Mackay (Waltham et al 2015). The average monthly readings at logger sites adjacent to the coral monitoring locations are provided in Appendix A. The average water temperatures in the summer of 2015 compared to the summer of 2016 did not differ markedly but were slightly higher on average (see highlighted grey columns). The highest summer maximum averages measured near coral monitoring locations in January 2015 ranged between 28.5°C to 29.15°C and in February 2016 ranged between 28.9°C to 29.22°C.

3.2 Benthic Cover during the Ambient Surveys

Benthic turfing algae and macroalgae were common on these fringing reefs and were the dominant benthic group on Victor Islet and Keswick Island reefs (Table 3-2, Figure 3-4). On the other two locations, algal cover was approximately equal to total hard coral cover (Figure 3-4). At the time of the May 2016 ambient survey, algae covered 20% and 18% of the substratum at Round Top Island and Slade Islet respectively, and over 32% at Victor Islet and 38% at Keswick Island. In spite of these apparent differences, algal cover was not significantly different between the four locations during the three ambient surveys (Table 3-3). The genera Sargassum and Lobophora were the most abundant algal groups but a range of other species were also present including Padina, Caulerpa and Halimeda. Algal cover fluctuated significantly over the three ambient surveys, being lower during the two post-wet season surveys and higher during the pre-wet season survey. Although the fluctuations in algal cover were approximately in synchronisation between the three inshore locations, much lower changes on Keswick Island were enough to give a significant Time x Location interaction (Table 3-3, Figure 3-5).

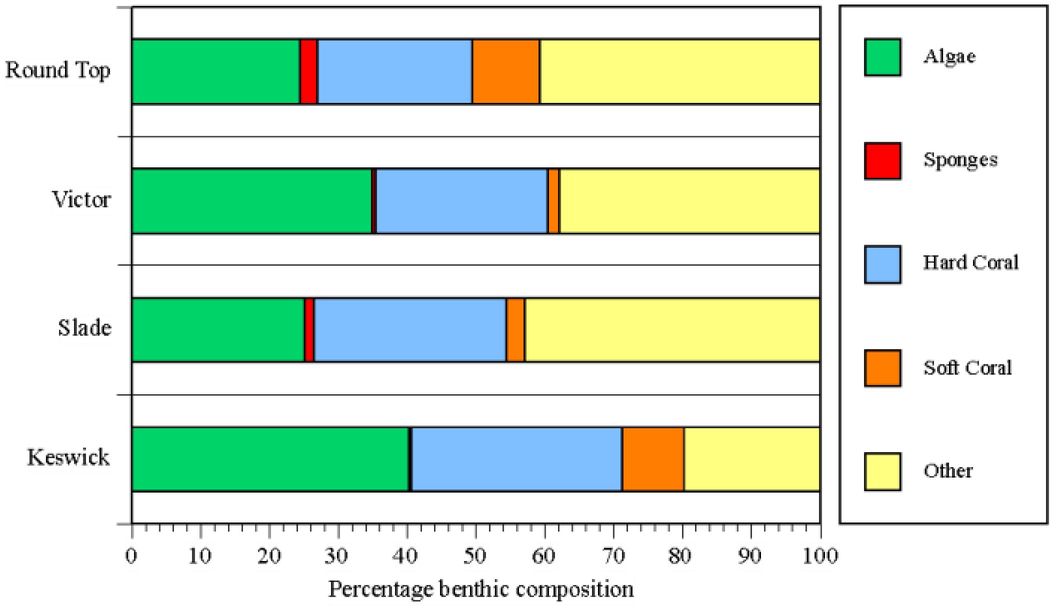


Figure 3-4 Benthic Community Composition in the Four Locations during the Ambient Surveys

Graphs show grand mean percentage benthic composition from the three ambient surveys at each location. Benthic category 'Other' = bare reef + crustose corallines + algal turf less than 10 mm high.

Table 3-2 Benthic organism mean percentage cover during ambient surveys at four locations (sd = standard deviation))

Family/Group	March 2015		November 2015		May 2016	
	mean (%)	sd	mean (%)	sd	mean (%)	sd
ROUND TOP						
Total algae	24.4	*11.7*	28.9	*10.1*	20.2	*11.9*
Total sponges	2.2	*2.3*	2.1	*2.1*	2.9	*2.4*
Total hard corals	23.0	*13.9*	21.9	*12.9*	23.0	*13.7*
Acropora spp.	0.8	*2.0*	1.1	*2.9*	1.0	*2.4*
Montipora spp.	4.3	*6.8*	4.0	*6.4*	4.7	*6.9*
Pocilloporidae	0.7	*1.6*	0.8	*1.7*	0.8	*1.9*
Siderasteridae	3.4	*2.8*	3.3	*2.7*	3.4	*3.2*
Turbinaria spp.	8.5	*7.0*	7.2	*5.3*	7.1	*5.7*
Faviidae	2.5	*1.5*	3.0	*1.8*	3.0	*1.9*
Poritidae	2.4	*2.8*	2.3	*2.6*	2.4	*2.3*
Total soft corals	8.8	*6.4*	10.9	*8.5*	9.8	*8.0*
VICTOR						
Total algae	29.1	*13.1*	43.4	*22.2*	32.3	*15.5*
Total sponges	0.4	*0.5*	0.4	*0.6*	0.6	*0.8*
Total hard corals	24.5	*24.9*	24.6	*25.7*	25.7	*27.3*
Acropora spp.	2.0	*4.1*	2.2	*4.5*	2.5	*5.2*
Montipora spp.	10.6	*20.5*	10.7	*20.8*	10.9	*21.6*
Pocilloporidae	1.0	*2.5*	1.1	*3.2*	1.3	*3.2*
Siderasteridae	2.3	*3.6*	2.3	*3.4*	2.5	*3.4*
Turbinaria spp.	3.4	*3.8*	3.1	*3.4*	3.2	*3.5*
Faviidae	3.6	*3.0*	3.6	*2.8*	3.7	*2.7*
Poritidae	1.2	*3.3*	1.1	*3.0*	1.3	*3.2*
Total soft corals	2.0	*2.2*	1.3	*2.2*	2.0	*2.3*
SLADE						
Total algae	18.0	*12.4*	39.8	*17.2*	17.7	*10.8*
Total sponges	1.2	*1.4*	1.1	*1.1*	1.6	*1.5*
Total hard corals	27.2	*17.4*	29.1	*20.2*	27.4	*17.2*
Acropora spp.	1.3	*3.1*	2.0	*3.5*	1.8	*4.2*
Montipora spp.	16.1	*15.4*	18.1	*18.4*	16.6	*15.6*
Pocilloporidae	0.7	*1.4*	0.5	*1.1*	0.7	*1.2*
Siderasteridae	2.8	*3.0*	2.3	*2.5*	2.4	*2.5*
Turbinaria spp.	1.7	*2.1*	1.7	*2.0*	1.5	*1.8*
Faviidae	1.7	*1.9*	1.6	*2.0*	1.6	*1.9*
Poritidae	2.2	*4.3*	2.2	*4.2*	1.9	*3.0*
Total soft corals	2.8	*3.9*	2.4	*3.8*	3.0	*3.7*
KESWICK						
Total algae	41.1	*16.3*	41.9	*16.5*	37.9	*15.7*
Total sponges	0.2	*0.5*	0.3	*0.5*	0.5	*0.8*
Total hard corals	28.5	*11.3*	29.3	*12.6*	34.0	*12.8*
Acropora spp.	11.8	*17.1*	12.8	*17.8*	13.8	*19.6*
Montipora spp.	4.1	*5.8*	4.8	*6.6*	6.4	*7.5*
Pocilloporidae	0.9	*1.0*	1.0	*0.9*	1.0	*1.1*
Siderasteridae	0.3	*0.7*	0.3	*0.5*	0.5	*0.9*
Turbinaria spp.	0.3	*0.7*	0.2	*0.7*	0.2	*0.7*
Faviidae	2.1	*1.7*	1.9	*1.5*	2.3	*1.7*
Poritidae	5.6	*5.8*	4.2	*4.2*	5.5	*6.8*
Total soft corals	8.4	*7.7*	9.0	*7.9*	9.3	*8.1*

Table 3-3 ANOVA results for the analysis of the benthic change between the three surveys

Family/Group	Location	Site (L)	Time	L x T	S x T(L)
Total algae	NS	***	***	***	***
Total hard corals	NS	***	***	**	*
Acropora spp.	NS	***	*	NS	***
Montipora spp.	NS	***	**	NS	*
Pocilloporidae	NS	**	*	NS	NS
Siderasteridae	*	**	NS	NS	NS
Turbinaria spp.	**	***	*	*	NS
Faviidae	NS	***	NS	NS	NS
Poritidae	NS	***	NS	NS	NS
Total soft corals	*	***	NS	NS	***

NS = not significant; * = 0.05>p>0.01, ** = 0.01>p>0.001; *** = p<0.001

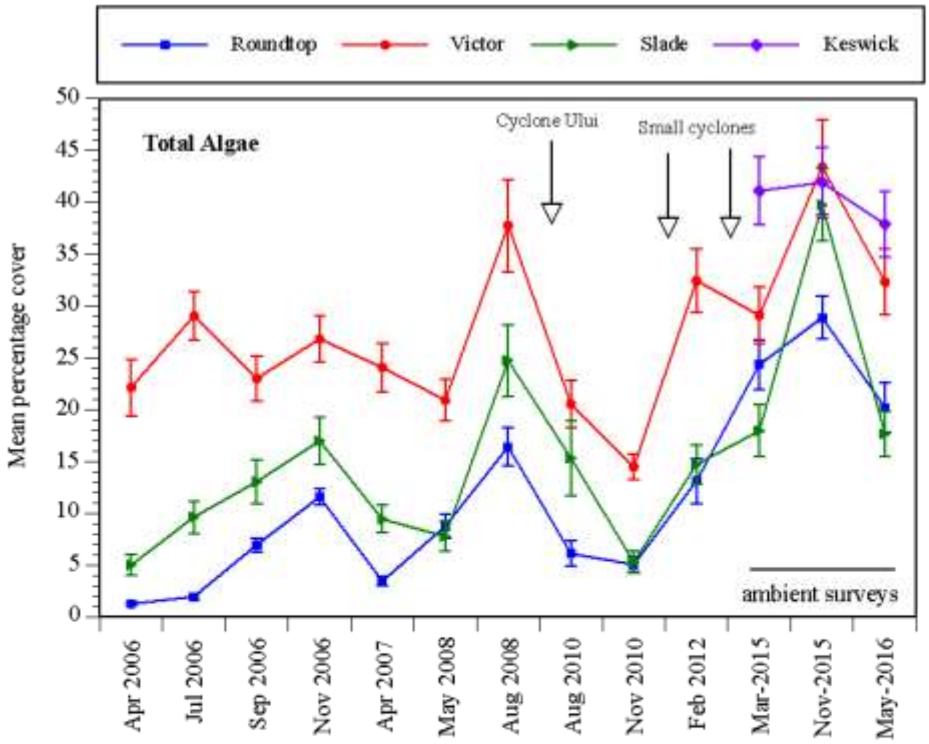


Figure 3-5 Changes in Percentage Cover of Algae

Graphs show grand mean percentage algal cover from the three ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors.

Sponges were not common in any of these locations (Figure 3-4) but were most abundant on Round Top Island, where the cover of this benthic group was 2.4% during the ambient surveys (Table 3-2).

Total hard coral cover was not significantly different between the four locations during the three ambient surveys (Table 3-3, Figure 3-6). Grand mean coral cover during the ambient surveys ranged from 23% on Round Top to 30% on Keswick, with 25% on Victor and 28% on Slade. Coral cover was similar during the two 2015 surveys but had increased significantly between the November 2015 and May 2016 surveys (Table 3-3, Figure 3-6).

This increase was higher on Keswick than on the three inshore locations and as a result the Time x Location interaction was significant for total coral cover. The increase in coral cover on Keswick was due to growth of the fast growing Acropora spp. and Montipora spp. coral groups. The nominal dip in coral cover for the pre-wet season survey on Slade Islet and Round Top Island was probably due to the high algal cover during that survey; dense cover of algae can make accurate recording of underlying hard corals difficult.

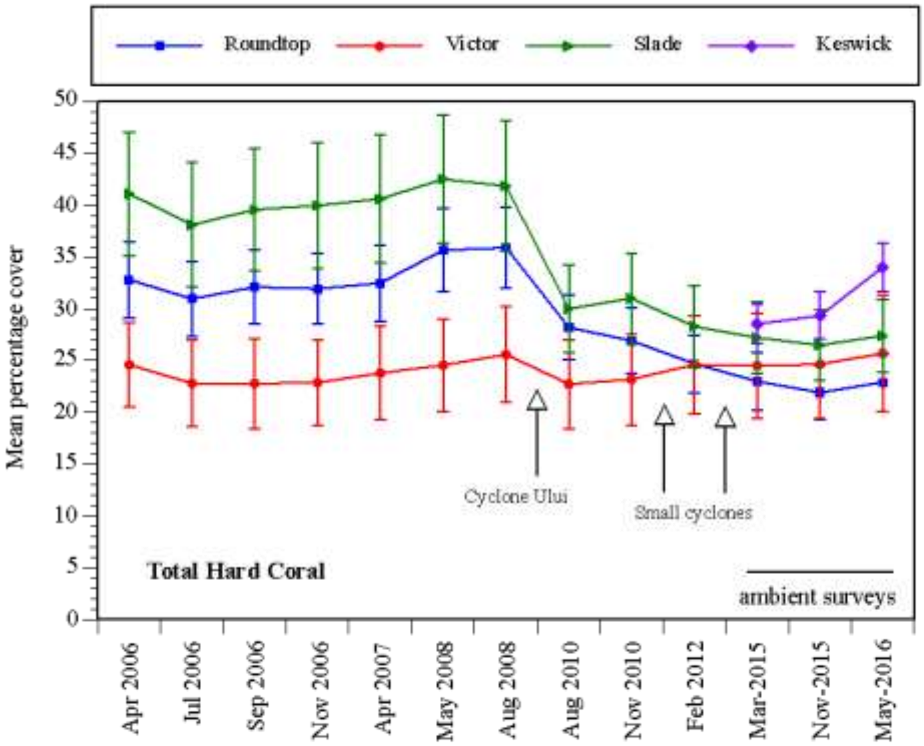


Figure 3-6 Changes in the Cover of Total Hard Coral

Graphs show grand mean percentage benthic cover from the three ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors.

Hard coral community composition was different in each location (Figure 3-7). Coral communities at Round Top Island were dominated by Turbinaria spp. (34% of total coral cover) with siderasterids, Montipora spp., faviids and poritids also common. Victor Islet reefs were dominated by Montipora spp. corals (43% of coral cover), with Turbinaria spp., faviids and siderasterids also common. On Slade Islet, spreading Montipora spp. corals accounted for over 60% of all hard coral cover, with siderasterids and poritids also common. Keswick Island coral communities were dominated by Acropora spp. corals (42% of coral cover), with Montipora spp. and poritids also common. On Keswick a range of species rare or absent on the inshore islands were also an important part of the coral community, including Pachyseris speciosa, Lobophyllia hemprichii and Merulina ampliata. Two coral groups that were dominant on all three inshore islands (Turbinaria spp. and siderasterids) were uncommon on Keswick Island.

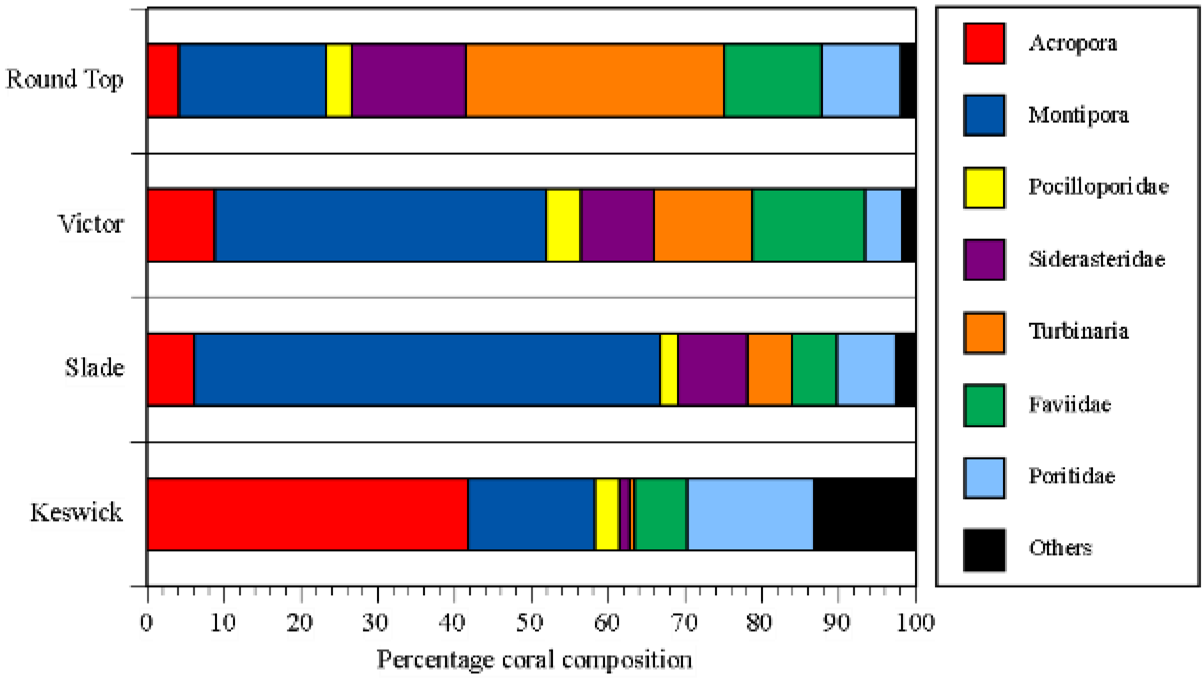


Figure 3-7 Coral Community Composition in the Four Locations During the Ambient Surveys

Graphs show mean percentage composition of the major coral groups from the four locations. Composition is averaged across all three ambient surveys.

Over the fourteen months spanned by the three ambient surveys there have been slight but significant increases in the cover of Acropora spp. corals, Montipora spp. corals and pocilloporid corals and a significant decrease in the cover of Turbinaria spp. corals (Figure 3-8, Figure 3-9). The decrease in Turbinaria spp. corals was greatest on Round Top where this coral group was most abundant and the Location x Time interaction was significant for this group. The percentage cover of Faviid and Poritid corals families was low at all sites compared to other coral family groups and remained relatively stable over the ambient monitoring period (Figure 3-10).

Only two coral groups showed significant location differences during the three ambient surveys. Both Turbinaria spp. and siderasterid corals were more abundant on Round Top Island and less abundant on Keswick Island than in the other two locations (Figure 3-9).

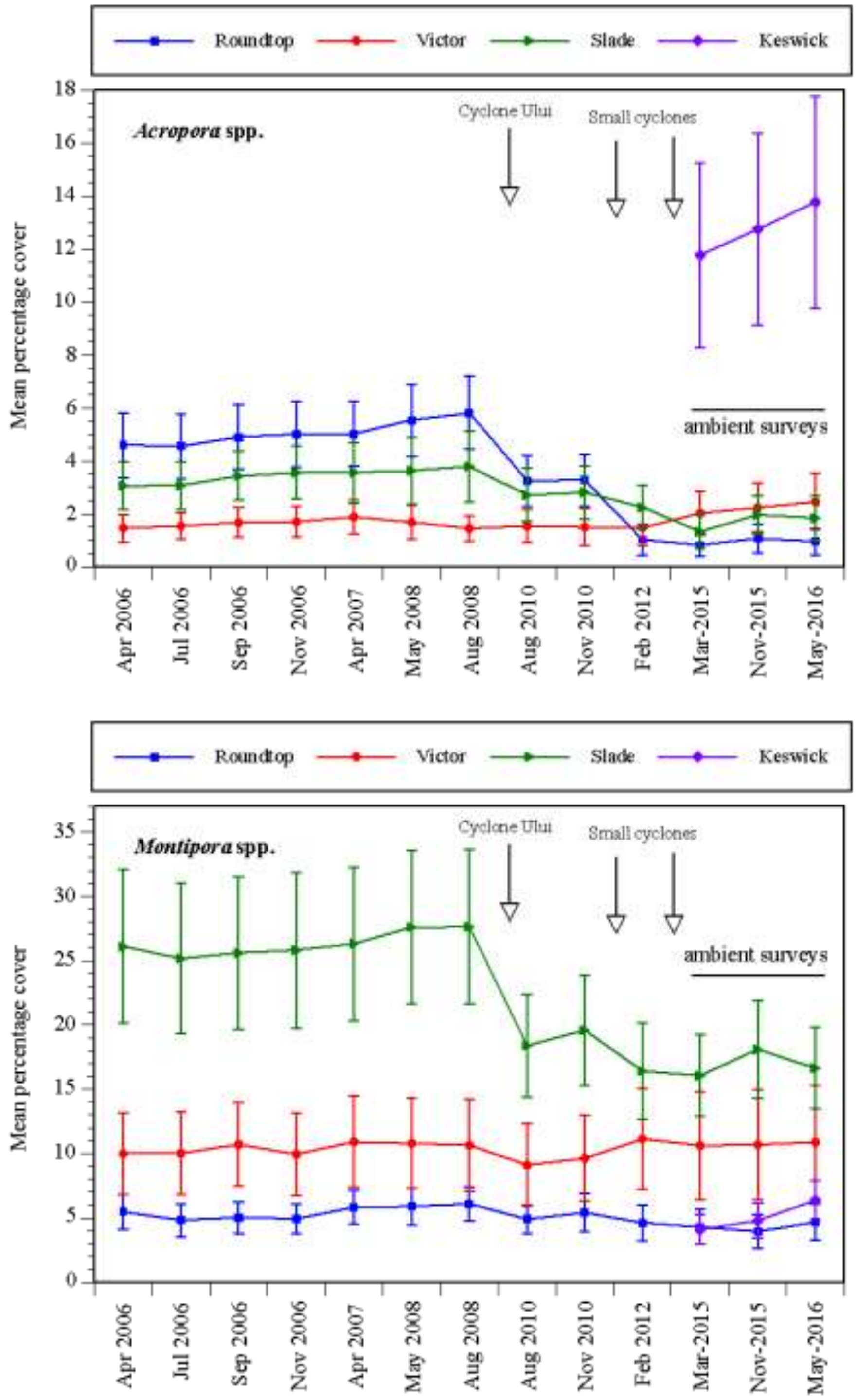


Figure 3-8 Changes in the Cover of Coral Groups: Acropora Corals and Montipora Corals

Graphs show grand mean percentage benthic cover from the three ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors.

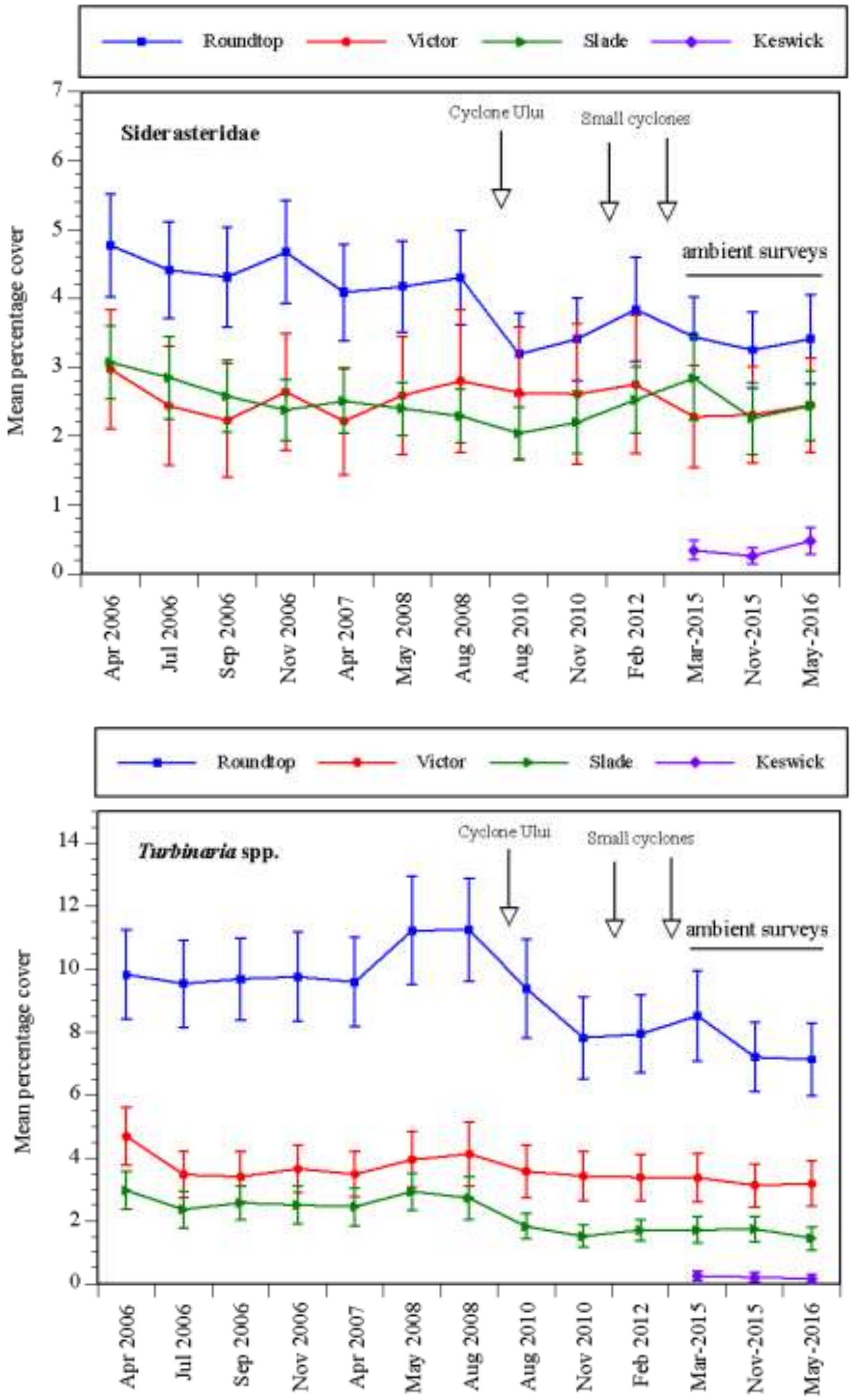
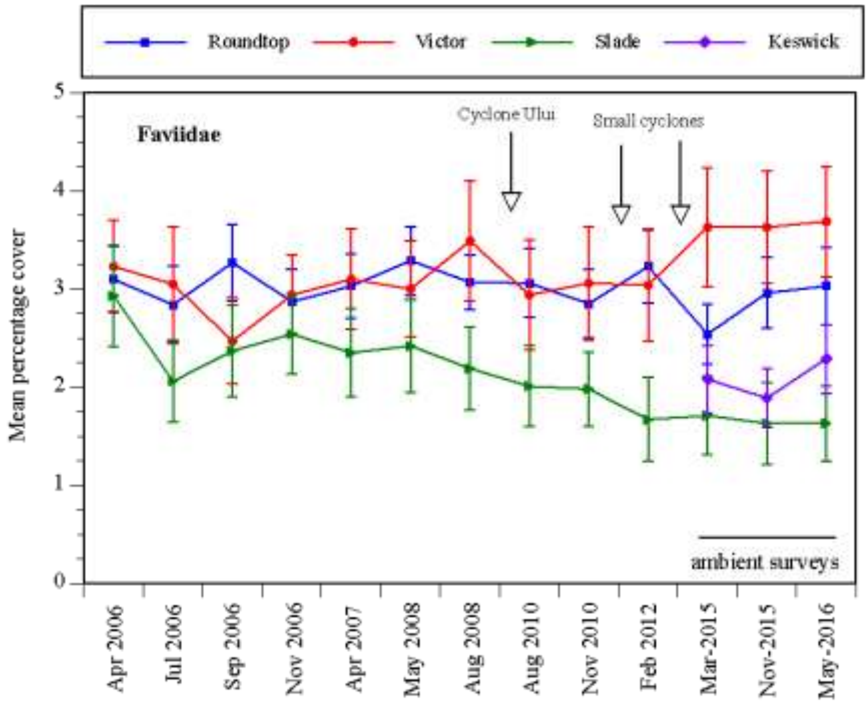


Figure 3-9 Changes in the Cover of Coral Groups: Siderasterid Corals and Turbinaria Corals

Graphs show grand mean percentage benthic cover from the three ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors.



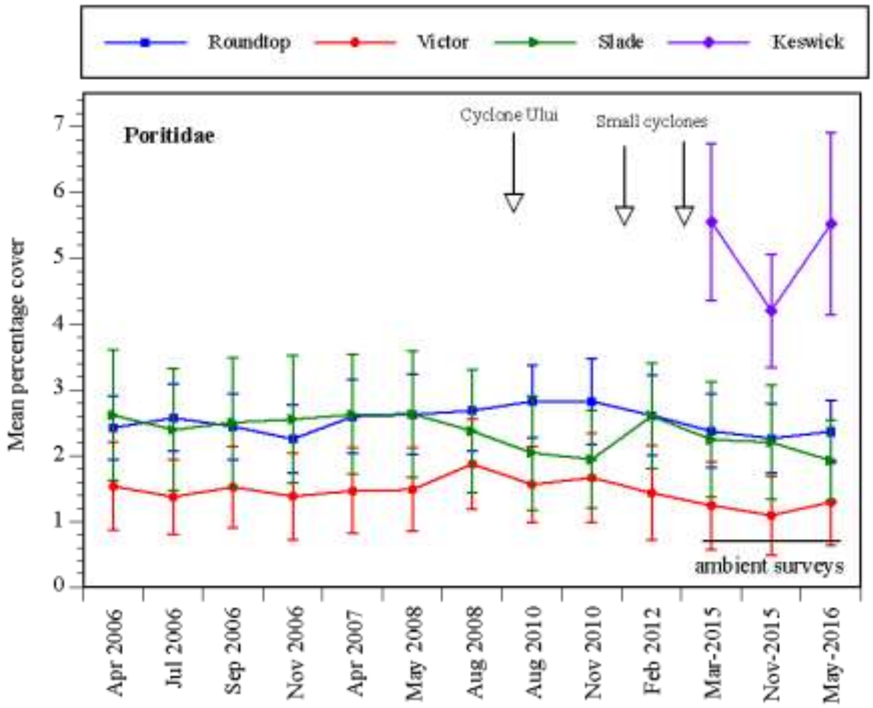


Figure 3-10 Changes in the Cover of Coral Groups: Faviid Corals and Poritid Corals

Graphs show grand mean percentage benthic cover from the three ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors.

Soft corals were significantly more abundant on Round Top Island and Keswick Island (where this group covered a mean of over 9% of the substratum) than in the other two locations (Table 3-2, Table 3-3, Figure 3-11). Although soft coral cover increased nominally over the three ambient surveys this change was not significant.

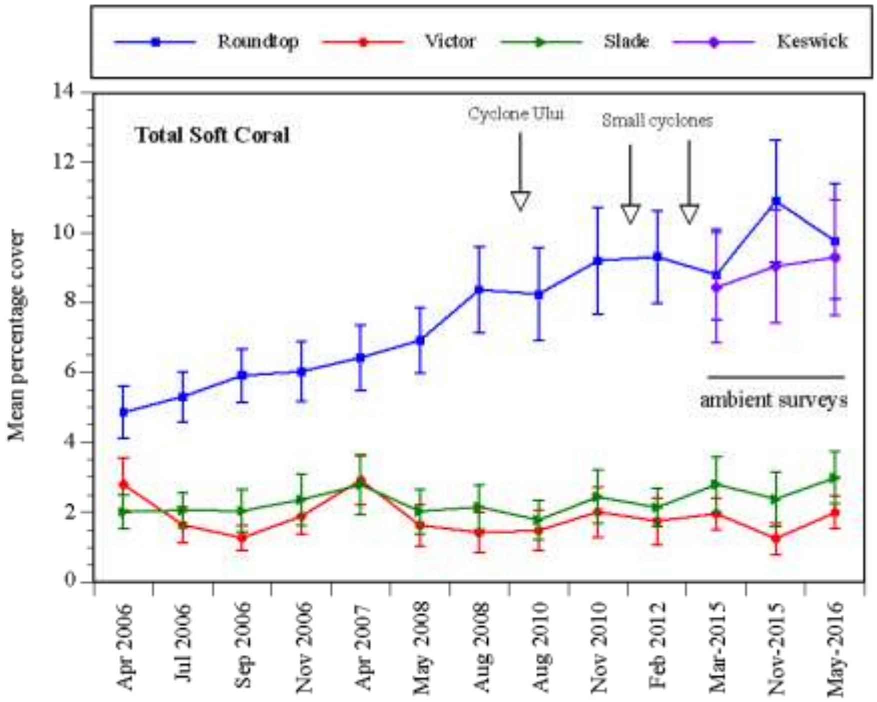


Figure 3-11 Changes in the Cover of Total Soft Coral

Graphs show grand mean percentage benthic cover from the three ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors.

3.3 Partial Bleaching

The first ambient survey in March 2015 was at the end of summer and a moderate number of corals showed evidence of partial bleaching (pale colouration) at this time. Bleaching was highest on Round Top Island where 3.2% of corals were paler than normal in colour (Table 3-4, Figure 3-14). There were significantly lower numbers of partially bleached corals on Victor Islet (0.9% of corals) than on the other three locations (Table 3-4).

Levels of bleaching were significantly lower during the second and third ambient surveys at all sites except Keswick Island (Table 3-4, Table 3-5 and Figure 3-12). There was moderate bleaching on Keswick during the May 2016 survey in spite of low levels in the other three locations and hence the Location x Time interaction was significant for the ambient survey analysis (Table 3-5).

Table 3-4 Coral colony health status during the three ambient surveys

Location	March 2015	Nov 2015	May 2016
Round Top			
Mean total coral colonies per 40m^2	103	ns	ns
Healthy coral colonies (%)	~95.5%	97.9%	99.0%
Partially bleached colonies (%)	3.2%	0.3%	0.3%
Disease damaged colonies (%)	0.9%	1.3%	0.5%
Sediment damaged colonies (%)	~0.4%	0.5%	0.2%
Victor			
Mean total coral colonies per 40m^2	100	ns	ns
Healthy coral colonies (%)	~97.0%	98.8%	97.8%
Partially bleached colonies (%)	0.9%	0.2%	0.0%
Disease damaged colonies (%)	0.9%	0.7%	1.5%
Sediment damaged colonies (%)	~1.2%	0.3%	0.7%
Slade			
Mean total coral colonies per 40m^2	100	ns	ns
Healthy coral colonies (%)	~95.7%	97.1%	98.5%
Partially bleached colonies (%)	2.3%	0.4%	0.7%
Disease damaged colonies (%)	1.2%	2.2%	0.7%
Sediment damaged colonies (%)	~0.8%	0.3%	0.1%
Keswick			
Mean total coral colonies per 40 m^2	79	ns	ns
Healthy coral colonies (%)	~94.9%	97.7%	97.4%
Partially bleached colonies (%)	2.2%	0.4%	1.5%
Disease damaged colonies (%)	1.9%	0.8%	0.9%
Sediment damaged colonies (%)	~1.0%	1.1%	0.2%

Healthy and damaged corals are recorded as a percentage of the total number of colonies; for the March 2015 survey sediment damage was estimated from the transect photos. ns = not sampled

Table 3-5 ANOVA results for the analysis into the changes in density of partially bleached, diseased and sediment damaged corals between the three ambient surveys at all sites

Factor	Location	Site (L)	Time	L x T	S X T(L)
Partial bleaching changes	*	***	***	**	***
Coral disease changes	NS	***	*	NS	***
Sediment damage changes	NS	***	**	NS	***

NS = not significant; * = 0.05>p>0.01, ** = 0.01>p>0.001; *** = p<0.001

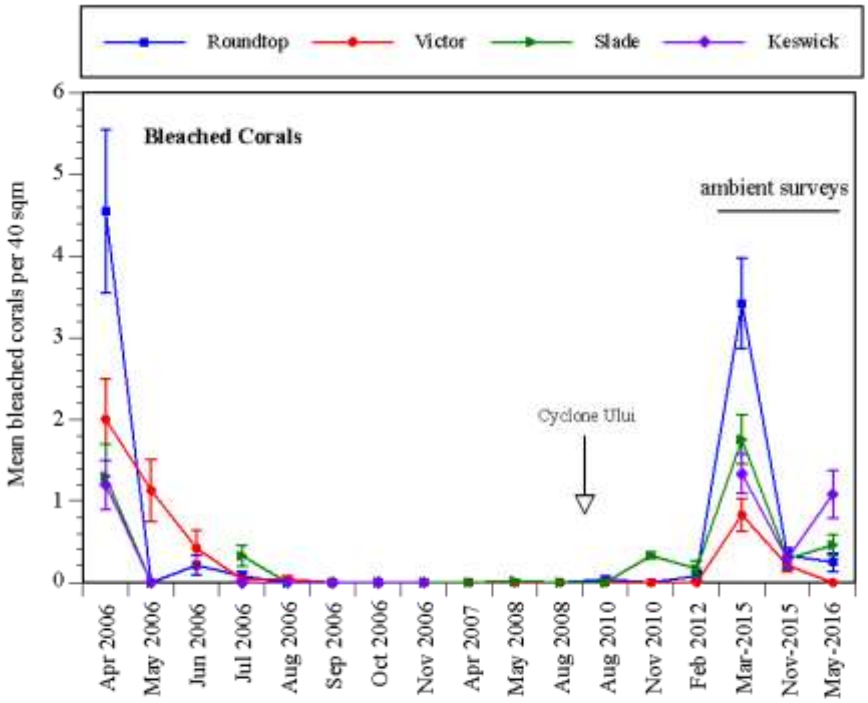


Figure 3-12 Changes in Density of Bleached and Partially Bleached Coral Colonies

Graphs show grand mean density of bleached and partially bleached corals per 40sq m from six sites of four 20 x 2m transects in each location from the three ambient surveys and all previous surveys. Error bars are standard errors.

3.4 Sediment Deposition on Coral Colonies

During the ambient surveys approximately 20% of coral colonies had recordable sediment on at least part of their surface (Table 3-6). The percentage of colonies with surface sediment during the ambient surveys was highest on Victor Islet where 30% of corals had sediment and lowest on Slade Islet and Round Top Island where 10% and 14% of corals had surface sediment. Mean depth of these patches of sediment on living coral colonies showed a similar pattern (Table 3-6), being nominally highest on Victor and lowest on Slade and Round Top, but these location differences were not significant due to the large variation in sediment depths (range of zero to 14 mm).

Sediment depths were significantly higher during the first ambient survey and lower in the other two surveys (Table 3-6, Table 3-7, Figure 3-13). Sediment depth did not decrease as much on Victor Islet as in the other three locations and hence the Location x Time interaction was significant (Table 3-7).

Table 3-6 Changes in frequency (%) and depth of sediment (mm) load on corals over the three survey events at each survey location

Survey date	Round Top		Victor		Slade		Keswick	
Percent of total colonies with sediment load								
Mar 2015	10.6%		31.7%		19.0%		23.1%	
Nov 2015	9.6%		29.3%		4.3%		23.3%	
May 2016	21.5%		30.2%		8.5%		17.3%	
Mean Maximum sediment depth (mm)								
Mar 2015	0.18	*0.82*	0.56	*1.39*	0.31	*1.07*	0.42	*1.30*
Nov 2015	0.08	*0.33*	0.26	*0.55*	0.06	*0.39*	0.42	*1.39*
May 2016	0.17	*0.53*	0.40	*0.94*	0.05	*0.20*	0.13	*0.35*

Figures are grand mean sediment depth in mm with standard deviations in italics where appropriate. ns= not surveyed

Table 3-7 ANOVA results for the changes in sediment depth on coral colonies between the three reefs during ambient surveys

Factor	Location	Site (L)	Time	L x T	S x T(L)
Coral sediment changes	NS	***	***	***	***

NS = not significant; * = 0.05>p>0.01, ** = 0.01>p>0.001; *** = p<0.001

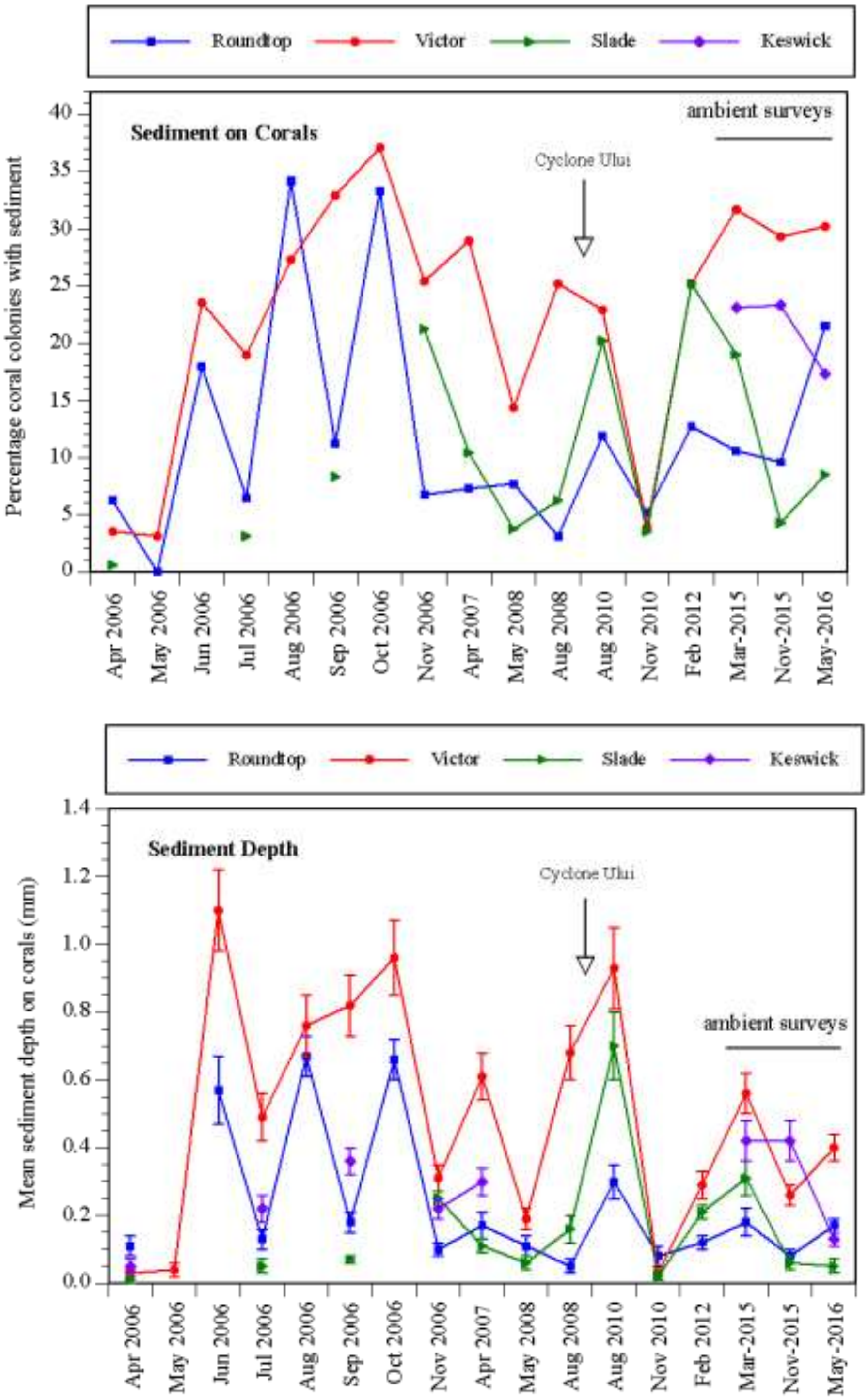


Figure 3-13 Changes in Number of Corals with Sediment Load and Sediment Depth

Graphs show percentage of the 480 coral colonies examined in each location that had measurable sediment on part of the surface during each survey and the mean depth in mm of that sediment for the three ambient surveys and for all previous surveys. Error bars where appropriate are standard errors

3.5 Sediment Damage and Disease in Coral Colonies

Heavy sediment deposition on living coral can cause patches of mortality on the corals surface. During the first ambient survey the high sediment levels had caused a small amount of mortality on less than 1% of coral colonies (Table 3-4). Levels of sediment induced mortality were not significantly different among the four locations (Table 3-5). Rates of sediment mortality decreased significantly over the three ambient surveys (Table 3-5, Figure 3-14).

A small number of diseased corals are present in most coral reef communities. The coral groups most often affected by disease in the region were Acropora, Montipora, and Turbinaria but massive faviid, siderastreid and poritid corals were also sometimes damaged by disease. Disease levels were about average during the ambient surveys with a grand mean of about 1% of corals affected (Table 3-4). There were no significant differences in disease levels between the four locations during the three ambient surveys (Table 3-5). Disease levels during the final ambient survey were significantly lower than during the first two surveys (Figure 3-14). Changes in disease levels were similar in the four locations during the ambient surveys and the Location x Time interaction was not significant (Table 3-5).

3.6 Coral Demography Patterns

Hard coral recruits less than 10 cm in diameter were common on these reefs during the ambient surveys (Figure 3-15). Recruit numbers were significantly higher on Round Top and Slade than on Victor and Keswick (Table 3-8), and were also significantly higher in both post-wet season surveys than in the pre-wet season survey (Table 3-8, Figure 3-15). The dominant coral group represented in the recruit population for the three inshore locations was dendrophyllid corals in the genus Turbinaria. This group accounted for between 50% and 70% of total coral recruits in these locations (Figure 3-16). Faviids and pocilloporids also recruited well on these inshore locations. The recruit population on the offshore Keswick Island was different with faviids accounting for over 30% of recruits and Acropora (13%) and pocilloporids (9%) also important. Other corals that were rare on the inshore reefs were also important as recruits on Keswick Island. This group included species such as *Pachyseris speciosa*, *Lobophyllia hemprichii* and *Merulina ampliata*.

Table 3-8 ANOVA results for the analysis into the patterns of density of hard coral recruits between the three ambient surveys

Factor	Location	Time	L x T
Hard coral recruits	*	***	NS

NS = not significant; * = 0.05>p>0.01, ** = 0.01>p>0.001; *** = p<0.001

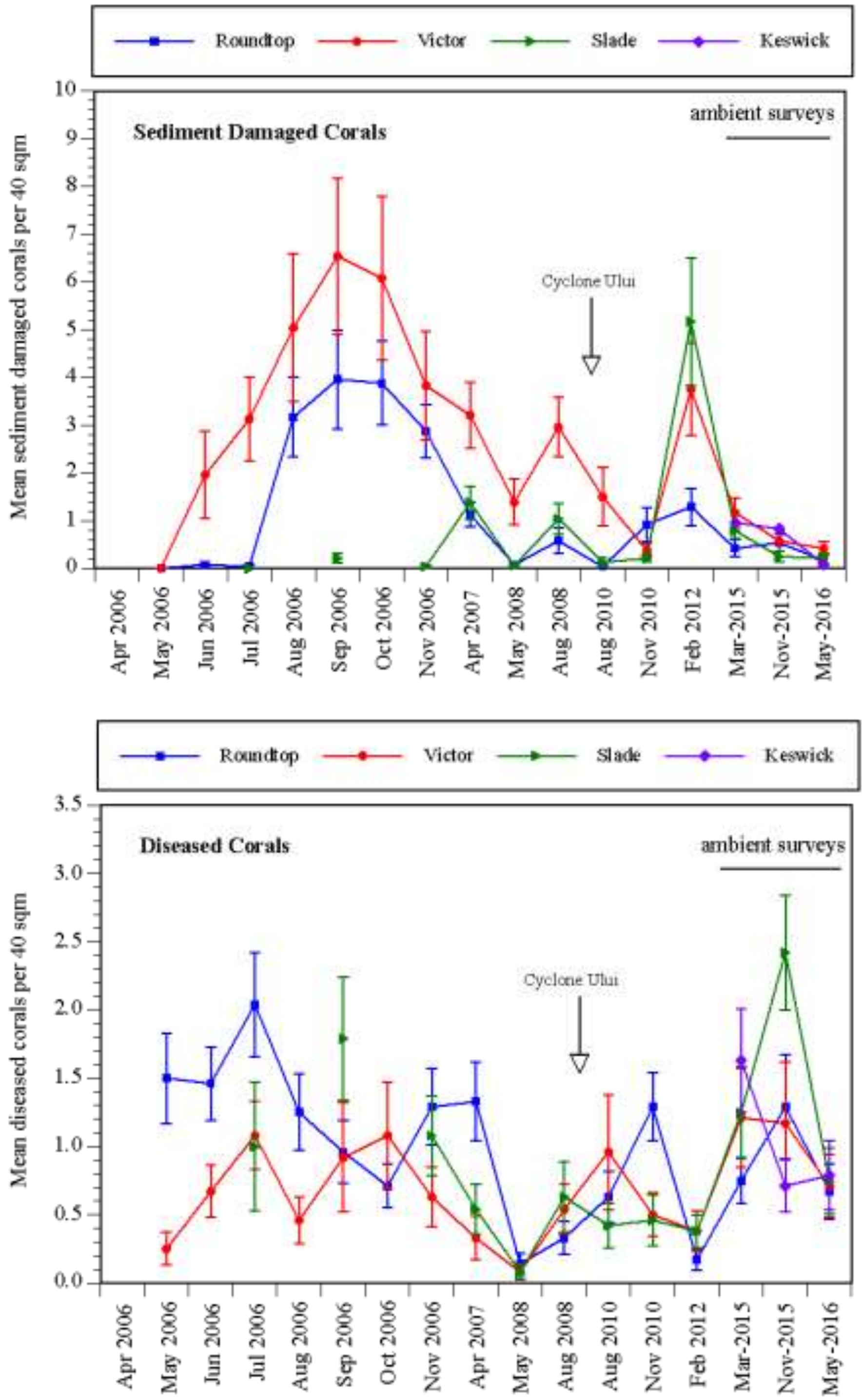


Figure 3-14 Changes in Density of Sediment Damaged and Diseased Coral Colonies

Graphs show grand mean density of diseased coral colonies and sediment damaged corals per 40sq m from six sites of four 20 x 2m transects in each location from the three ambient surveys and all previous surveys. Error bars are standard errors.

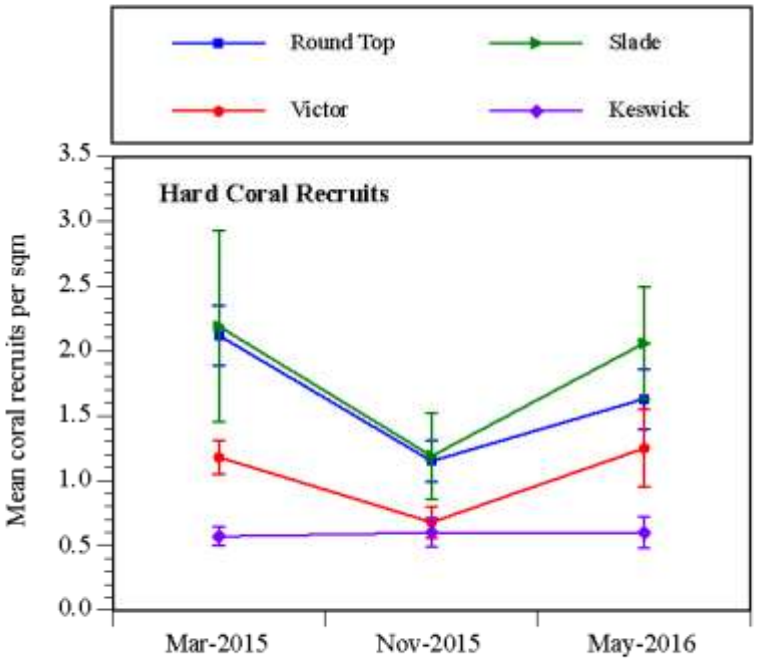


Figure 3-15 Changes in Density of Hard Coral Recruits Over the Ambient Surveys

Graphs show mean density of hard coral recruits per m^2 from six sites in each location for the three ambient surveys. Error bars are standard errors.

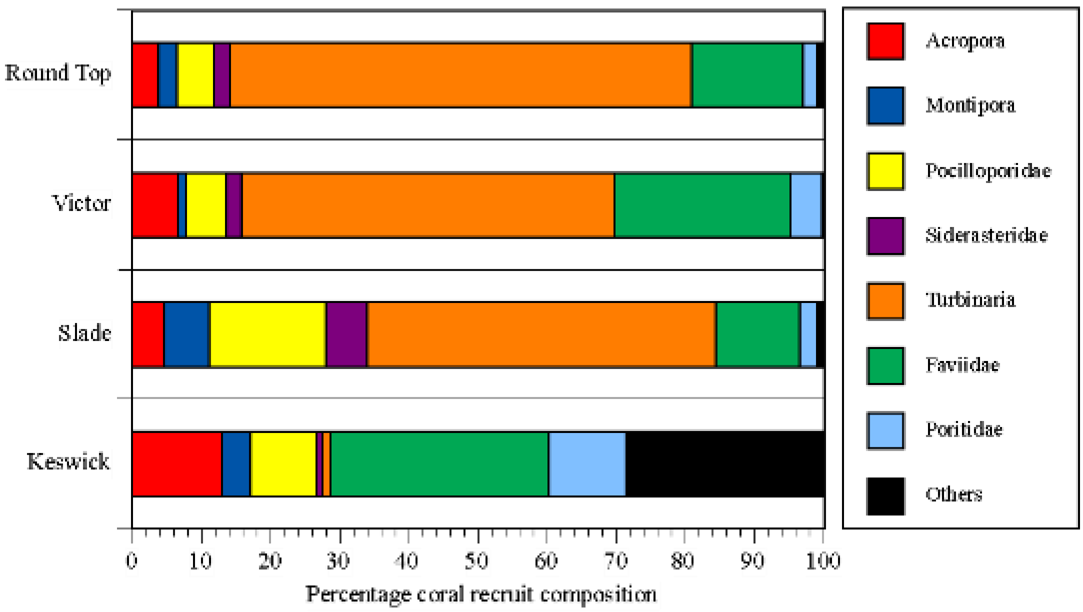


Figure 3-16 Composition of the Hard Coral Recruit Population in the Four Locations

Graphs show mean percentage composition of the major groups of coral recruits from the four locations. Composition is averaged across all three ambient surveys.

3.7 Benthic community images

Examples of the benthic community structure at each site and examples of coral disease, sedimentation and bleaching are provided in Figure 3-17 to Figure 3-36.

Figure 3-17 Turbinaria spp. corals (centre and left) were dominant at Round Top Island, with siderastreids (lower left and lower right) and faviids (below Turbinaria) also common (Site 5)

Figure 3-18 Gorgonians and Sarcophyton soft corals amongst a field of Turbinaria spp. corals on Round Top Island Site 5 during the November 2015 survey

Figure 3-19 Although Acropora corals had decreased on Round Top Island as a result of cyclone impact they were still common at some sites (Site 1)

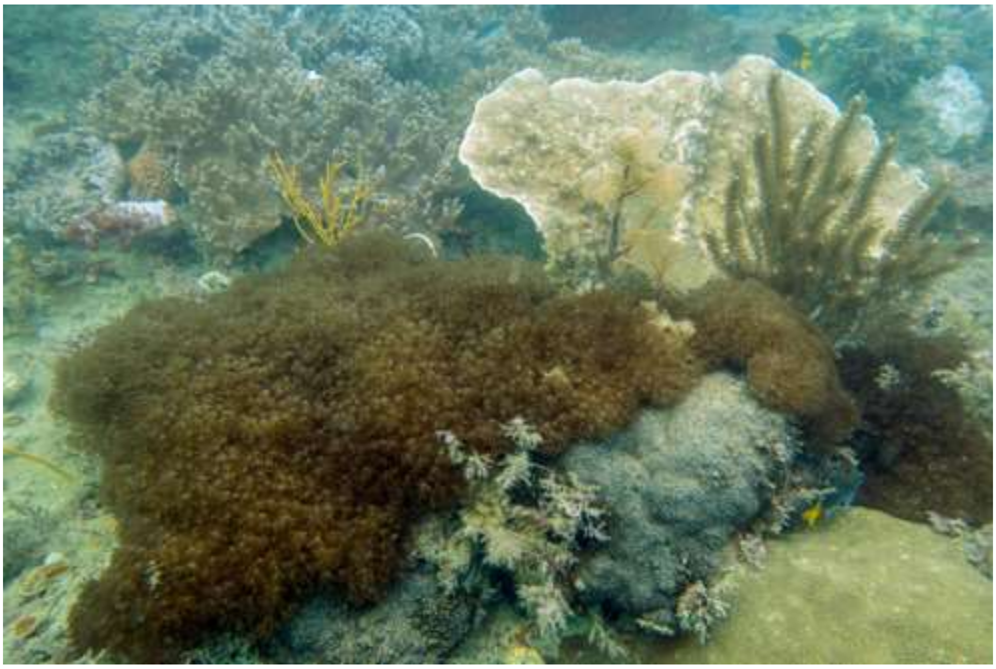


Figure 3-20 Soft corals, including the feathery brown Sansibia (lower left) and Sinularia colonies (top left), were significantly more abundant on Round Top Island than in the other two inshore locations (Site 6)

Figure 3-21 Algal cover had increased markedly on Round Top Island over the past ten years (Site 2)

Figure 3-22 A Sarcophyton soft coral (lower left), Pocillopora hard coral (centre and right) and Sargassum algae (top left) at Round Top Island Site 2

Figure 3-23 Most corals on Victor Islet were healthy at the time of the May 2016 ambient survey (Site 2)

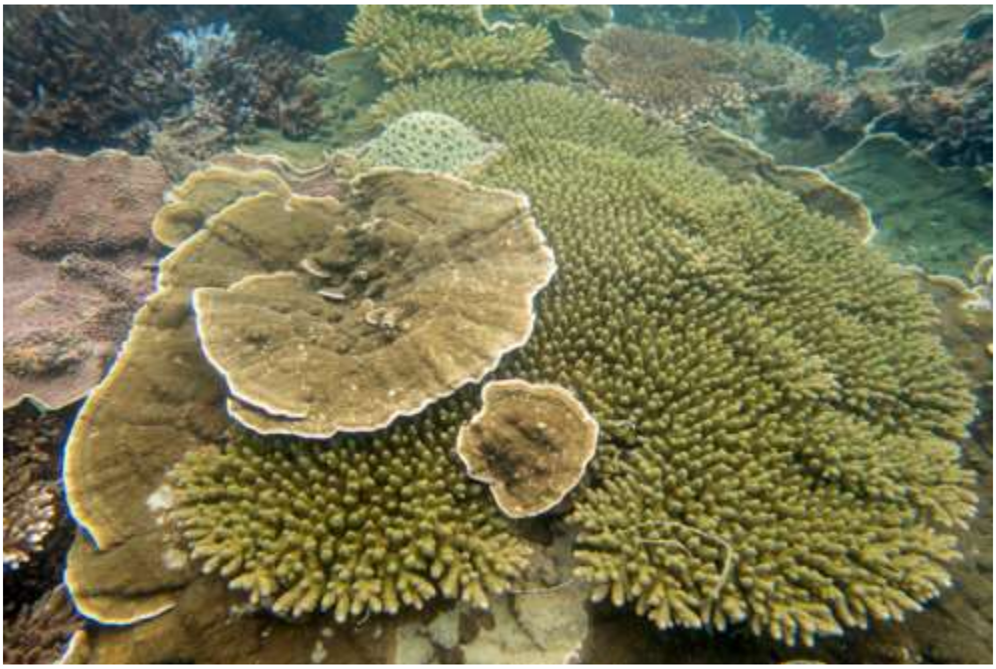


Figure 3-24 Montipora corals (centre left), Acropora corals (centre right), Turbinaria (left) and faviid corals (above Montipora) were aggressively competing for space at Victor Site 2

Figure 3-25 Turbinaria and faviid corals with dense Sargassum algae at Victor Islet site 3; Algal cover had increased at the three inshore locations over the past ten years

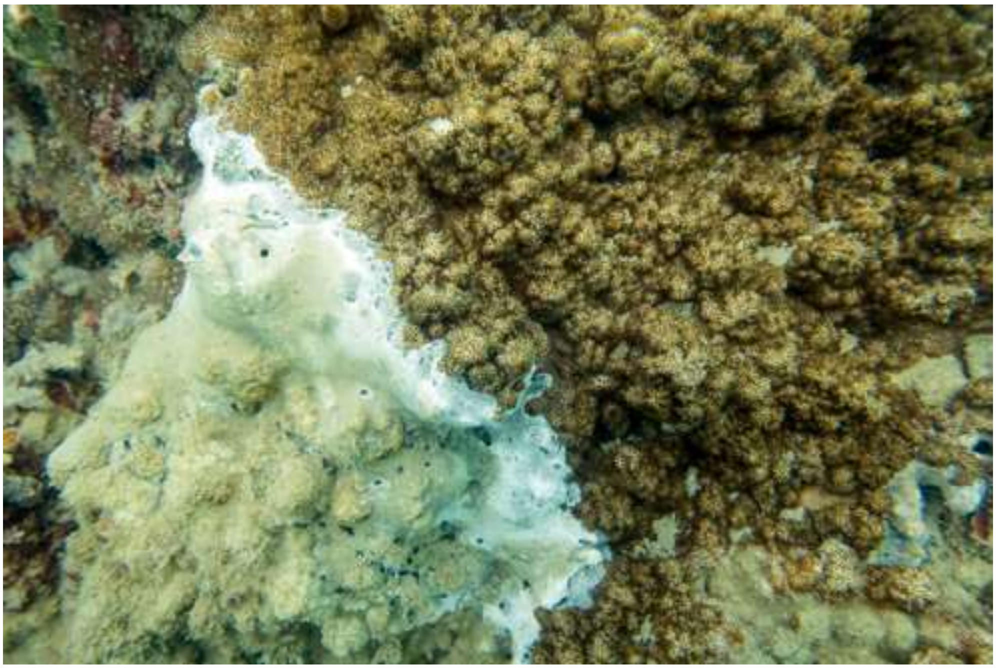


Figure 3-26 Disease patches on a Montipora colony at Victor Islet Site 2

Figure 3-27 A variety of healthy corals on the NE face of Slade Islet (Site 5)

Figure 3-28 Spreading sheets of Montipora corals were the dominant corals on the NE face of Slade Islet (Site 3)

Figure 3-29 Partially bleached Montipora coral on the NE face of Slade Islet during the March 2015 ambient survey (Site 3)

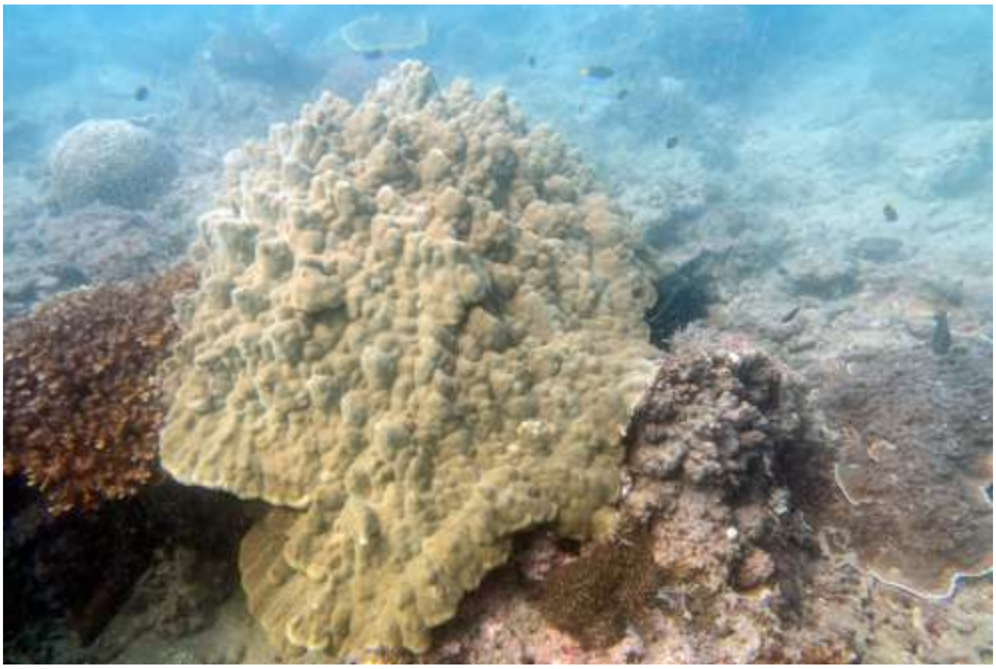


Figure 3-30 On the southwest face of Slade Islet coral communities were dominated by robust faviid and poritid colonies, along with Pocillopora, siderasterid and Montipora corals (Site 2)

Figure 3-31 Sargassum algal forests dominated the benthic community on Keswick Island, covering around 40% of the substratum during the ambient surveys (Site 5)

Figure 3-32 A variety of corals amongst Sargassum algae on Keswick Island: faviid (centre left), Merulina (centre right), Porites (lower left) and Echinophyllia (lower right) (Site 6)

Figure 3-33 Acropora staghorn corals dominated the benthic community in Homestead Bay, on St Bees Island immediately adjacent to Keswick Island (Site 3)

Figure 3-34 Soft corals covered about 9% of the substratum on Keswick Island (Site 2)

Figure 3-35 Patches of sediment covering about 30% of the surface of a Montipora colony on Keswick Island (Site 1)

Figure 3-36 The same Montipora colony illustrated above with the sediment swept from the surface showing small patches of mortality (white patches)

4 Discussion

4.1 Benthic Cover during the Ambient Surveys

The major change recorded during the three ambient surveys was natural seasonal fluctuations in algal abundance. Algal growth is highest in spring when more nutrients are available and hence algal cover was highest during the pre-wet season survey in November 2015. These seasonal fluctuations were higher in the three inshore locations than on Keswick Island where the changes in algal cover over the ambient surveys were not significant. The reasons for the higher cover and lower fluctuations of algal abundance on Keswick Island are not clear but may be related to better average water clarity compared to the more turbid inshore locations.

The main change in hard coral communities during the ambient surveys was an increase in coral cover on Keswick Island driven by natural growth of the fast growing acroporid and pocilloporid coral groups. There was also a slight decrease in the cover of Turbinaria corals, primarily on Round Top Island where this coral group was most abundant. This decrease is probably related to the high levels of coral disease that were recorded during the pre-wet season ambient survey. Although there were nominal fluctuations in soft coral cover during the ambient surveys these changes were not significant.

4.2 Long-Term Changes in Benthic Communities

A series of ANOVA analyses were used to establish the significance of any benthic or coral damage changes over all the surveys that have been consistently carried out at the three locations (Round Top, Slade and Victor) since April 2006 (refer to ANOVA results in Table 4-1).

Table 4-1 ANOVA results for the analysis of benthic changes between all surveys at three locations

Family/Group	Location	Site (L)	Time	L x T	S x T(L)
Total algae	*	***	***	NS	***
Total hard corals	NS	***	***	**	***
Acropora spp.	NS	***	***	***	***
Montipora spp.	NS	***	***	***	***
Pocilloporidae	NS	*	NS	**	***
Siderasteridae	NS	**	**	NS	**
Turbinaria spp.	*	***	***	NS	***
Faviidae	NS	***	NS	***	NS
Poritidae	NS	**	NS	NS	NS
Total soft corals	**	***	**	***	***

NS = not significant; * = 0.05>p>0.01, ** = 0.01>p>0.001; *** = p<0.001

4.2.1 Changes in algal cover

Thirteen surveys spanning a decade have been made on the three inshore locations since April 2006. Algal cover was significantly higher on Victor Islet over this period than in the other two locations (Table 4-1, Figure 3-5). Although there were large fluctuations in algal cover on these inshore locations, there also appears to have been an overall upward trend over the past decade, especially on Round Top Island and Slade Islet.

Similar benthic surveys for another project were carried out on Keswick Island in 2001 (Ayling and Ayling 2001). This survey looked at three sites in each of the three bays incorporated into the present ambient survey. Mean algal cover over the three bays in 2001 was 35%, very similar to the mean of 38% cover fifteen years later during the last ambient survey.

Algal cover (which includes macroalgae and turf algae) during the ambient surveys was higher than at any other time during the past 10 years. Macroalgae are an important food source for herbivorous fish and form an important habitat for number of other organisms; increases in macroalgae cover over time may be an indicator of overfishing of herbivorous fish or degradation of water quality via elevated nutrient and sediment inputs (Diaz-Pulido and McCook 2008). Increases in macroalgae abundance may also hinder the recovery of coral cover on Round Top Island and Slade Islet, the locations that were most affected by Cyclone Ului and the subsequent smaller cyclone events in 2011 and 2014.

4.2.2 Changes in hard coral cover and community structure

There have been significant changes in the cover of hard coral over the past decade at all three inshore locations (Table 4-1, Figure 3-6). Between the capital dredging baseline in April 2006 and the impact of Cyclone Ului in March 2010 (see section 3.1.2), coral cover at all three locations only fluctuated slightly (Figure 3-6), with 23-25% cover on Victor, 32-35% on Round Top and about 40% on Slade. Tropical Cyclone Ului had a marked impact on all three inshore study locations when it crossed the coast near the Whitsunday Islands in March 2010. The cover of most major coral groups was significantly reduced, along with the cover of algal populations. Corals were broken up, turned over or smothered with large quantities of sand and rubble. Cyclone damage usually stimulates growth in many coral species (Ayling and Ayling 2005) and many of the broken or damaged corals had begun to recover only three months after the event.

Damage from Cyclone Ului reduced coral cover at all three locations but the effect was greatest on Slade (from 42% down to 30%) and Round Top (36% down to 28%) compared with Victor (26% down to 23%). Since then there have been further reductions in coral cover on Round Top Island and Slade Islet due to disease, floods and cyclone events, but Victor Islet has managed a nominal increase in coral cover and is now nominally higher than during the April 2006 baseline (Figure 3-6). The six years of declining coral cover on Round Top and Slade have only reversed over the last six months.

There have been significant changes in the cover of many major coral groups over the past decade (Table 4-1, Figure 3-8, Figure 3-9, Figure 3-10). The cover of Acropora species was significantly higher on Round Top Island than Victor and Slade until the Cyclone Ului event (Figure 3-8). The cyclone caused a large drop in Acropora cover on Round Top Island and there was a similar large drop in cover over the 15 months between November 2008 and February 2012 due to flood and further cyclone impacts. At the time of the first ambient survey Acropora cover on Round Top Island was reduced by 85% from the pre-Ului peak and was nominally lower than the other two inshore locations. This Acropora decline appears to have halted during the ambient surveys. Acropora cover did not decline on Victor Islet and hence the Location x Time interaction was significant (Table 4-1).

The cover of Montipora spp. corals was significantly higher on Slade Islet compared with Victor Islet, with Round Top Island significantly lower than Victor Islet (Figure 3-8). Cover of this coral group did not change significantly on Victor Islet (about 10% cover), or on Round Top Island (about 5% cover) over the ten years encompassed by these surveys. However, Montipora cover reduced significantly on Slade Islet following the Cyclone Ului impact and suffered a further reduction between November 2010 and February 2012. During the first ambient survey Montipora cover on Slade Islet was 42% lower than pre-Ului levels. The large decline in Montipora cover on Slade was the dominant influence for the observed overall reduction in Montipora cover, with populations at other sites remaining stable since cyclone Ului. (Table 4-1)

There were significant fluctuations in the cover of siderasterids caused by disease episodes and the Cyclone Ului event but these patterns were similar in all three locations and the Time x Location interaction was not significant (Figure 3-9, Table 4-1). Turbinaria corals in the family Dendrophylliidae were the dominant benthic group on Round Top Island where they covered about 8% of the substratum during the ambient surveys (Figure 3-9). These corals were significantly more abundant on Round Top Island than in the other locations (Table 4-1). There have been significant reductions in Turbinaria cover over the ten years covered by these surveys, caused by disease and Cyclone Ului. Although these reductions were nominally greater on Round Top Island than in the other locations the Time x Location interaction was not significant (Table 4-1). Robust corals in the families Faviidae and Poritidae were moderately common at all three locations and did not change significantly in abundance during the ten years spanned by these surveys (Table 4-1, Figure 3-10). Faviid cover decreased on Slade Islet compared to the other locations and increased on Victor Islet so the Time x Location interaction was significant for this coral group (Table 4-1).

Soft coral cover steadily doubled from ~5% in 2006 to ~10% cover in 2016 on Round Top Island over the ten years of these surveys, giving a significant time effect, but did not change on Slade Islet and Victor Islet so the Time x Location interaction was also significant (Table 4-1). The significant increase in soft coral cover at Round Top Island over the ten years of survey appears to have been due to the natural growth of Sarcophyton and Sansibia soft coral colonies.

The Keswick Island reefs were not monitored over the period of cyclonic impacts but comparison of changes in the four sites that were common between the 2006 capital dredging monitoring program and the present ambient monitoring program suggests that corals in this location had already recovered to more than pre-cyclone levels by the time of the first ambient survey. Coral cover on Keswick increased significantly during the ambient monitoring program and mean coral cover in May 2016 was over 40% higher than during the 2006 baseline. Coral cover on Victor Islet increased during the ambient surveys and in May 2016 was at least nominally higher than during the April 2006 baseline. Coral cover also increased nominally on Round Top and Slade over the second half of the ambient survey period, despite the increased algae recorded, suggesting that coral communities in these two locations are showing strong signs of stabilised recovery after five years of natural events.

4.2.3 Coral Bleaching

Levels of *partial* bleaching (for partial bleaching, the colony is pale in colour not white) were higher during the ambient surveys than at any time since the baseline survey in April 2006 (Figure 3-12). Very few soft corals were bleached during the March 2015 hard coral bleaching peak whereas around 50% of soft coral colonies on Round Top showed *partial* bleaching in April 2006 (GHD 2006). Minor to moderate coral bleaching was observed in the Mackay/Capricorn Management Area during extensive aerial and in water surveys undertaken in February and March 2016 (GBRMPA 2016a). The subsequent coral mortality associated with the preceding bleaching event measured on coral reefs in May/June 2016 in the Mackay/Capricorn Management Area was estimated at between 0 and 9.9% of all corals (GBRMPA 2016b). Measurements of sea temperatures by TropWATER dataloggers located near the coral monitoring sites did not show a marked increase in average sea temperatures between the summer months of 2015 and the summer months of 2016.

4.2.4 Sedimentation and Coral Damage

The number of sediment damaged corals on the three inshore reefs reached a peak during the 2006 capital dredging event on both Round Top and Victor (Figure 3-14). There was another much smaller peak in damage levels during the 2008 maintenance dredging. The elevated sedimentation during dredging and subsequent sediment related damage did not translate into a significant drop in coral cover at any monitoring site.

Flood and cyclone events during 2010/2011 increased sediment-related damage at Victor Islet and caused large scale physical damage and sediment damage to coral colonies (in particular *Montipora* spp.) on Slade Islet (Figure 3-14). Although both sediment depths and percentage of corals with sediment were high during the ambient surveys, the levels of coral damage were much lower than during most of the last ten years. This implies that the current coral community is resilient to certain levels of transient sedimentation and short term elevated sedimentation does not translate into loss of coral cover.

Massive mobilisation of sediment and rubble during Cyclone Ului caused some sediment damage at Round Top; however most damaged patches were recovering by the time of the August 2010 survey and damage was not recorded (Figure 3-14).

During the first ambient survey, coral sediment levels and sediment damage had again increased to levels about half of those recorded during the capital dredging program. It is assumed that this increase was due to flood and cyclone events during 2013/2014. The Mackay region experienced gales and high rainfall during the Cyclone Ita and Cyclone Dylan events in early 2014 and April 2014 respectively (see Section 3.1.2). During the ambient monitoring surveys the amount of sediment on corals in all four locations was relatively high, being within the range recorded during the 2006 capital dredging program and those recorded during cyclone Ului.

The capital dredging program in 2006 had a marked effect on sediment deposition on coral colonies on Victor Islet reefs, with a maximum of 6.5% of coral colonies suffering some sediment damage. However, mean coral cover was not significantly affected by the increased fine sediment levels and mortality only occurred on a few small patches of the affected colonies, leading to an estimated reduction in coral cover of <0.1%. The maintenance dredging operations in 2008 also added fine sediment to some Victor sites and the density of sediment damaged corals remained above pre-capital dredging levels through this program.

Cyclone Ului in March 2010 re-mobilised fine sediments and caused more sediment damage in the normally protected back reef sites but many of these damaged patches were again recovering by the time of the August 2010 pre-dredging survey. The 2010 maintenance dredging operations had not noticeably added sediment to the Victor Islet environment and at the time of the November 2010 post-dredging survey both coral-sediment levels and the density of sediment-damaged corals were at low levels not recorded since the capital dredging baseline in early 2006 (<0.5% damaged colonies).

Sediment had caused very low levels of damage on the Slade Islet location reefs during the capital dredging program (0-1% of colonies damaged). There had been considerable sediment damage to coral colonies on the three high coral cover northeast sites at Slade Islet in early 2010 due to sediment mobilisation during Cyclone Ului (A.M. Ayling personal observations). Resuspended sediments and rubble fragments were deposited on the extensive flat sheets of Montipora that dominated these three sites. The sediment then collected in depressions on the surface and caused many patches of mortality. This is a frequent natural process on fringing reefs (Ayling and Ayling 2005) and most of these patches were actively recovering by the time of the November 2010 survey (A.M. Ayling personal observations). At the time of the February 2012 survey Slade Islet had high levels of sediment induced coral damage probably resulting from the flood and cyclone events of which occurred in 2011. Over 5% of coral colonies had minor sediment damage at this time, a level comparable with that recorded on Victor Islet at the height of the capital dredging program. Sediment levels were also high on Slade Islet corals during the first ambient survey.

At all four locations sediment levels have returned to the low 2006 baseline levels only once in the last ten years i.e. during the November 2010 survey. The actual sources of the sediment are likely to be both local and regional and may include:

- sediments from local and regional riverine inputs (Pioneer River, Plane Creek) into the nearshore environment every year during the wet season
- sediment remobilised during the daily tidal cycle (especially during spring tides) travelling up the coastline with the prevailing currents and winds from Broadsound to the south

- potential remobilisation of sediments from the nearby existing spoil grounds
- re-suspended sediments due to the macrotidal environment at Mackay

Additional work to classify the resuspended sediments will aid in identifying potential sources.

4.2.5 Mortality and Coral Disease

There were significant fluctuations in the density of diseased corals over the ten years spanned by the surveys reported here, with order of magnitude changes at each location (Figure 3-14). Disease affected corals were present at all four locations and there were no overall trends in abundance at any location (Figure 3-14). Small colonies sometimes died completely when affected by disease but usually disease only caused partial colony mortality.

Levels of coral disease during the ambient surveys were relatively high but were in line with levels recorded over the ten years spanned by the previous surveys. Less than 1% of hard corals were affected by disease on these locations at any one time and trends have been down or flat over this ten year period. Diseased corals are often present on fringing reefs especially during the warmer summer months and rarely cause significant coral mortality (Ayling and Ayling 2005). There is no evidence that stress caused by past dredging operations, cyclones and flooding has increased the susceptibility of corals in this region to disease outbreaks.

4.3 Recommendations

Ambient surveys of benthic communities should continue into the future to monitor the recovery of the benthic communities after the damage caused by cyclone Ului and to identify long term trends in benthic community health. The surveys provide sound baseline information for comparison in the event any impact monitoring that may be undertaken by NQBP in the future.. Ambient benthic community data and ambient water quality information should be combined where possible to look more closely at any potential water quality drivers of benthic community change.

The sources of sediments in the marine environment which have small but significant impacts on individual coral colonies (and therefore the whole community) at the monitoring locations over time should be better quantified.

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Appendix A Sea Temperatures July 2014 – July 2016

Site	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16
Freshwater Point	19.02	20.39	22.35	24.61	27.20	28.68	28.96	28.03	28.86	26.15	22.44	21.23	19.91	20.84	22.98	24.33	27.40	28.32	28.87	29.04	27.93	27.48	24.36	22.34	20.19
Hay Reef	19.06	20.43	22.44	24.79	26.30	-	-	27.84	28.99	26.40	22.85	21.44	20.08	20.49	23.00	24.88	27.53	28.41	28.95	29.25	28.04	26.49	25.22	22.63	20.42
Keswick Is	20.64	20.89	22.14	23.98	25.79	27.61	28.50	28.11	28.46	27.20	24.35	22.91	21.67	21.05	-	24.42	26.00	27.77	28.50	28.90	28.19	26.90	25.18	23.81	22.14
Roundtop Is	19.13	20.38	22.17	24.46	26.93	28.64	29.10	28.07	28.81	26.60	22.94	21.58	20.21	20.51	22.84	23.94	26.95	28.38	28.82	29.13	-	25.76	25.14	-	-
Slade Is	19.17	20.30	22.21	24.64	27.17	28.63	29.15	27.99	28.78	26.48	22.85	21.44	20.07	20.76	22.96	24.11	27.29	28.50	28.98	29.22	28.24	26.60	25.19	22.95	20.78
Victor Is	19.07	20.46	22.47	24.72	27.28	28.77	29.12	28.05	28.94	26.42	22.80	21.51	20.15	20.70	23.05	24.85	27.45	28.34	28.84	29.09	28.03	26.52	25.17	22.70	20.58
Spoil grounds	-	-	-	-	-	-	-	-	-	-	-	-	19.82	20.38	22.61	23.43	26.35	28.10	28.67	29.11	27.90	26.44	24.95	22.86	20.55