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SEA RESEARCH

JAMES COOK UNIVERSITY
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Ports of Mackay and Hay Point Ambient Coral Monitoring Surveys: 2018-2019

Ayling T, Ayling A, Chartrand KM, and Rasheed MA

Report No. 20/02
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A Report for North Queensland Bulk Ports

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KEY FINDINGS

1. Coral monitoring at Round Top Island, Victor Islet, Slade Islet and Keswick Island was completed in 2018/2019 as part of an ambient monitoring program for the Port of Mackay and Hay Point to measure benthic cover, coral health, sedimentation and coral recruitment. The majority of these locations have been surveyed 21 times since 2006.

2. The mean relative decrease in hard coral cover on the three inshore locations between the 2006 baseline and the post-Cyclone Debbie (August 2017) coral cover low has been 40% (from 33% down to less than 20% coral cover). Overall, the significant reduction and resulting similar low coral cover at all three locations has been driven by cyclonic impacts.

3. In the first 18 months following Cyclone Debbie, between March 2017 and September 2018, there was no recovery evident in hard and soft coral cover at any location. In contrast, macroalgal cover increased dramatically at the three inshore locations.

4. Since July 2018, coral cover finally began to increase on the three inshore locations, increasing from a grand mean of 19% cover to 21.5% cover in June 2019. The slow recovery of hard coral communities on these fringing reefs since Cyclone Debbie is a cause for concern.

5. Over the past 12 months, macroalgal cover has reduced slightly to a mean of 29% cover following a peak of 47% in August 2017 post-Cyclone Debbie. However, this is still more than 3x baseline levels following the gradual increase in macroalgae since monitoring began.

6. Over the thirteen years of monitoring these locations, coral community composition overall has only slightly changed. The main change has been a decrease in the proportion of *Acropora* corals in the inshore locations.

7. New coral recruits increased to more normal levels during the 2019 ambient surveys following the significant drop recorded in 2018 related to Cyclone Debbie acute impacts.

8. Sediment levels on corals increased following Cyclone Debbie in March 2017 but not to the highs measured following previous cyclones nor the 2006 capital dredging campaign. During the 2019 ambient surveys both the number of corals with sediment and sediment depth were at very low levels except on Victor in January 2019. An unprecedented 45% of corals on Victor had surface sediment during this survey although sediment depths did not reach previous highs.

9. Overall, the major driver of change on these fringing reefs appears to be sporadic cyclone events. All other impacts have been slight and non-significant.

10. It is recommended that Keswick Island be dropped from future ambient surveys as it is significantly different in shelf position and benthic composition to the other three inshore locations. A reduction in the number of sites surveyed per location from six to four would increase efficiency and reduce variability in the data.

11. The water quality loggers should also be relocated to better align with coral monitoring sites, resulting in improved ability to integrate data and linking water quality trends with sensitive receptor habitat (i.e. coral) responses.

IN BRIEF

Coral monitoring sites were set up on four locations in the vicinity of the Ports of Mackay and Hay Point prior to the 2006 Hay Point capital dredging program. These locations were Round Top Island, Victor Islet, Slade Islet and Keswick Island. Six sites of four permanently marked 20 m survey transects were set up at each location in the depth stratum of highest coral cover. Measures of benthic cover, coral health, sedimentation and coral recruitment were made along each transect.

Surveys were made in at least three of these locations on 12 occasions between the April 2006 baseline and September 2013. Starting in March 2015 North Queensland Bulk Ports began the biannual ambient coral monitoring program at all four locations to gain a greater understanding of background coral condition and the main drivers of change in these communities. This program enables the greater management and mitigation capacity during periods of Port related activities.

Hard coral cover during the 2006 baseline ranged from 20% on Keswick Island, to 25% on Victor Islet, to 33% on Round Top Island and was highest at 41% on Slade Islet. Macroalgae were also characteristic in the benthic communities at some of these locations during the baseline survey with <1% cover at Round Top Island, 5% on Slade Islet, 22% on Victor Islet and 33% on Keswick Island. Soft corals were not common, ranging from 2% cover on Slade Islet to a high of 9% on Keswick Island. Sponges were rare covering only 0.8-2.1% of the substratum.

Four cyclonic weather events impacted these locations between 2010 and 2015, reducing hard coral cover from 41% to 27% on Slade Islet and from 33% to 23% on Round Top Island. Hard coral cover was not affected on Victor Islet, remaining around 25%, and increased nominally on Keswick Island from 20% to 23%. Sponge cover and soft coral cover remained similar over this time period but macroalgae increased markedly at all locations: from <1% to 24% on Round Top Island, from 5% to 18% on Slade Islet, from 22% to 29% on Victor Islet and from 33% to over 40% on Keswick Island.

Over the first three ambient surveys (March 2015 – May 2016) coral cover remained similar at the three inshore locations. Some sites were changed on Keswick Island compared with pre-2015 surveys and coral cover increased at this location from 29% in March 2015 to 34% in May 2016. Sponges and soft corals remained similar during this period except for soft corals on Round Top Island which increased to 11% cover, up from 5% during the 2006 baseline. Macroalgal cover fluctuated but remained high at all four locations during this period.

The inshore survey locations were severely impacted by Cyclone Debbie in late March 2017, between the January 2017 and August 2017 ambient surveys. Extensive physical damage caused coral cover to drop from 23% to 20% on Round Top Island, from 25% to 18% on Victor Islet and from 29% to 19% on Slade Islet but stay the same on Keswick Island at around 31%. The mean relative decrease in hard coral cover on the three inshore locations since the 2006 baseline has been 40% (from 33% down to less than 20% coral cover). Sponge cover and soft coral cover also both decreased slightly following Cyclone Debbie. Macroalgal cover decreased markedly with many plants physically torn from the substratum. Mean algal cover decreased from 26% to 22% on Round Top Island, from 40% down to 28% on Victor Islet, from 33% down to 25% on Slade Islet and from 40% down to 27% on Keswick Island. These reduced levels were still well above those recorded during the 2006 baseline at all the inshore locations.

In the first 18 months following Cyclone Debbie hard and soft coral cover did not change, with no recovery evident at any location. Macroalgal cover increased dramatically at the three inshore locations between January and July 2018: from 18% to 42% on Round Top, from 24% to 51% on Victor and from 20% to 49% on Slade. Macroalgal cover did not increase on Keswick, remaining at around 32%.

Macroalgal cover decreased markedly on the inshore locations during the 2019 surveys from the 2018 peak grand mean of 47% to 29% cover. Over the same period hard coral cover finally started to increase, up from a grand mean of 19% to 21.5% cover. Soft coral cover also increased, up from a grand mean of 2.7% cover to 3.9% cover.

Coral community composition was different at the four locations. At Round Top Island *Turbinaria* corals were dominant, accounting for 33% of hard coral cover, with *Montipora*, siderastreids and faviids also important. At Victor Islet *Montipora* corals were dominant (50% of coral cover), with *Turbinaria* and faviids also important. At Slade Islet *Montipora* corals were dominant, accounting for 58% of coral cover. At Keswick Island *Acropora* corals were dominant (39% of cover), with *Montipora* and poritids also important. There have only been slight changes in coral community composition over the thirteen years covered by these surveys, with decreases in the percentage of *Acropora* corals in the inshore locations.

Sediment levels on living hard corals were low during the 2006 baseline with less than 4% of coral colonies having any surface sediment and a mean sediment depth of only 0.05 mm. These sediment levels have fluctuated by more than an order of magnitude over subsequent surveys with increases associated either with natural sediment resuspension events, such as cyclones and other strong wind episodes, or with the 2006 capital dredging campaign. Maintenance dredging can also cause temporary increases in coral sediment levels. The Port of Mackay maintenance dredging in 2013—while not directly causing increased turbidity or sediment on corals during dredge activity—was followed by a strong wind episode which increased coral sediment levels on Slade Islet. Peak levels have been around 30-40% of corals affected and mean sediment depths of around 1 mm. Sediment deposition on living coral colonies can cause patches of mortality with over 5% of coral colonies affected in severe events in these locations but the resulting coral cover reductions have usually been much less than 1% and are rarely significant. Physical damage to corals from cyclonic events is more than an order of magnitude higher than any sedimentation damage.

Coral bleaching has affected corals in these locations on a number of occasions over the past thirteen years but has never affected more than about 1-3% of hard coral colonies and has caused no measurable changes to coral cover.

Disease sometimes affects hard coral colonies and may cause partial or occasionally total mortality. Only 1-2% of coral colonies are affected at any one time and disease levels are usually higher in summer when the water is warmer and lower during the winter months. Disease levels do not appear to be during or after dredging episodes. A disease outbreak during the 2006 summer caused a short-term but significant reduction in coral cover at Slade and Victor Islet and yet the impact of disease on hard corals is an order of magnitude less than physical cyclone damage over the last thirteen years.

Coral cover has increased significantly at the offshore Keswick Island location and macroalgal cover has been relatively stable. However, there have been marked and significant changes in benthic cover at all three inshore locations over the thirteen years covered by these surveys. The cover of macroalgae increased from a mean of 9% cover in 2006 to a peak of 47% at the time of the July 2018 ambient survey and was 29% in June 2019. Physical cyclone damage has been the major impact on hard coral cover at these inshore locations, with all other impacts usually slight or non-significant. These changes in macroalgal and hard coral cover appear to largely be due to natural causes, however, it could be argued that they are partly due to nutrient increases and global warming that are human related. Unless rates of coral recovery improve over what has previously been measured during inter-cyclone periods in this region, or cyclone events become less frequent, it is unlikely that these inshore locations will regain baseline coral condition in the near future. Recovery times are estimated to be 3-6 years given best-case recovery scenarios and no further impacts. To better relate these changes to local changes in water quality it might be appropriate to make sure some loggers are moved closer to the coral monitoring locations.

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ACRONYMS AND ABBREVIATIONS

TropWATER	Centre for Tropical Water & Aquatic Ecosystem Research
NQBP	North Queensland Bulk Ports Corporation
GIS	Geographic Information System
dbMSL	Depth below Mean Sea Level
MSQ	Maritime Safety Queensland

1 INTRODUCTION

1.1 Project Background

The Port of Mackay, located on the Queensland coast five kilometres north of Mackay City, is a multi-commodity port servicing the sugar, mining and grain industries. The Port of Hay Point is situated approximately 20 kilometres south of Mackay. Hay Point is one of the largest coal export ports in the world. North Queensland Bulk Ports Corporation Limited (NQBP) is the port authority and port manager for these ports under the*Transport Infrastructure Act 1994* (TI Act). The functions of NQBP as a port authority include establishing effective and efficient port facilities and services in its ports and making land available for the establishment, management and operation of port facilities in its ports by other persons.

Mackay Port's throughput tonnage for 2016-2017 financial year was almost 3 million tonnes. The current export capacity through both existing coal terminals in the Port of Hay Point is approximately 106 Mtpa.

Beginning in 2006 extensive coral monitoring has been undertaken for NQBP (previously known as Ports Corp Queensland) at key locations surrounding the Ports of Hay Point and Mackay (Figure 1): Round Top Island (Figure 2), Victor Islet (Figure 3), Slade Islet (Figure 4) and Keswick Island (Figure 5). These previous investigations were focused around port dredging activities and, whilst some temporary increase in sedimentation was identified, there was minimal overall recorded impact as a result of this (<1% coral cover loss). The development of the present ambient coral monitoring program was triggered in order to gain a greater understanding of ambient conditions and the drivers of these conditions which would also allow for a greater capacity to manage potential influences during periods of Port related activities. Advisian (formerly WorleyParsons), in association with Sea Research, conducted surveys at all established monitoring locations in March 2015, November 2015 and May 2016. Sea Research were asked to continue these ambient surveys with two surveys of these four locations during the 2016/2017 period. TropWATER and Sea Research have continued these surveys during the 2017-2019 time period.

1.2 Objectives of Survey

NQBP proposed relating surveys to the seasons, with the first survey being in the Spring, pre-wet season period and the second in the late Autumn post-wet season period. This ensured that surveys were made before and immediately after the period of maximum likely natural impacts, whether floods, cyclones or bleaching, enabling the causes of any benthic changes to be established reliably. The same sites that had been set up for the original capital dredging monitoring program in 2006 and in subsequent monitoring programs, were relocated and repaired to be used during this ambient monitoring project. On Keswick Island two of the original four Horseshoe Bay sites 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.

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 documents the findings of the two most recent ambient surveys at all four Hay Point/Mackay locations over the 12 months between mid-2018 and mid-2019 that have not been included in previous reports, but makes comparisons with the results from all previous surveys.

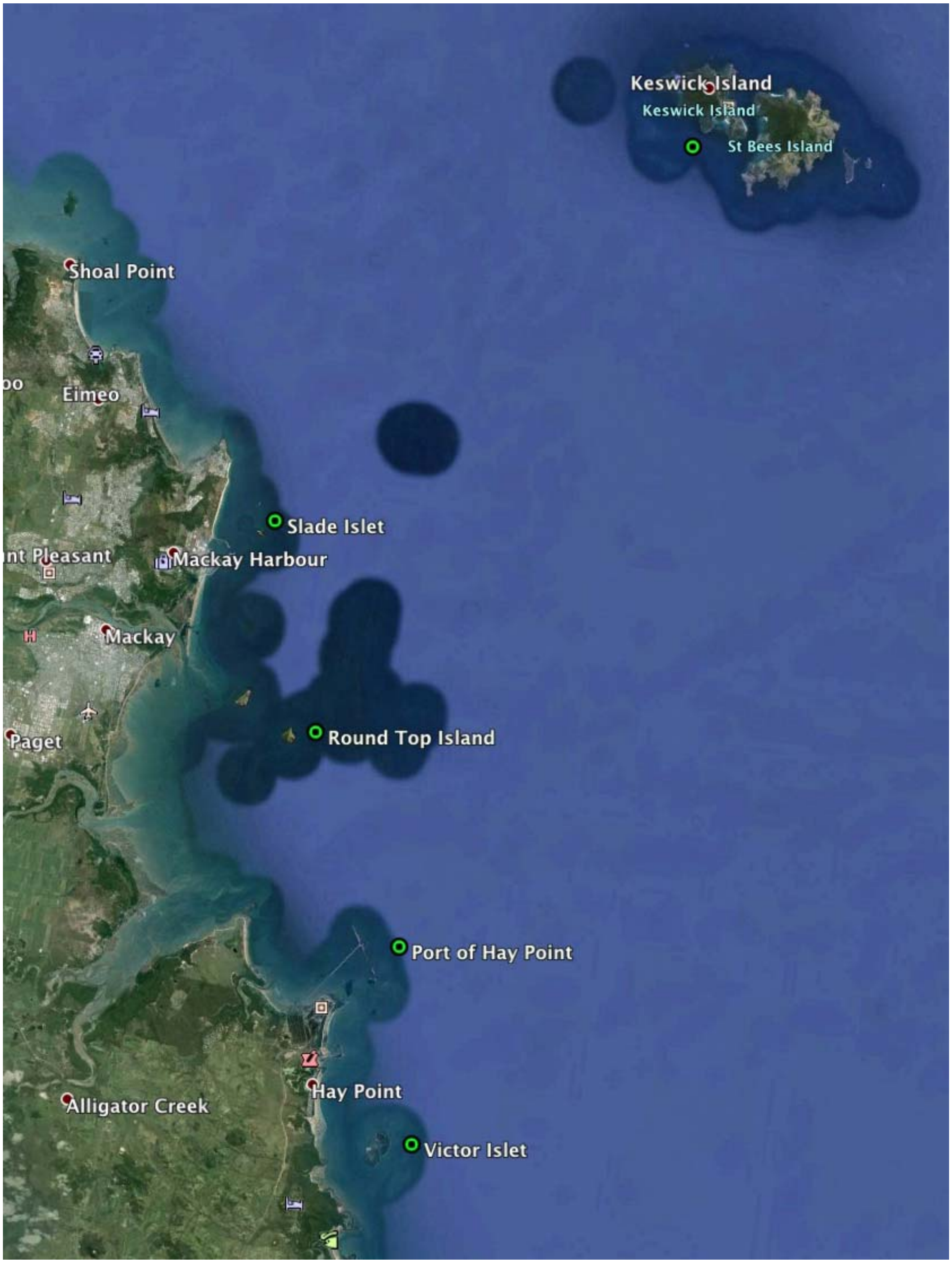


Figure 1. Location of the Port of Mackay (Mackay Harbour), the Port of Hay Point and the Coral Monitoring Locations

Figure 2. Round Top Island Location Showing Position of the Six Coral Monitoring Sites

Figure 3. Victor Islet Location Showing Position of the Six Coral Monitoring Sites

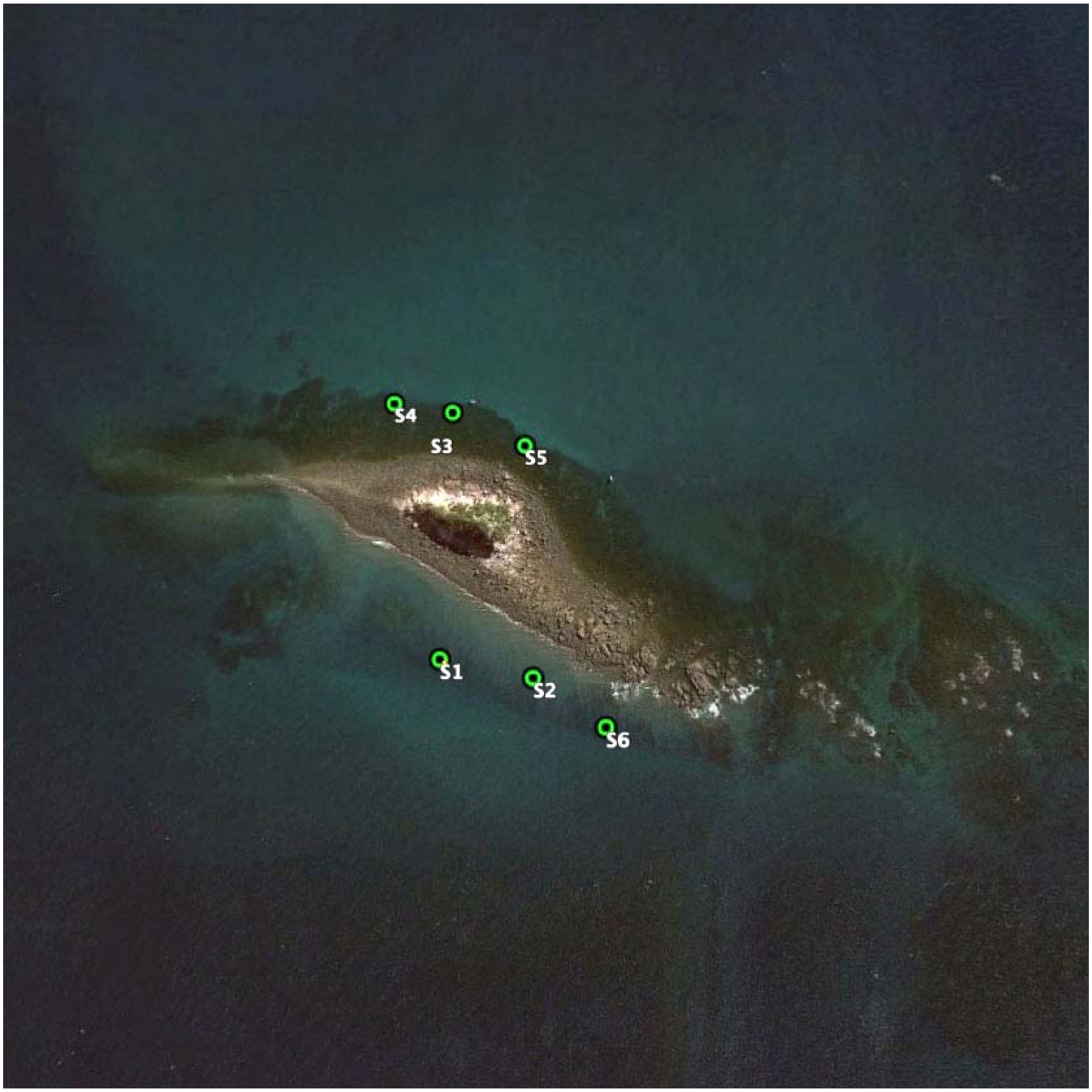


Figure 4. Slade Islet Location Showing Position of the Six Coral Monitoring Sites

Figure 5. Keswick/St Bees Island Location Showing Position of the Six Coral Monitoring Sites

2 METHODS

2.1 Mackay/Hay Point Locations

Fringing reefs were surveyed around four island locations in the Mackay/Hay Point region (Figure 1). Two near-shore islands close to the Port of Hay Point were incorporated (Round Top Island and Victor Islet), along with another 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), 40 km NNE of the Port of Mackay.

Table 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 site 2	-20.9132	149.4171
Keswick/St Bees Island	S3	Homestead site 1	-20.9303	149.4280
Keswick/St Bees Island	S4	Homestead site 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 (Figures 2-5) and these were maintained and used for several more monitoring programs since 2006 (Table 2). As described previously these monitoring sites were maintained and/or relocated for the present ambient coral monitoring program. On Keswick Island two of the four Horseshoe Bay sites used previously were relocated to Homestead Bay on nearby 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. Summary of all coral surveys made at the four Hay Point 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
Jan 2017	X	X	X	X
Aug 2017	X	X	X	X
Jan 2018	X	X	X	X
Jul 2018	X	X	X	X
Jan 2019*	X	X	X	X
Jun 2019*	X	X	X	X

X indicates locations that were included during each survey. * Surveys covered by this report

2.2 Survey Period

This report provides a summary of coral conditions observed during two different surveys undertaken at all four Mackay reef locations over the period January 2019 to June 2019. The two survey periods were 'pre-wet', from 17-24 January 2019 and post-wet from 13-17 June 2019.

The pre-wet survey was again delayed from the ideal October/November time period due to poor weather. Mackay had an early start to the wet season with 290 mm of rain in December 2018 and another 140 mm prior to the January 2019 survey period. The highest daily rainfall total during this period was 61 mm. However, there was a further 800 mm of rain in the four months following the surveys with a maximum daily total of 90 mm and hence the surveys were before the majority of the wet. Although most coral reef impacts occur during the summer months most are from wind and bleaching rather than wet season flooding. The delayed pre-wet survey was before any substantial heating which tends to peak in Feb/March each year. The most important reason for doing two surveys a year is to ensure that the reasons for any impact are clear and small differences in the timing are not going to compromise this.

During rough weather underwater visibility in the study areas can be zero due to high levels of turbidity, especially given the naturally highly turbid nature of the inshore areas of the Mackay / Hay Point region (Waltham et al. 2018). During the January pre-wet survey visibility was poor ranging from 1-3 m at Victor Islet to 5 m at the Keswick/St Bees sites. During the June post-wet survey, underwater visibility was higher than has been recorded in 13 years of surveys, ranging from 8-15 m at Round Top and 5-10 m at Slade, Victor and Keswick.

2.3 Benthic Line Intercept Surveys

Abundance surveys of the marine communities surrounding these islands were made at six sites around each island. At each site, cover of major benthic reef organisms was assessed by four 20 m, haphazardly positioned, line intercept transects run within a narrow depth stratum 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.

These sites had been set up originally prior to the capital dredging baseline survey in 2006 but have been repaired where necessary during subsequent surveys. The sites on Keswick Island were not surveyed between 2007 and March 2015. All sites were re-located and repaired following Cyclone Debbie in August 2017. The marker stakes are remarkably resistant to cyclone waves and the majority of markers survived the cyclone although many of them were bent over or broken off near the base.

For each transect a survey tape was stretched tightly between the stakes close to the substratum and the length of intercept with the tape of all benthic organisms directly beneath it was measured. 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:

- Sand and mobile rubble;
- Macroalgae;
- Algal turf and crustose coralline algae;
- 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 (Ayling and Ayling 2005; 2002; 1995; Mapstone et al. 1989). These methods align with the MMP methodologies thereby ensuring data collected under this ambient program is able to be compared to, and incorporated in, the broader State-wide mapping and reporting programs.

2.4 Sediment Deposition on Corals

Depth of sediment deposition (whether natural or dredge derived) was measured on 20 hard coral colonies haphazardly selected within a metre of each transect. If sediment was present on living parts of 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. To sample a wider area the following parameters were also measured along each transect line:

- Counts of bleached or partially bleached colonies along a 20 x 2 metre transect centred on each transect line were recorded for each of the major coral groups.
- Counts of all sediment damaged colonies along a 20 x 2 m transect centred on each transect line 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 coral colonies along a 20 x 2 m transect centred on each transect line 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.
- Counts of all colonies damaged by sponge overgrowth or *Drupella* or crown-of-thorns grazing along the same 20 x 2 m transects.

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 these surveys. The technique employed by the Australian Institute of Marine Science for their inshore reef surveys was used (Jonker et al. 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

Given the large amount of natural patchiness in the abundance of all marine organisms, and the variation in abundance changes through time within each patch, it is necessary to use statistical analysis to determine if any change is significant. The variation may be so high that what appears to be quite a large nominal change may not be a real change but just due to sampling the natural variation within the community differently. Analysis of variance techniques are usually used to determine the significance of any apparent changes in abundance 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 2-2). Because the transects were fixed and the same bits of the benthic community were assessed during each survey a more powerful repeated measures analysis is 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 (or three) 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 e.g. 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 caused by ambient conditions 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, even though the mean coral cover may not have changed between the two surveys (the increase at one location could cancel out the decrease at another location 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 then repeated measures analysis is not appropriate. 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 11 months covered by the three most recent surveys of all four locations (July 2018, Jan 2019, June 2019) was tested with one series of anovas (Table 3**Error! Reference source not found.**) but another series of analyses were used to establish the significance of any benthic or coral damage changes over all the surveys that have been carried out at the three inshore locations since April 2006 (Table 4).

Table 3. Repeated measures benthic cover analysis of variance design for determination of significance of differences between the last three ambient surveys at four locations (df = degrees of freedom)

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

Table 4. Repeated measures benthic cover analysis of variance design for determination of significance of differences between all nineteen surveys of the three inshore locations (df = degrees of freedom)

Source of variation	df	Denominator
Between Transects:		
Location	2	Error (transects)
Site (location)	15	Error (transects)
Error (transects)	54	
Within Transects:		
Time	16	Error (transects x Time)
Location x Time	32	Error (transects x Time)
Site (location) x Time	240	Error (transects x Time)

Error (transects x Time)	864

3 RESULTS

3.1 Climatic Conditions

One of the key drivers of coral community health is the climatic conditions experienced by that community over time. Major climatic drivers of coral health include local and regional rainfall and river discharges into the nearshore environment, cyclonic conditions, other strong wind episodes and sea water temperatures. The following section deals with the climatic conditions during the present ambient monitoring period from August 2018 to July 2019 and compares these conditions to data collected since coral monitoring began in early 2006. The Pioneer River which discharges into the nearshore environment inshore from Round Top Island is used here as an indicator of local river inputs.

3.1.1 Rainfall and River Flows

The rainfall measured by the Bureau of Meteorology (BOM) at the Mackay Airport (BOM 2019) is provided graphically in Figure 6A. The Pioneer River discharge at Dumbleton Weir (16km from the mouth of the River) is presented using data provided by the Queensland Government Water Monitoring Information Portal (Sea Research 2017; WIMP 2019) in millions of litres per day (ML/day) (Figure 6B).

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. During this year (2011) nearly twice the mean rainfall was recorded in Mackay; 2,904mm compared to the mean rainfall of 1,536mm (BOM 2017). Additional rainfall in the catchment areas inland from Mackay contributed to the elevated river discharges. Since then river discharges have been lower than average (Sea Research 2017; Advisian 2016; TropWATER 2018). The 2018/2019 wet season was slightly below average in terms of rainfall, with only 896mm recorded for the January-April period compared to the 1,080mm average but was about average when December 2018 was included (1,186mm compared with the 1,206mm average). More than 50mm in 24hr rainfall was only recorded on six days during this wet season period making this a second consecutive year of lower than average rainfall (Figure 6A).

Water discharge events from the Pioneer River were also mostly well below average for the 2018/2019 period (Figure 6B) with an overall annual riverflow at the 10 year average levels. Five peaks of over 10,000 ML/day were recorded and the maximum flow of about 95,000 ML/day occurred during the February 2019 monsoonal event that affected much of Queensland. This is low compared to previous extreme rainfall events, with river flows of over 100,000 ML per day recorded on at least ten occasions throughout the past decade while few such extreme events occurred in the last three years.

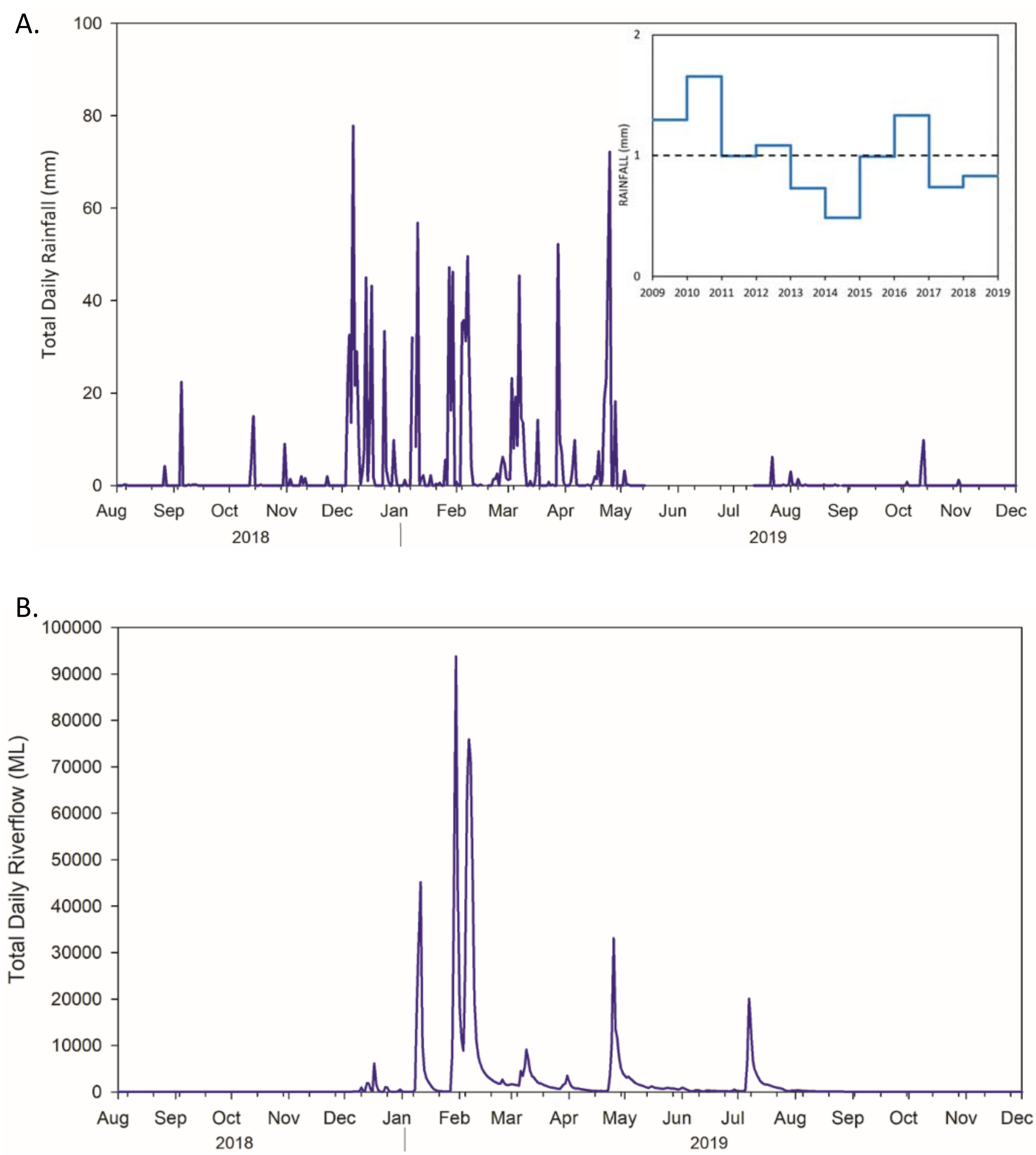


Figure 6. A. Daily rainfall measured at the Mackay Airport with inset of change in rainfall as a proportion of the long-term average, B. the Pioneer River discharge at Dumbleton Weir

3.1.2 Cyclones

During the 2018/2019 ambient monitoring period no cyclones passed near Mackay but a severe monsoonal event between 4-9 February 2019 impacted the region. Strong SE winds and widespread heavy rainfall were associated with this event. Sustained winds at Hay Point were between 35-60 km/hr for the six day event with gusts of between 40-75 km/hr. Almost 150mm of rain fell at Mackay Airport during this event and daily river flows peaked at about 94,000 ML (Figure 6B). Water quality loggers indicated the event led to significant spikes in NTU (2237 NTUe) and sedimentation deposition (27.75 mg cm^{-2} $10min^{-1}$) markedly around Slade Islet on 8 February. This was the major weather event of the past 12 months in terms of river flow and higher than anything experienced over the past three years.

Prior to 2019 a number of cyclones passed close to Mackay leading to strong or damaging winds and high rainfall that may have impacted the benthic communities in all the coral monitoring locations (Table 5). The most damaging cyclone was Severe Tropical Cyclone Debbie in late March 2017 that generated sustained winds at Hay Point of between 60-80 km/hr for more than 50 hours. This system caused severe physical damage to the Mackay region benthic communities. Extensive fringing reef damage in this region was also caused by Severe Tropical Cyclone Ului that crossed the coast in the Whitsunday Region on 20 March 2010. Cyclone Ului caused widespread flooding in the Mackay region and nearshore benthic communities suffered physical damage from the large waves associated with this cyclone and subsequent deleterious impacts due to a sustained reduction in ambient light due to sediment resuspension and flooding. Cyclone Ului and Cyclone Debbie appear to be the main causes of impacts to the benthic communities at the four monitoring locations over the past twelve years.

Table 5. Cyclones that influenced climatic conditions near Mackay since 2006

Tropical Cyclone	Date
TC Ului	20 March 2010
TC Yasi	30 January – 3 February 2011
Ex TC Oswald	25 January 2013
TC Dylan	31 January 2014
TC Ita	13 April 2014
TC Marcia	20 February 2016
TC Debbie	27-29 March 2017
TC Iris	3-4 April 2018

3.1.3 Sea Water Temperatures

Sustained elevated water temperatures that may cause coral bleaching were not recorded during the 2018/2019 summer period in the Mackay region. Sea temperature measurements are collected by TropWATER at a number of sites in the nearshore environment offshore from Mackay (Waltham et al. 2015). The highest temperatures recorded in the summer of 2018/2019 ranged from 29.0°C to 30.2°C at Round Top Island and Keswick Island respectively (Figure 8). Water temperatures during the July 2019 survey were at the annual minimum, also at Round Top Island and Keswick respectively. Keswick Island in general recorded a milder temperature range to the other three locations; likely due to the greater oceanic flushing dampening the temperature range compared to the more inshore monitoring locations. Overall, sea surface temperatures have increased from the long term average† in the Great Barrier Reef Marine Park (Figure 8).

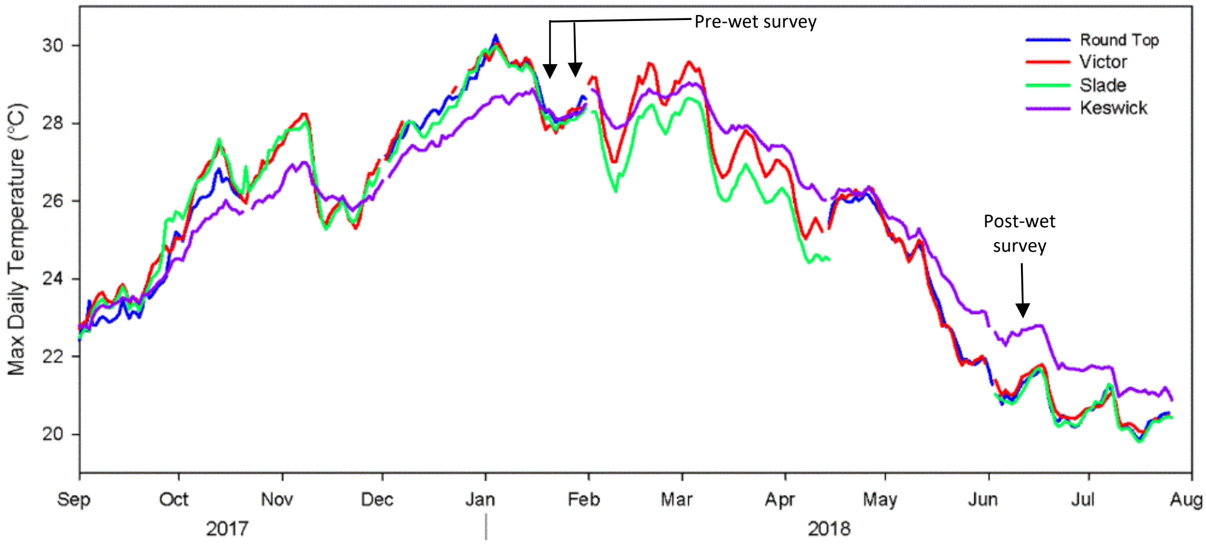


Figure 7. Maximum daily temperature recorded at monitoring locations in 2018-2019.

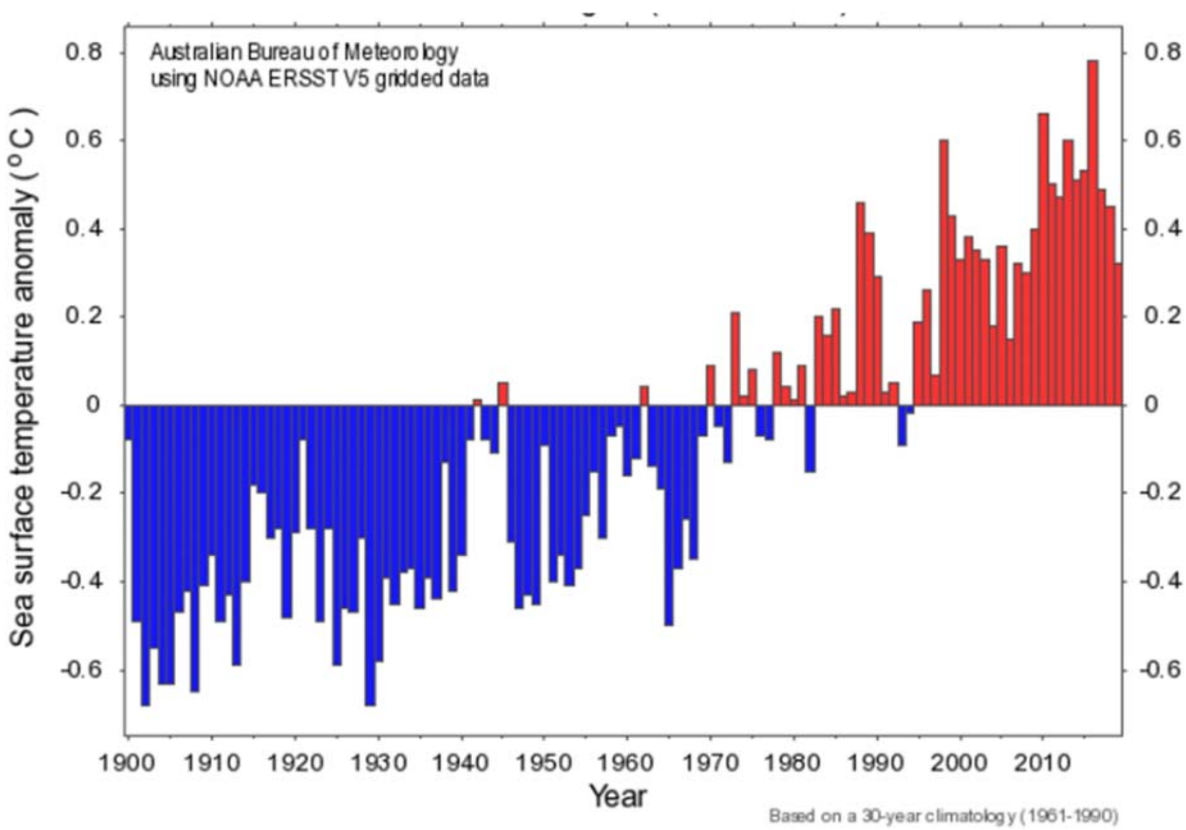


Figure 8. Annual sea surface temperature anomaly for the Great Barrier Reef (1900 to 2019) based on 1961 – 1990 climatology; Bureau of Meteorology

† The long-term sea surface temperature average calculated by the Bureau of Meteorology is from 1961 to 1990, in line with the current international standard period for the calculation of climate averages.

3.2 Benthic cover during the ambient surveys

Macroalgae were common on these fringing reefs. During the January 2019 survey macroalgal cover ranged from 18% to 30% on the inshore locations, much lower than during the July 2018 survey, and was 35% on

Keswick Island. There was a significant increase in algal cover over the six months between the latest two surveys but this increase did not happen on Keswick Island and the Time x Location interaction was also significant (Table 7). During the June 2019 survey algal cover had increased to around 21-40% on the inshore locations but decreased slightly to 30% on Keswick Island (Figure 9, Table 3-2). 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,* as well as some fast-growing filamentous algae.

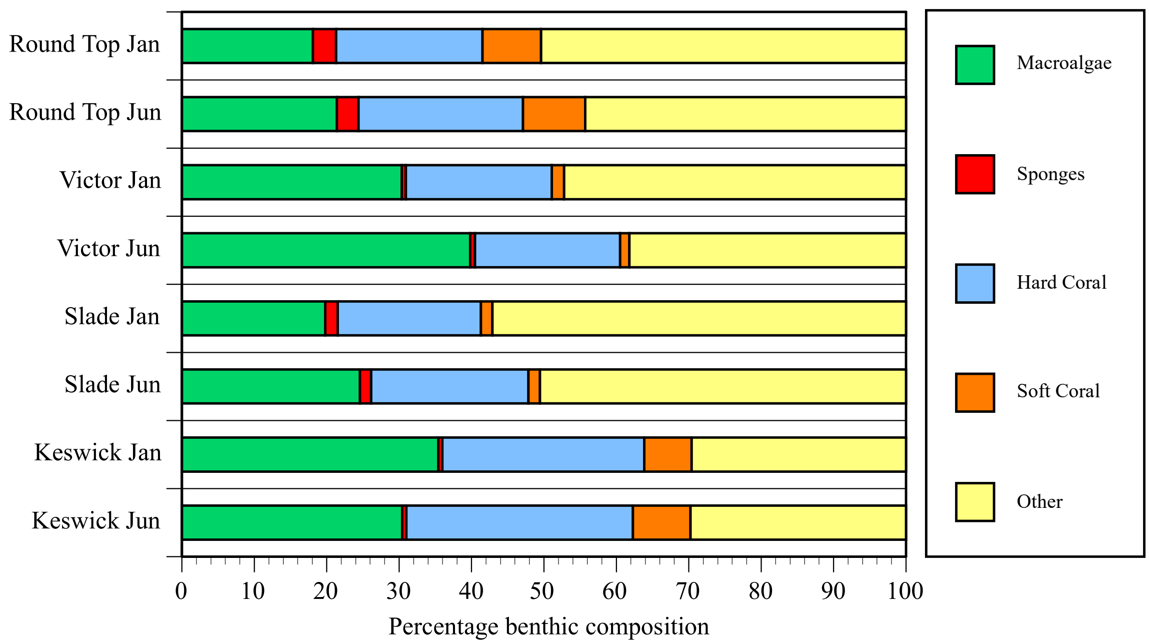


Figure 9. Changes in benthic composition in the four locations between January and June 2019. Plot shows mean percentage benthic composition from the last two ambient surveys at each location. Benthic category 'Other' = sand + bare reef + crustose corallines + algal turf.

Sponges were not common in any of these locations (Figure 9) but were most abundant on Round Top Island where the cover of this benthic group was 3.0% during the June 2019 ambient survey. (Table 6). The most abundant sponge was brown *Turpios* sp. that takes over living coral. Although not analysed because of the overall low cover, sponge cover has remained low over the past 12 months (Table 6).

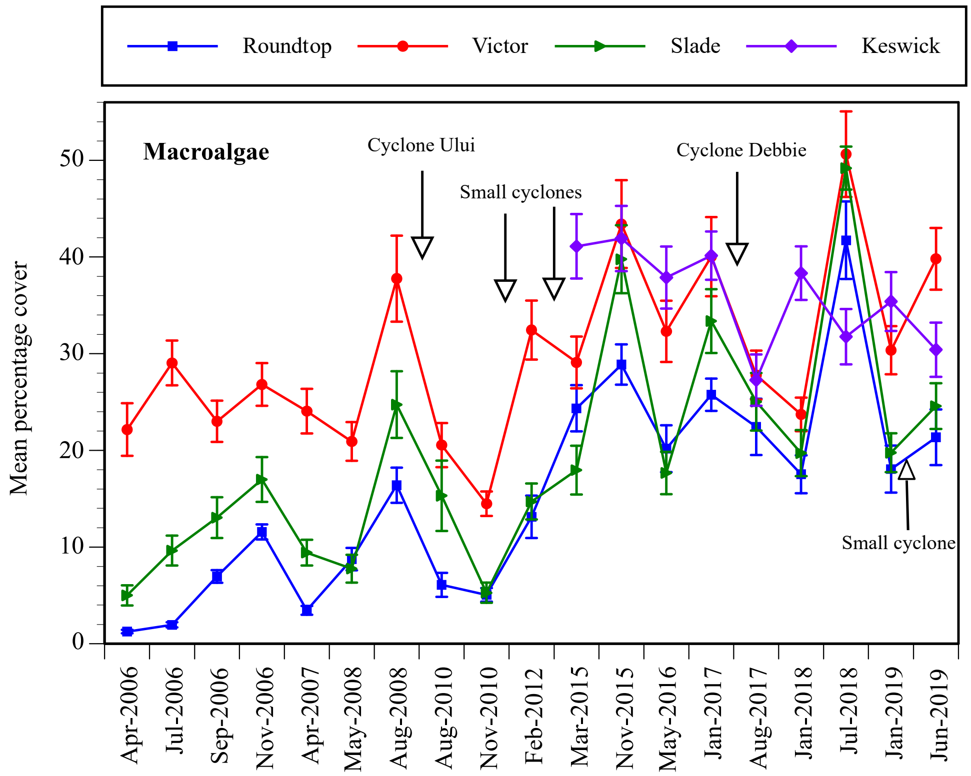


Figure 10. Changes in percentage cover of macroalgae.
Graphs show grand mean percentage algal cover from the 2019 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors.

Table 6. Hay Point fringing reefs benthic organism abundance during the last three ambient surveys (mean percentage cover with standard deviations)

Family/Group	July 2018		Jan 2019		June 2019	
	mean	***sd***	**mean**	***sd***	**mean**	***sd***
ROUND TOP						
Total algae	41.7	*19.6*	18.1	*12.0*	21.4	*14.1*
Total sponges	2.3	*2.4*	3.2	*3.2*	3.0	*2.9*
Total hard corals	19.9	*13.7*	20.2	*13.2*	22.7	*16.3*
Acropora spp.	0.5	*1.5*	0.6	*1.7*	0.6	*1.3*
Montipora spp.	3.9	*6.3*	4.2	*6.6*	4.7	*8.1*
Pocilloporidae	0.2	*0.4*	0.2	*0.5*	0.3	*0.6*
Siderasteridae	3.1	*2.9*	3.1	*2.7*	4.4	*4.3*
Turbinaria spp.	7.2	*6.8*	7.5	*7.2*	7.6	*6.4*
Faviidae	2.6	*2.4*	2.1	*1.4*	2.7	*2.6*
Poritidae	1.8	*2.5*	2.1	*2.8*	1.9	*2.7*
Total soft corals	5.9	*5.7*	8.1	*7.4*	8.7	*8.7*

VICTOR						
Total algae	50.6	*21.7*	30.4	*12.2*	39.8	*15.7*
Total sponges	0.4	*0.7*	0.6	*0.8*	0.6	*0.8*
Total hard corals	17.9	*20.5*	20.2	*21.4*	20.1	*22.3*
Acropora spp.	0.9	*2.2*	0.9	*2.3*	0.9	*2.1*
Montipora spp.	8.3	*17.3*	9.6	*18.4*	9.8	*19.6*
Pocilloporidae	0.4	*1.7*	0.4	*1.6*	0.4	*1.4*
Siderasteridae	1.7	*2.5*	1.9	*2.6*	1.9	*2.6*
Turbinaria spp.	2.8	*4.1*	2.9	*3.9*	3.0	*3.8*
Faviidae	2.3	*2.7*	2.5	*2.5*	2.6	*2.4*
Poritidae	1.2	*3.2*	1.5	*4.3*	1.1	*3.0*
Total soft corals	0.9	*1.6*	1.7	*2.2*	1.3	*1.7*
SLADE						
Total algae	49.2	*10.9*	19.8	*9.9*	24.6	*11.6*
Total sponges	1.1	*1.7*	1.7	*1.7*	1.6	*1.4*
Total hard corals	18.9	*12.9*	19.8	*13.0*	21.7	*14.7*
Acropora spp.	1.1	*1.9*	1.2	*2.0*	1.3	*2.2*
Montipora spp.	10.5	*10.7*	11.4	*11.1*	12.5	*12.4*
Pocilloporidae	0.7	*1.9*	0.8	*2.2*	0.9	*2.2*
Siderasteridae	1.7	*2.0*	1.7	*2.1*	1.8	*2.2*
Turbinaria spp.	1.1	*1.2*	1.4	*1.8*	1.4	*1.4*
Faviidae	1.5	*1.9*	1.0	*1.2*	1.6	*1.6*
Poritidae	1.8	*2.6*	1.9	*2.6*	1.8	*2.5*
Total soft corals	1.1	*1.3*	1.6	*1.7*	1.6	*1.9*
KESWICK						
Total algae	31.8	*14.0*	35.4	*14.9*	30.4	*13.8*
Total sponges	0.6	*0.9*	0.5	*0.9*	0.6	*0.8*
Total hard corals	30.1	*12.5*	27.9	*11.6*	31.3	*12.3*
Acropora spp.	11.4	*16.1*	11.0	*15.5*	12.3	*17.3*
Montipora spp.	6.4	*8.1*	5.9	*7.5*	6.7	*8.4*
Pocillopridae	0.7	*1.1*	0.7	*1.0*	0.8	*1.2*
Siderasteridae	0.5	*0.8*	0.1	*0.2*	0.1	*0.3*
Turbinaria spp.	0.4	*0.9*	0.4	*1.2*	0.3	*0.9*
Faviidae	2.4	*1.6*	2.0	*1.9*	2.2	*1.6*
Poritidae	4.3	*5.3*	4.2	*5.4*	5.2	*7.0*
Total soft corals	8.0	*6.8*	6.5	*6.3*	7.9	*6.5*

Figures are grand means from four 20 m transects at six sites in each location

Table 7. Benthic changes between the three most recent surveys from all four locations of the ambient monitoring project: Anova Results

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

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

Table 8. Benthic changes between all nineteen surveys of the three inshore locations since the original capital dredging baseline in April 2006: Anova Results

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

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

Total hard coral cover was significantly higher in the Keswick Island location than in the three inshore locations during the two 2019 ambient surveys (Table 7, Figure 11). Mean coral cover during these surveys was between 18% and 23% on Round Top, Victor and Slade and around 30% on Keswick. Over the past 12 months hard coral cover has started to increase significantly following Cyclone Debbie in the three inshore locations (Table 7, Figure 11). Coral cover decreased on Keswick between July 2018 and Jan 2019, due to disease, but increased again by June 2019 due to growth of fast-growing acroporid corals. Coral cover increased at all the inshore locations between July 2018 and June 2019 and the Time x Location interaction was significant for total hard coral cover.

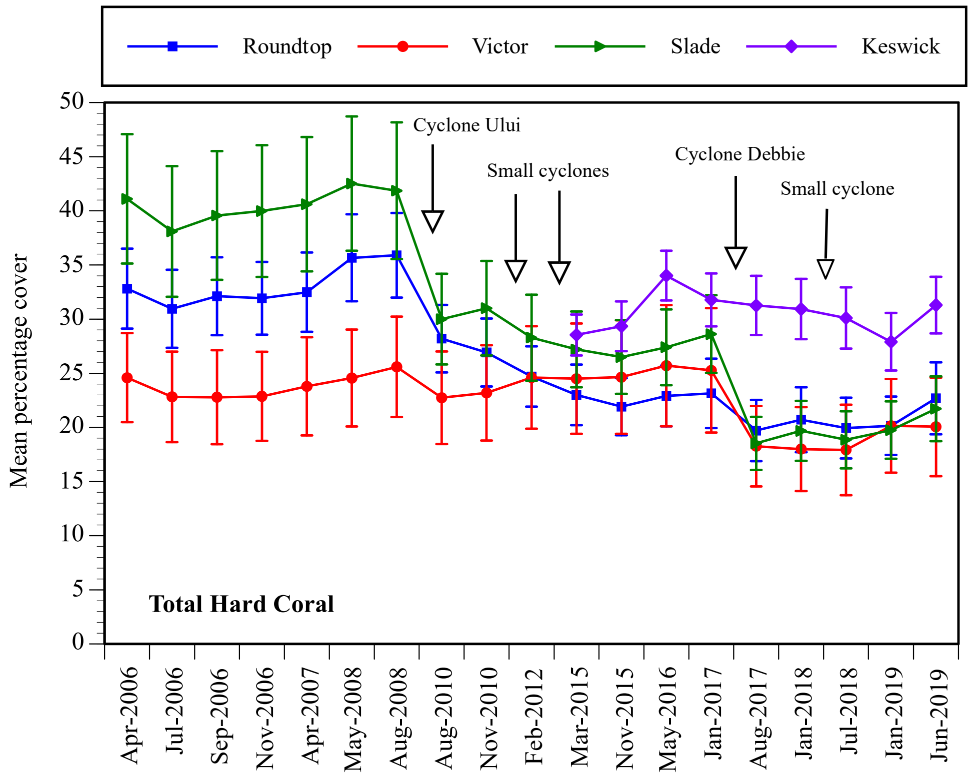


Figure 11. Changes in the cover of total hard coral.
Graphs show grand mean percentage benthic cover from the 2019 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors.

Hard coral community composition was different in each location (Figure 12). During the 2019 surveys coral communities at Round Top Island were dominated by *Turbinaria* spp. (33% of total coral cover) with siderasterids, *Montipora* spp., faviids and poritids also common. Victor Islet reefs were dominated by *Montipora* spp. corals (49% of coral cover), with *Turbinaria* spp., faviids and siderasterids also common. On Slade Islet spreading *Montipora* spp. corals accounted for 58% of all hard coral cover, with siderasterids and poritids also common. Keswick Island coral communities were dominated by *Acropora* spp. corals (39% of coral cover), with *Montipora* spp. and poritids (*Goniopora*) also common. Keswick is not an inshore island and a range of species rare or absent on the inshore islands were part of the coral community here, including *Pachyseris speciosa, Lobophyllia hemprichii* and *Merulina ampliata*. Two coral groups that were important on all three inshore islands (*Turbinaria* spp. and siderasterids) were uncommon on Keswick Island. Coral composition patterns have remained similar since Cyclone Debbie but with a recent slight increase in the percentage composition of the fast growing *Acropora* and *Montipora* species.

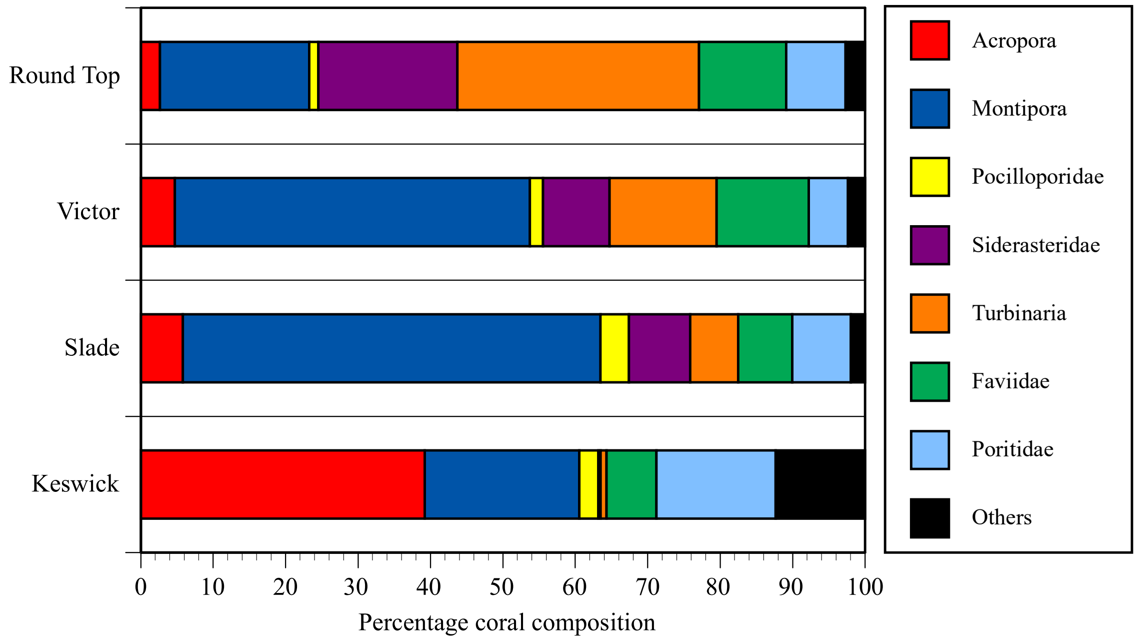
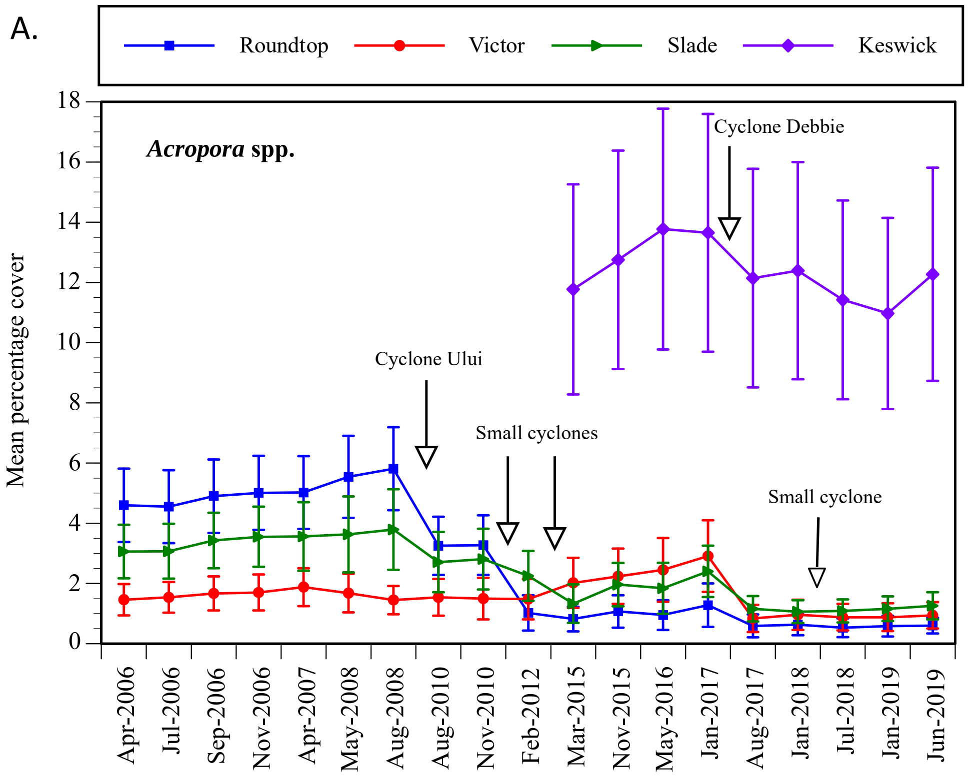


Figure 12. Coral community composition at the four locations for the last ambient survey. Graphs show mean percentage composition of the major coral groups from the four locations. Composition is shown for the latest, June 2019 survey.

All but the pocilloporid coral group showed significant location differences during the two 2019 ambient surveys (Table 7). *Acropora* corals were significantly more abundant on Keswick than in the three inshore locations (Figure 13A). *Montipora* was highest on Slade and lowest on Round Top (Figure 13B). Both *Turbinaria* spp. and siderastreid corals were more abundant on Round Top Island and less abundant on Keswick Island than in the other two locations (Figure 14). Faviid corals had lower cover on Slade than in the other three locations and Keswick had higher poritid cover than the other three locations (Figure 15). Over the eleven months spanned by the last three ambient surveys significant changes in cover were recorded for many of the coral groups. *Acropora* corals had decreased on the two St Bees (Keswick) sites since Cyclone Debbie due to brown-band disease in the staghorn thickets that covered about a third of the substratum at those two sites. This disease outbreak had eased by June 2019 and normal growth led to a significant increase in *Acropora* cover over the previous six months. *Acropora* cover did not increase significantly at any of the inshore locations and as a result the Location x Time interaction was significant. *Montipora* corals increased slightly in cover on the three inshore locations over the past eleven months but they did not change on Keswick and the Location x Time interaction was also significant for this group (Table 7). Siderastreid corals (*Psammocora* and *Coscinarea*) increased significantly on Round Top Island over the past six months but did not change at the other three locations giving a significant Time x Location interaction. The change on Round Top seems rather high for this slow growing coral group and it may be that some mis-identification has affected results in which case the next survey may reveal a less marked increase. Faviid corals showed a decrease and then an increase over the past three surveys except at Victor where there was a steady increase. As a result both the Time and Time x Location factors were significant.

A.



B.

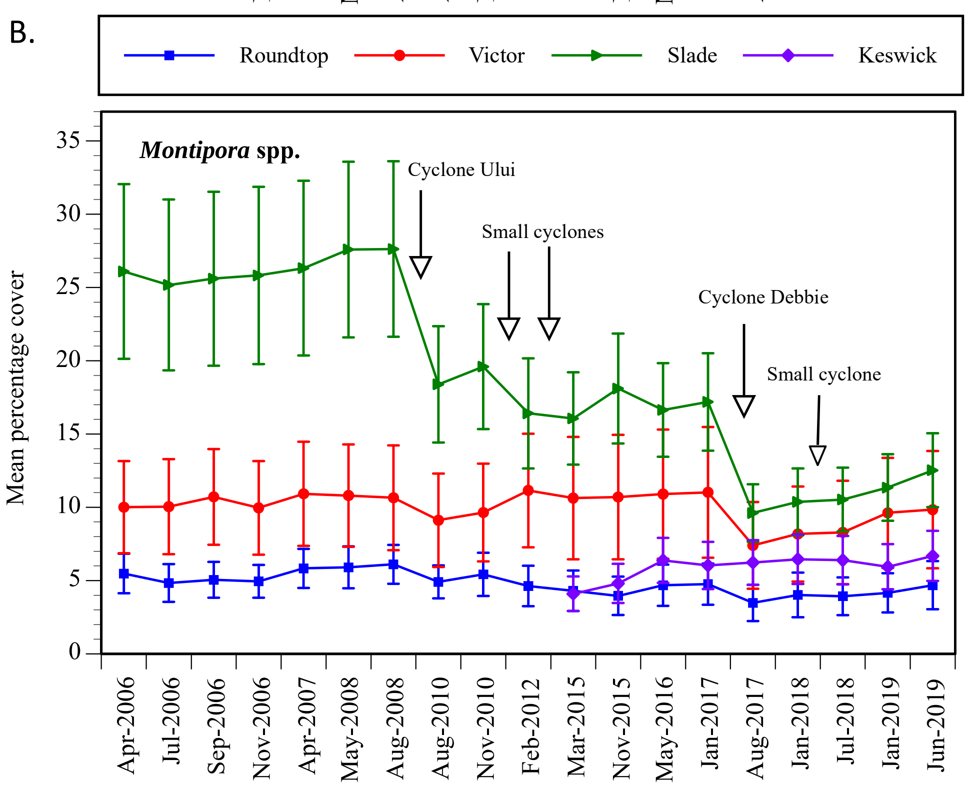


Figure 13. Changes in the cover of coral groups: *Acropora* corals and *Montipora* corals. Graphs show grand mean percentage benthic cover from the 2019 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors. Roundtop = Round Top Island.

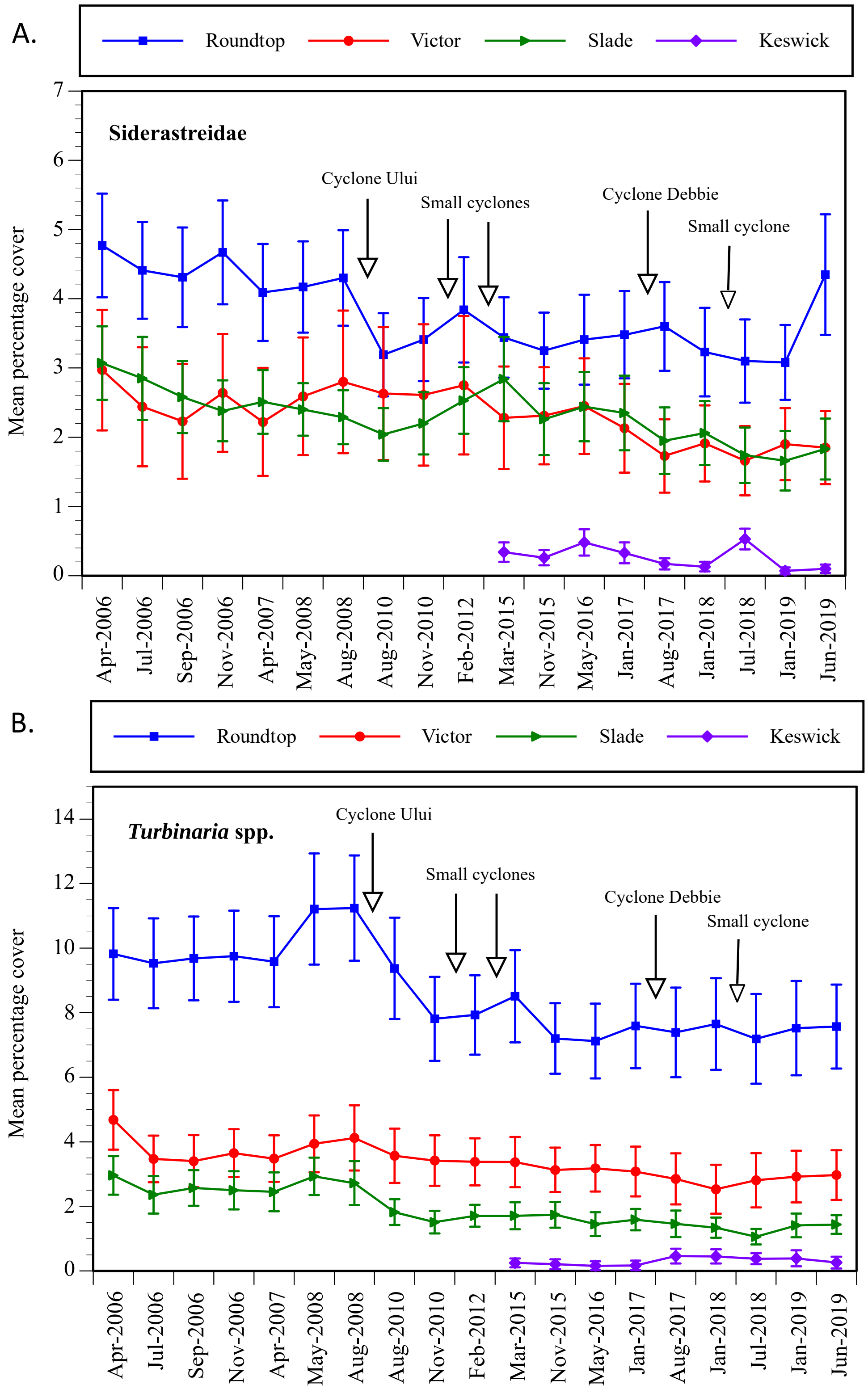


Figure 14. Changes in the cover of coral groups: Siderastreid corals and *Turbinaria* corals. Graphs show grand mean percentage benthic cover from the 2019 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors. Roundtop = Round Top Island.

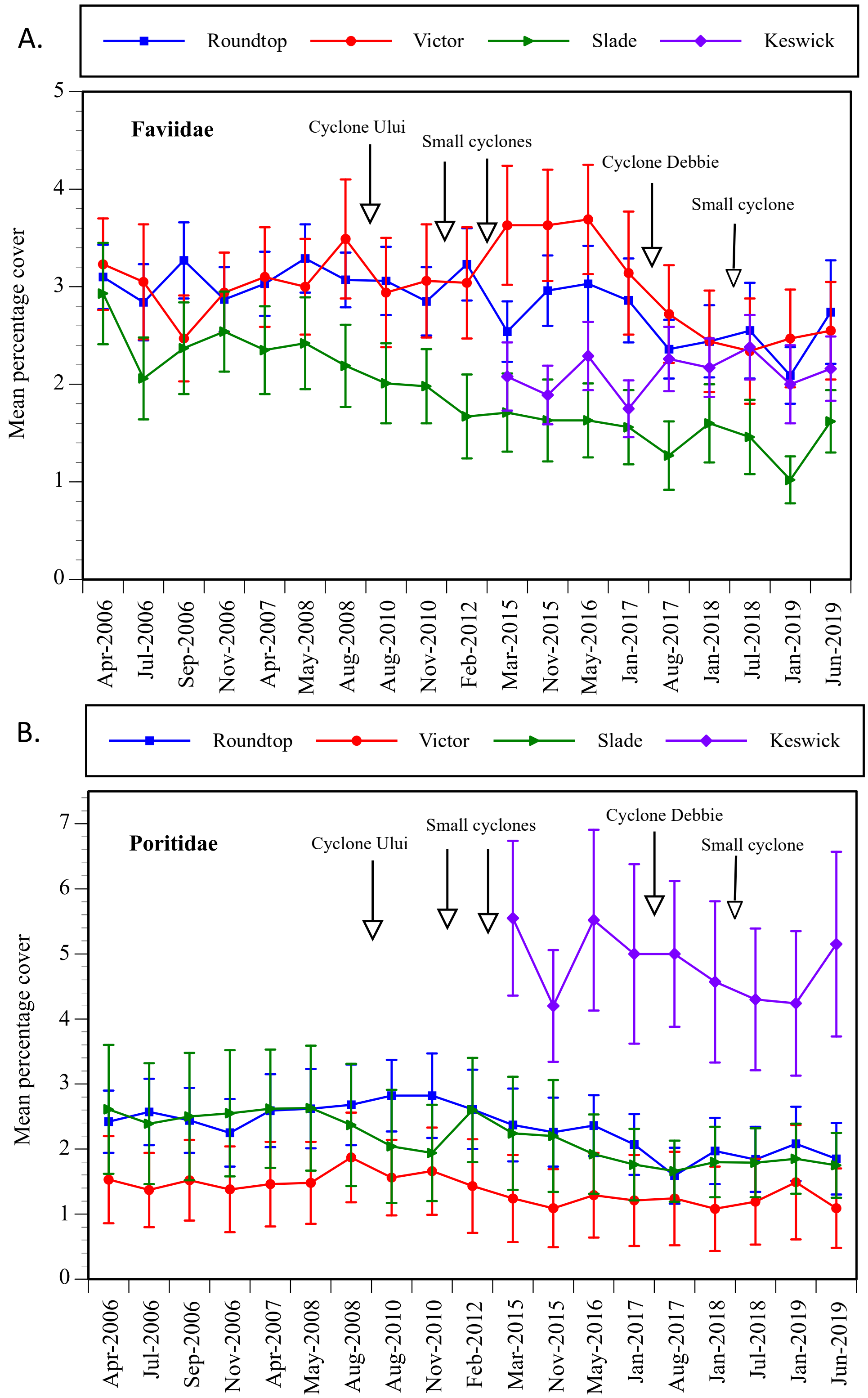


Figure 15. Changes in the cover of coral groups: Faviid corals and Poritid corals. Graphs show grand mean percentage benthic cover from the 2019 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors. Roundtop = Round Top Island.

Soft corals were significantly more abundant on Round Top Island and Keswick Island during the 2019 ambient surveys, where this group covered a mean of around 6-9% of the substratum, than in the other two locations (Table 6, Table 7, Figure 16). Soft coral cover increased significantly at Round Top between July 2018 and June 2019, fluctuated at Keswick and only increased nominally at Slade and Victor giving significant Time and Location x Time factors (Table 7).

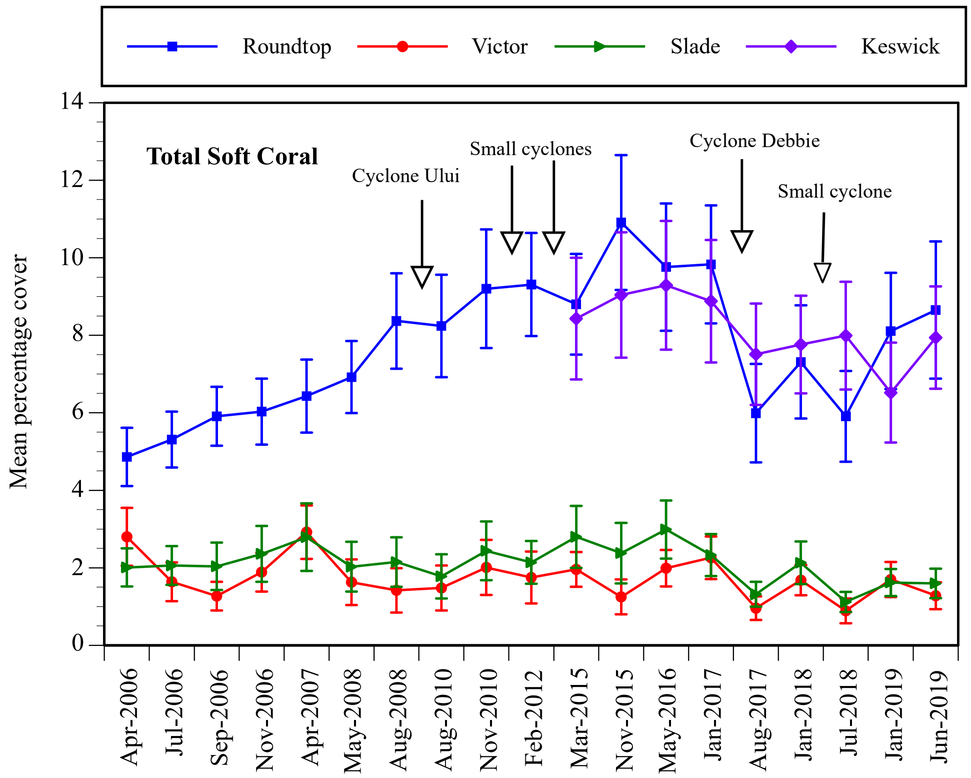


Figure 16. Changes in the cover of total soft coral.
Graphs show grand mean percentage benthic cover from the 2019 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors. Roundtop = Round Top Island.

3.3 Long-term changes in benthic communities at the three inshore locations

Nineteen surveys spanning more than thirteen years 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 inshore locations (Table 8, Figure 10). Although there were large and significant fluctuations in algal cover on these inshore locations there has also been an overall upward trend over the past thirteen years, especially on Round Top Island and Slade Islet. Since the 2006 baseline algal cover increased from about 1% to 21% on Round Top, 5% to 25% on Slade and 22% to 40% on Victor.

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%, slightly higher than the 30% recorded during the latest survey in June 2019 but similar to the Jan 2019 level. Algal cover seems to have remained very similar on Keswick for almost 20 years but has increased markedly on the inshore locations.

There have been significant changes in the cover of hard corals over the thirteen years at all three inshore locations (Table 8, Figure 11). Between the original capital dredging baseline in April 2006 and the impact of

Cyclone Ului in March 2010, coral cover at all three locations only fluctuated slightly (Figure 11), with 23-25% cover on Victor, 32-35% on Round Top and about 40% on Slade. 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%). In the following seven years there were further reductions in coral cover on Round Top Island and Slade Islet due to disease, floods and weaker cyclone events but Victor Islet managed an increase in coral cover to a level nominally higher than during the April 2006 baseline (Figure 11). Category 4 Cyclone Debbie impacted all three inshore locations in March 2017 causing further coral cover reductions, especially on Slade and Victor Islets. Coral cover did not increase in the first 18 months following Cyclone Debbie in these three locations and at between 18-20% was a mean of 42% lower than it was during the 2006 baseline. Over the past 12 months coral cover has finally begun to increase again at these inshore locations, increasing from a grand mean of 18.9% in July 2018 to 21.5% in June 2019.

Mean coral cover on Keswick Island during the 2001 survey mentioned above (Ayling and Ayling 2002) was 32%, almost the same as the coral cover of 31% recorded during the June 2019 ambient survey eighteen years later.

There have been significant changes in the cover of all major coral groups over the past thirteen years (Table 8, Figures 14 - 16). The cover of *Acropora* species was significantly higher on Round Top Island than Victor and Slade until the Cyclone Ului event (Figure 13A). That 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 March 2015 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. Although *Acropora* cover did not decline on Victor Islet during Cyclone Ului, as it did in the other two locations, the Location x Time interaction was not significant in the overall analysis (Table 8). *Acropora* cover increased slightly at all three locations by January 2017 but dropped significantly as a result of Cyclone Debbie and is now at a similar very low level in all three inshore locations. Grand mean *Acropora* cover in these three locations is now only 0.9%, a quarter of the pre-Ului peak (Figure 13A). The cover of these fast-growing corals has not increased significantly in the 30 months since Cyclone Debbie

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 13B). Cover of this coral group did not change significantly on Victor Islet (about 10% cover), or on Round Top Island (about 5% cover) until the Cyclone Debbie event in March 2017. However, *Montipora* cover reduced significantly on Slade Islet following both the Cyclone Ului and Cyclone Debbie events. Following Cyclone Debbie *Montipora* cover on Slade Islet was reduced to a third of pre-Ului levels. The decline in *Montipora* cover on Slade was much higher (about two thirds reduction) than in the other inshore locations (about a third reduction), giving a strongly significant Location x Time interaction for *Montipora* cover changes (Table 8). This was probably due to the shallow reef on Slade combined with the north-facing aspect of the three *Montipora* dominated sites. The cover of these fast-growing corals has been increasing steadily in the 30 months since Cyclone Debbie, from a grand mean of 6.8% cover to 9.0% cover.

There were significant fluctuations in the cover of siderasterid corals caused by disease episodes and the two major cyclone events. These patterns were similar in all three locations until the latest survey when cover apparently increased strongly on Round Top reefs. This resulted in a significant Time x Location interaction (Figure 14A, Table 8) but as has been mentioned this large increase may not be real and will be ground-truthed again during the next survey. These corals are rather slow-growing and therefore this potential sampling error is able to be addressed with a high degree of confidence. If mis-identification is found, the next report will include a back correction to ensure future statistical analysis is not skewed. *Turbinaria* corals in the family Dendrophylliidae were the dominant benthic group on Round Top Island where they covered about 7.6% of the substratum during the most recent surveys (Figure 14B). These corals were significantly more abundant on Round Top Island than in the other locations (Table 8). There have been significant reductions in *Turbinaria* cover over the twelve years covered by these surveys, caused by disease and Cyclone Ului. These reductions were greater on Round Top Island than in the other locations and the time x location interaction was significant (Table 8). Robust corals in the family Faviidae were moderately common at all three locations and declined significantly in abundance during the thirteen years spanned by these surveys (Table 8, Figure 15A). Faviid cover decreased more on Slade Islet than on the other locations so the time x location interaction was significant for this coral group (Table 8). Poritid corals are also robust but they too declined significantly in abundance from a grand mean of 2.2% cover to 1.6% cover over the thirteen years of these surveys (Table 8, Figure 15B).

Soft coral cover doubled on Round Top Island over the ten years till January 2017, giving a significant time effect, but changed very little on Slade Islet and Victor Islet so the time x location interaction was also significant (Table 8). There was a marked reduction in soft coral cover in all three inshore locations following Cyclone Debbie (Figure 16). Soft coral cover has fluctuated since Cyclone Debbie on Slade and Victor but has increased significantly on Round Top.

3.4 Coral Bleaching

Mass coral bleaching was only recorded on reefs north of Port Douglas in early 2016 but the early 2017 event affected reefs from Port Douglas south as far as the Whitsunday Islands (A.M. Ayling personal observations). Although the January 2017 ambient survey was carried out during this period only a small number of corals showed evidence of partial bleaching (pale colouration) at this time (Figure 17). Bleaching was highest on Round Top Island where less than 1% of corals were bleached or partially bleached. Bleached corals were significantly more abundant during the mid-Winter August 2017 survey, probably due to low-light stress caused by the long period of turbid water following Cyclone Debbie. This post-cyclone bleaching was significantly higher on Round Top and Victor compared to the other two locations (Figure 17). Levels of partial bleaching were higher during the August 2017 ambient survey than at any time since the original baseline survey in April 2006 and the March 2015 survey (Figure 17).

During the 2019 ambient surveys coral bleaching levels were very low at all four locations (Table 9), ranging from no bleaching to 0.2 bleached colonies per 40 sqm. The number of coral colonies partially bleached was significantly higher in Jan 2019 than in July 2018 or Jun 2019 (Table 10). Only a single partially bleached coral was recorded during the latest ambient survey in June 2019 (Table 9).

Table 9. Coral colony health status during the last three ambient surveys

Location	Jul 2018	Jan 2019	Jun 2019
ROUND TOP			
Healthy coral colonies (%)	99.3%	98.4%	99.3%
Partially bleached colonies (%)	0.0%	0.2%	0.1%
Disease damaged colonies (%)	0.3%	1.2%	0.5%
Sediment damaged colonies (%)	0.4%	0.2%	0.1%
VICTOR			
Healthy coral colonies (%)	98.4%	98.9%	99.4%
Partially bleached colonies (%)	0.0%	0.1%	0.0%
Disease damaged colonies (%)	0.2%	0.4%	0.2%
Sediment damaged colonies (%)	1.4%	0.6%	0.4%
SLADE			
Healthy coral colonies (%)	99.7%	99.4%	99.5%
Partially bleached colonies (%)	0.0%	0.0%	0.0%
Disease damaged colonies (%)	0.2%	0.5%	0.0%
Sediment damaged colonies (%)	0.1%	0.1%	0.5%

Location	Jul 2018	Jan 2019	Jun 2019
KESWICK			
Healthy coral colonies (%)	97.4%	97.2%	97.4%
Partially bleached colonies (%)	0.0%	0.1%	0.0%
Disease damaged colonies (%)	0.9%	2.2%	0.7%
Sediment damaged colonies (%)	1.7%	0.5%	1.9%

Healthy and damaged corals are recorded as a percentage of the total number of colonies.

Table 10. Hay Point fringing reefs: changes in the density of partially bleached, diseased and sediment damaged corals between the last three ambient surveys: ANOVA Results

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

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

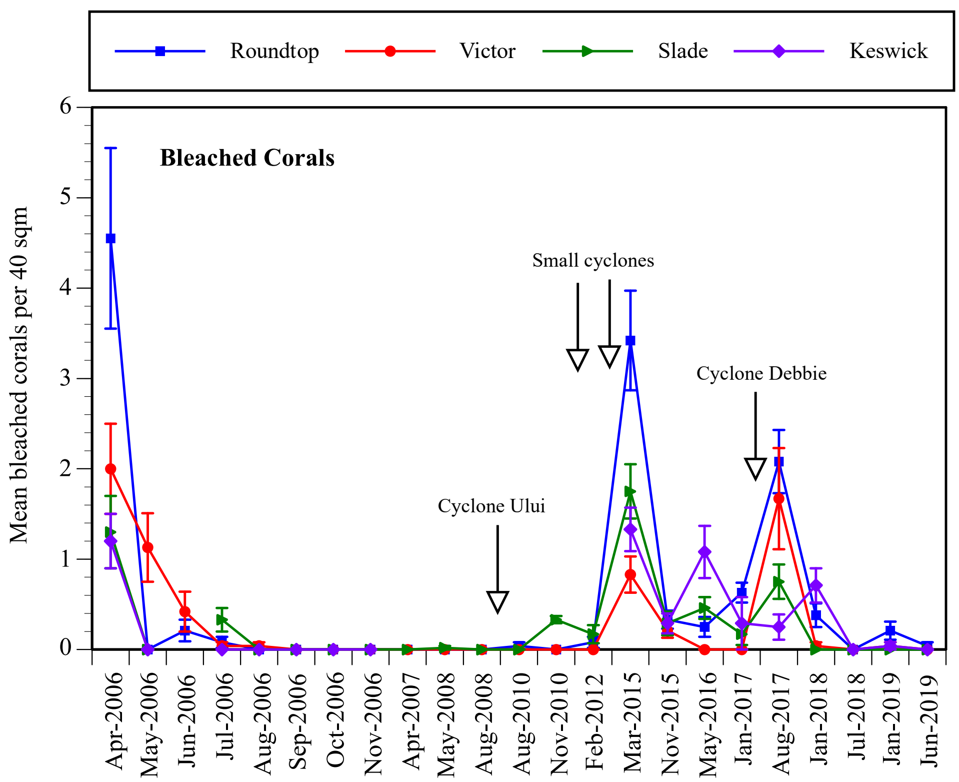


Figure 17. Changes in Density of Bleached and Partially Bleached Hard Coral Colonies. Graphs show grand mean density of bleached and partially bleached corals per 40sq m from six sites of four 20 x 2m transects in each location from the 2019 ambient surveys and all previous surveys. Error bars are standard errors. Roundtop = Round Top Island.

3.5 Sediment Deposition on Coral Colonies

Many corals on fringing reefs have some sediment on their surface as a result of natural sediment resuspension and movement during strong winds and/or spring tides. Port related activities such as dredging also have the potential to contribute to sediment in the water column. Maintenance dredging took place in the Port of Hay Point during April 2019 between the latest two ambient surveys. During the January 2019 ambient surveys, prior to the maintenance dredging, a mean of around 10% of coral colonies had recordable sediment on at least part of their surface on Round Top, Slade and Keswick Islands but an unprecedented 44% of colonies on Victor Islet had at least some surface sediment (Table 11). Mean sediment depth was less than 0.1mm on Round Top, Slade and Keswick but was just over 0.3mm on Victor, lower than during previous highs. In June 2019 sediment cover and depth was still low on Round Top and Slade but had reduced on Victor in spite of the maintenance dredging. Sediment cover and depth had increased on Keswick by June 2019 and as a result of these patterns sediment depths were significantly different among locations, had changed through time and the Location x Time interaction was significant (Table 12).

Both the number of corals with sediment load and the depth of sediment on the corals, increased rapidly on Round Top Island and Victor Islet after the commencement of the 2006 capital dredging program, reaching a high of over 1.0mm on Victor Islet (Figure 18). On the Slade Islet location reefs the number of corals with sediment and the depth of sediment was significantly lower than on Round Top Island and Victor Islet during the capital dredging (GHD 2006). Sediment loads on corals increased again at all inshore locations during the Cyclone Ului event, but had reduced close to baseline levels by the November 2010 survey (Figure 18A). Sediment levels on corals and the percentage of corals with sediment had increased again at all locations at the time of the March 2015 survey and were within the range of levels recorded during the 2006 capital dredging (Figure 18B). Sediment levels on corals again increased following Cyclone Debbie in March 2017 but not to the highs experienced during the capital dredging or following Cyclone Ului (Figure 18B). During the 2018 surveys both the number of corals with sediment and sediment depth were at very low levels. Levels were still low in 2019 on Slade and Round Top but had increased on Victor.

Table 11. Changes in frequency and depth of sediment load on corals over the three most recent survey events

Location:	Round Top Is.		Victor Is.		Slade Is.		Keswick Is.	
PERCENT OF TOTAL COLONIES WITH SEDIMENT LOAD								
Jul 2018	6.9%		13.8%		6.3%		17.3%	
Jan 2019	9.2%		44.0%		8.8%		12.3%	
Jun 2019	5.4%		22.5%		9.2%		29.4%	
MEAN MAXIMUM SEDIMENT DEPTH (mm)								
Jul 2018	0.08	*0.47*	0.13	*0.54*	0.03	*0.13*	0.24	*0.96*
Jan 2019	0.07	*0.28*	0.32	*0.49*	0.05	*0.16*	0.09	*0.29*
Jun 2019	0.03	*0.12*	0.19	*0.66*	0.06	*0.20*	0.20	*0.37*

Figures are grand mean sediment depth in mm with standard deviations in italics where appropriate.

Table 12. Hay Point Fringing Reefs: Changes in sediment depth on corals between the last three ambient surveys: Anova Results

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

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

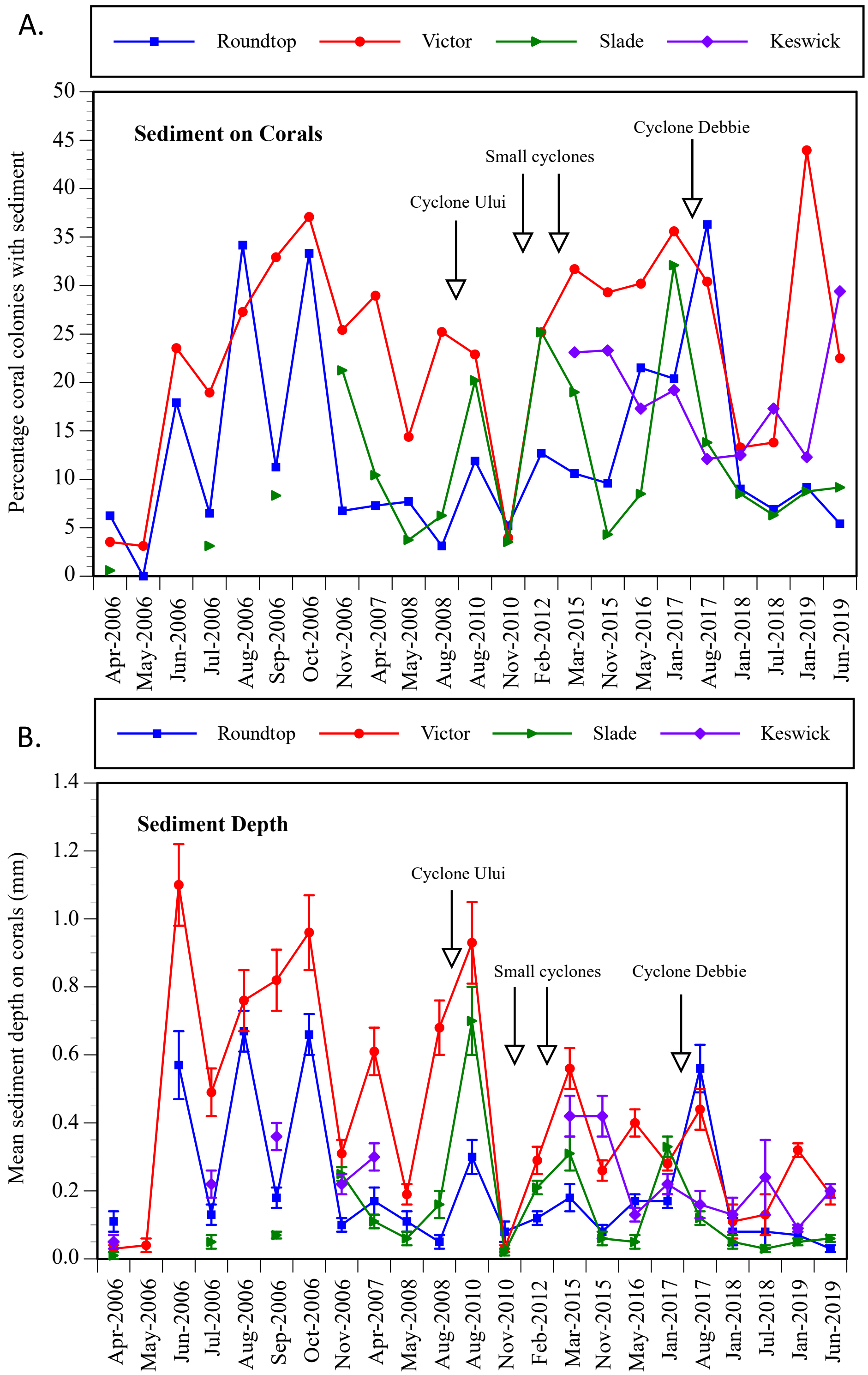


Figure 18. Changes in Number of Corals with Sediment Load and Sediment Depth.
Graphs show percentage of the 480 coral colonies examined in each location that had measurable sediment on part of the surface during each survey and the mean depth in mm of that sediment for the 2019 ambient surveys and for all previous surveys. Error bars where appropriate are standard errors. Roundtop = Round Top Island. *Note incomplete dataset at Victor Islet in 2006 and therefore no trajectory is shown since it is not representative of remaining time points.

3.6 Sediment Damage and Disease in Coral Colonies

Heavy sediment deposition on living coral can cause patches of mortality on the coral surface. Numbers of sediment damaged corals have reduced significantly since the Cyclone Debbie event. This drop in sediment induced mortality was significantly higher on Round Top and Victor than in the other two locations and the Location x Time interaction was significant (Table 10, Figure 19).

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 19A). Damage levels on Slade Islet were low during this event (Figure 19A). There was another much smaller peak in damage levels during the 2008 bed-levelling event on all three locations. Flood and cyclone events during 2011 increased sediment damage at Victor Islet to near capital-dredging levels and caused unprecedented damage on Slade Islet reefs (Figure 19A). During the four ambient surveys between March 2015 and January 2017 the levels of coral sediment damage were much lower than during most of the last thirteen years but this was ended by sediment resuspension during Cyclone Debbie with damage at all locations and unprecedented damage at Round Top Island (Figure 19A). Sediment damage levels were relatively low during the 2018 and 2019 ambient surveys despite maintenance activity occurring between the 2019 surveys.

A small number of diseased corals are present in most coral reef communities. The coral groups most often affected by disease in the Hay Point region were *Acropora*, *Montipora*, and *Turbinaria* but massive faviid, siderastreid and poritid corals were also sometimes damaged by disease. Disease levels were above average during the January 2019 ambient surveys with a grand mean of about 0.9% of corals affected but had decreased by the June 2019 survey (Table 9). There were significantly more diseased corals in the Keswick location than in the Victor and Slade locations during the 2019 ambient surveys (Table 10). Changes in disease levels over the last three ambient surveys were similar in all locations and the Location x Time interaction was not significant (Table 10).

There were significant fluctuations in the density of diseased corals over the thirteen years spanned by the surveys reported here, with order of magnitude changes at each inshore location (Figure 19B). Disease affected corals were present at all four locations and there were no overall trends in abundance at any location (Figure 19B). Small colonies sometimes died completely when affected by disease but usually disease only caused partial colony mortality.

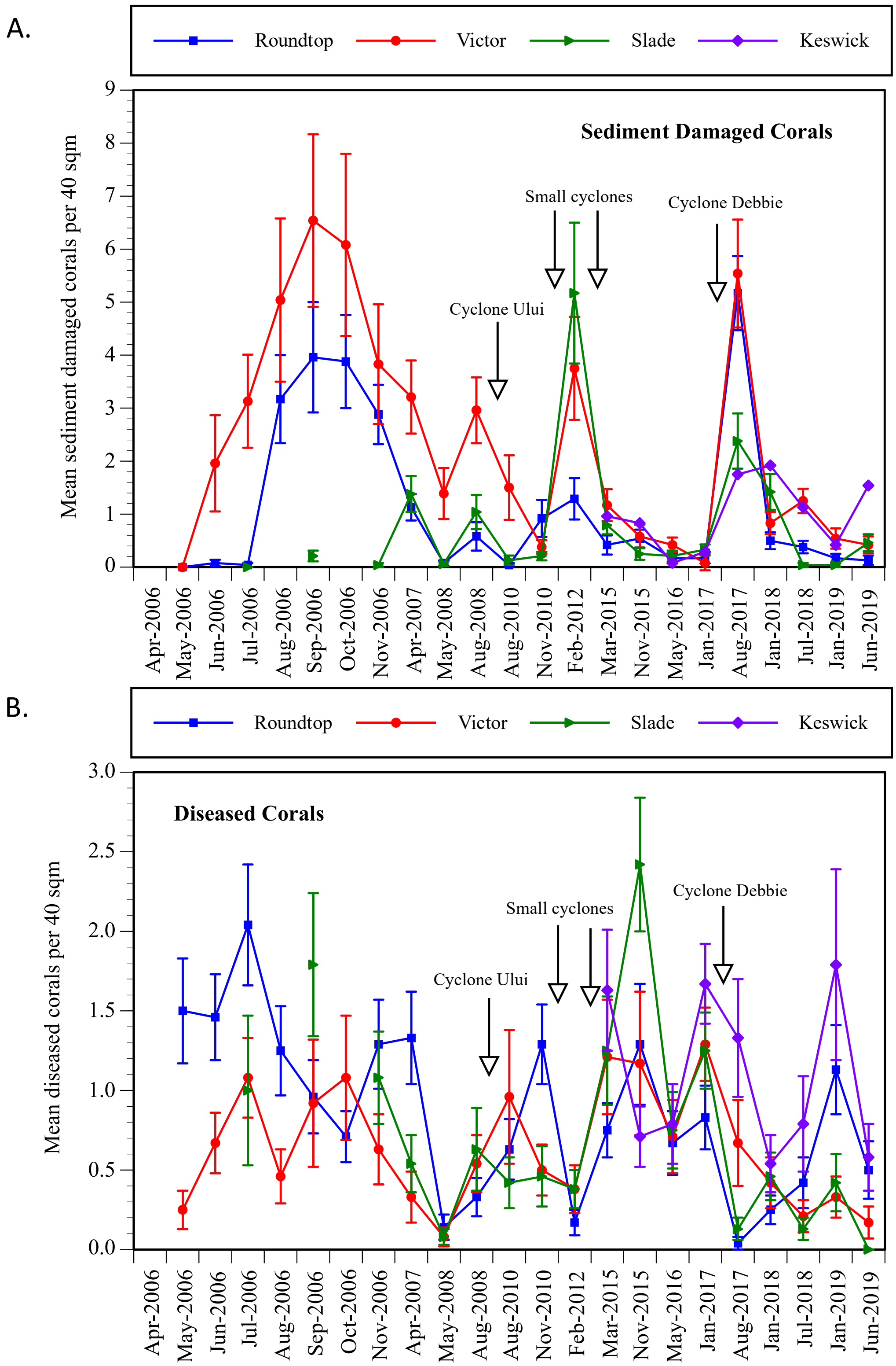


Figure 19. Changes in density of sediment damaged and diseased coral colonies.
Graphs show grand mean density of diseased coral colonies and sediment damaged corals per 40sq m from six sites of four 20 x 2m transects in each location from the 2018 ambient surveys and all previous surveys. Error bars are standard errors. Roundtop = Round Top Island. *Note incomplete dataset at Victor Islet in 2006 and therefore no trajectory is shown since it is not representative of remaining time points.

3.7 Coral Recruitment Patterns

Numbers of hard coral recruits less than 10 cm in diameter remained the same on these reefs during the 2019 ambient surveys, with a grand mean over all locations of about 1.0-1.1 per square m compared to 0.6 per square m in July 2018 (Figure 20). This is within the range of means ranging from 0.7 to 1.8 per sq m from surveys of other GBR fringing reef areas using the same method (A.M. Ayling unpublished data). Recruit numbers were significantly higher on Round Top and Slade than on Victor and Keswick (Table 13).

Recruit numbers have only been recorded since March 2015. As would be expected there was a significant decrease in recruit numbers caused by Cyclone Debbie in 2017 (Figure 20). The decrease in recruit numbers during 2018 was probably due to the marked increase in algal cover over this time. This dense algal cover may have smothered recruits or caused a bias in the counts by making it hard to detect the small corals reliably. In addition, lower reproductive output by corals in the region due to lethal and sublethal stress from the 2017 bleaching events may have reduced recruitment which would have been measurable at these locations in July 2018. Recruit numbers have increased again since the July 2018 survey.

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 70% and 90% of total coral recruits in these locations (Figure 21). Faviids also recruited well on these inshore locations. The recruit population on the offshore Keswick Island was different, with faviids accounting for 50% of recruits and pocilloporids (24%) 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* and accounted for 20% of all recruits.

Table 13. Hay Point Fringing Reefs: Patterns in the Density of Hard Coral Recruits Between the Last Three Surveys: ANOVA Results

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

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

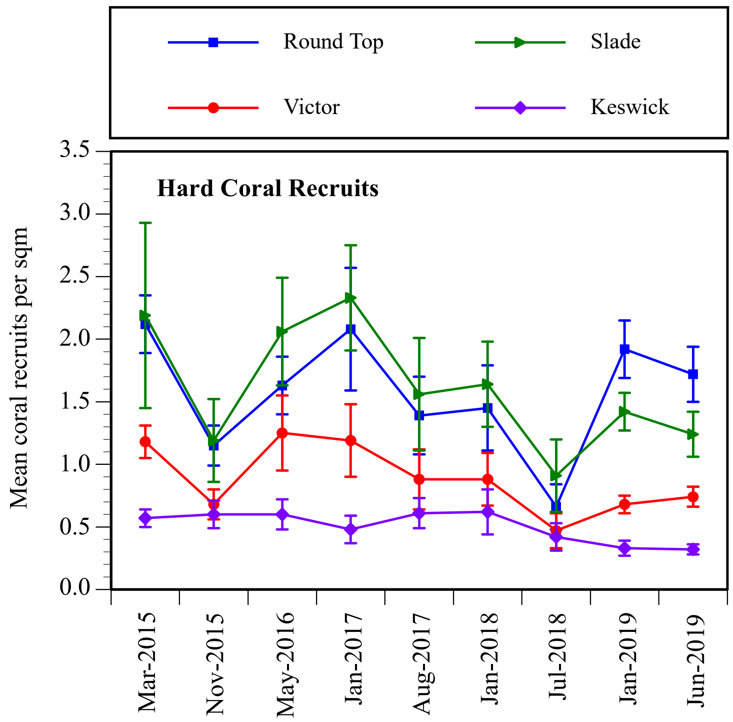


Figure 20. Changes in density of hard coral recruits over the ambient surveys. Graphs show mean density of hard coral recruits per m^{-2} from six sites in each location for the past nine ambient surveys. Error bars are standard errors.

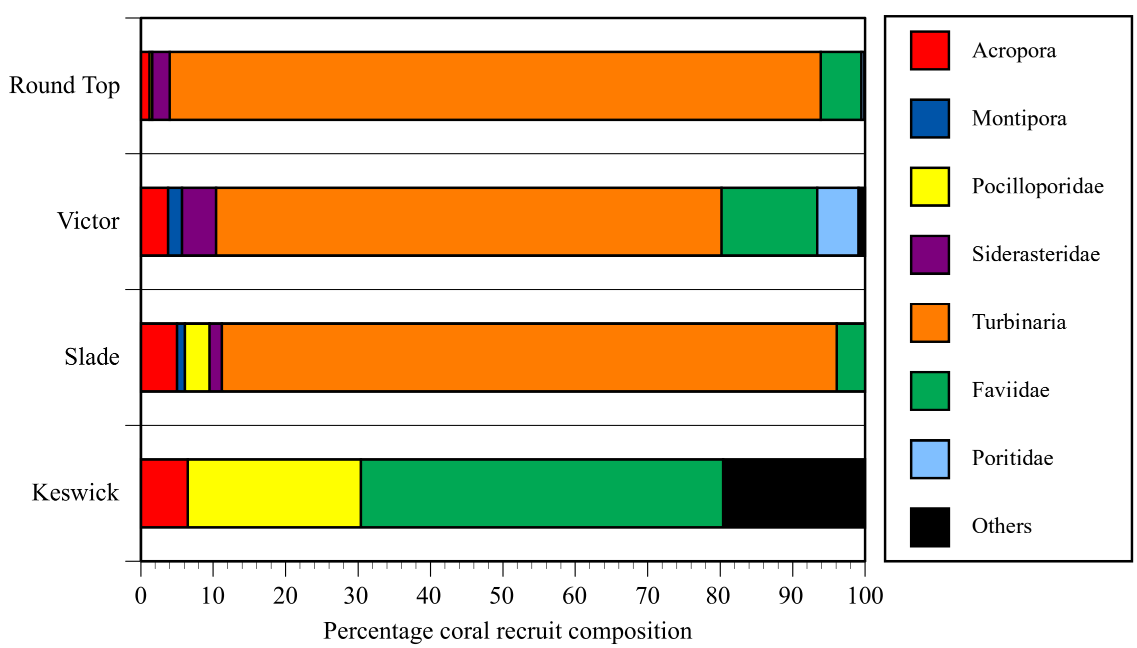


Figure 21. Composition of the hard coral recruit population in the four locations over the ambient surveys. Graphs show mean percentage composition of the major groups of coral recruits from the four locations. Composition is averaged across both 2019 ambient surveys.

3.8 Benthic Community Images

Examples of the benthic community structure at each site and examples of coral health impacts are provided in Figure 23 to Figure 44.

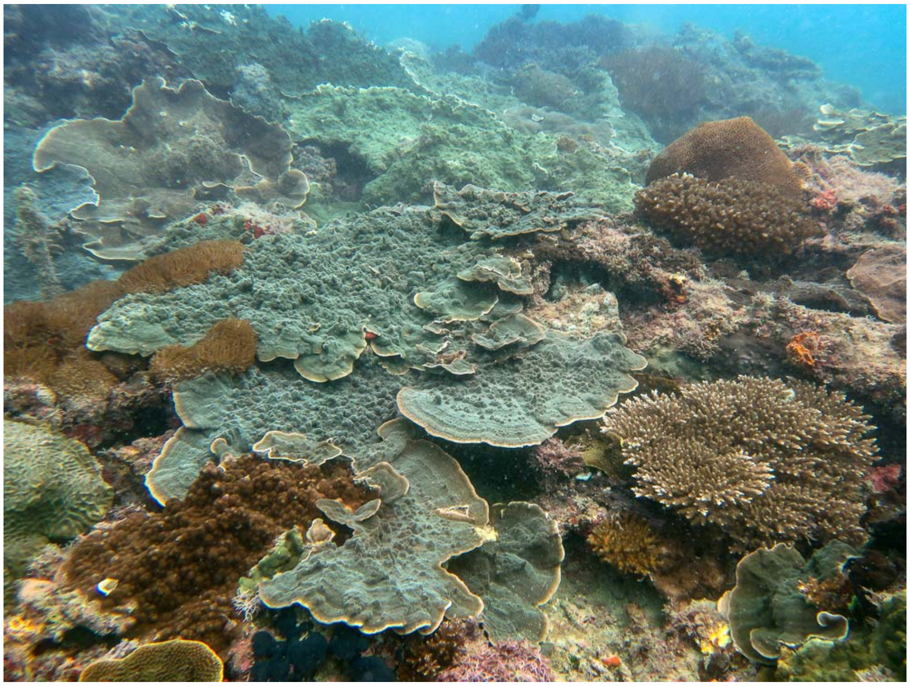


Figure 23. A variety of healthy corals at Round Top Island (Site 4) during the June 2019 survey. Corals include *Montipora*, *Acropora*, *Psammocora*, *Turbinaria* and *Pocillopora*.

Figure 22. *Turbinaria* (top) and *Psammocora* (bottom) were both common at Round Top Island (Site 6).

Figure 23. Algal cover, including *Sargassum*, had decreased on Round Top Island compared to July 2018 but was still over 20% at the time of the latest survey (Site 2).

Figure 24. Soft coral cover on Round Top Island was almost back to pre-Cyclone Debbie levels: Sansibia colony at Round Top Island Site 6, June 2019.

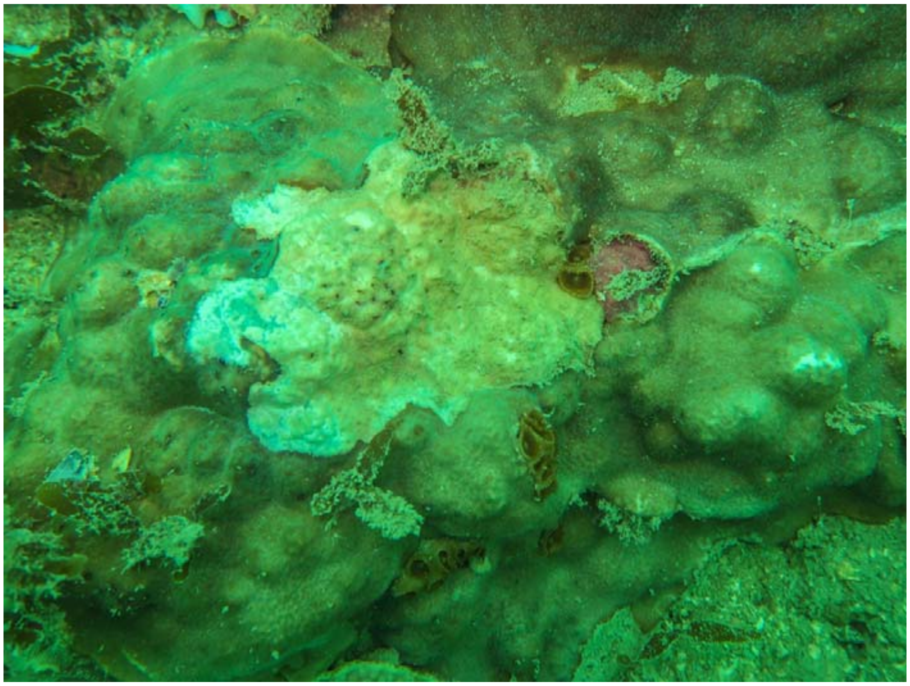


Figure 25. Active disease patch on a *Psammocora* coral colony at Round Top Island Site 3 in Jan 2019.

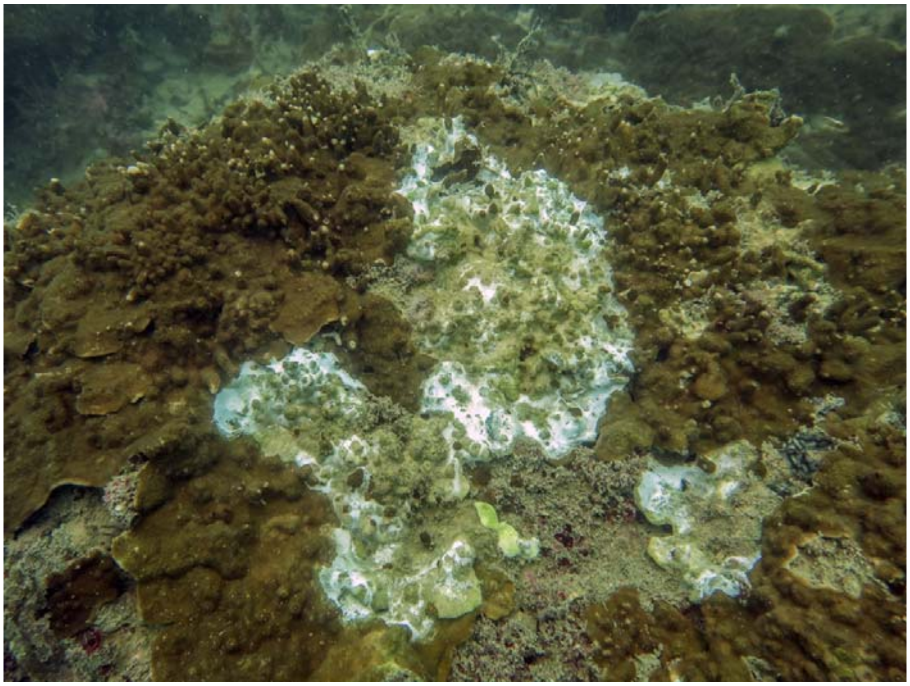


Figure 26. Patches of disease on a *Montipora* coral colony at Round Top Island Site 1 in Jan 2019.

Figure 29. Healthy corals on Victor Islet (Site 2) in June 2019, including *Montipora* (centre and bottom), *Acropora* (top right) and *Psammocora* (top far right).

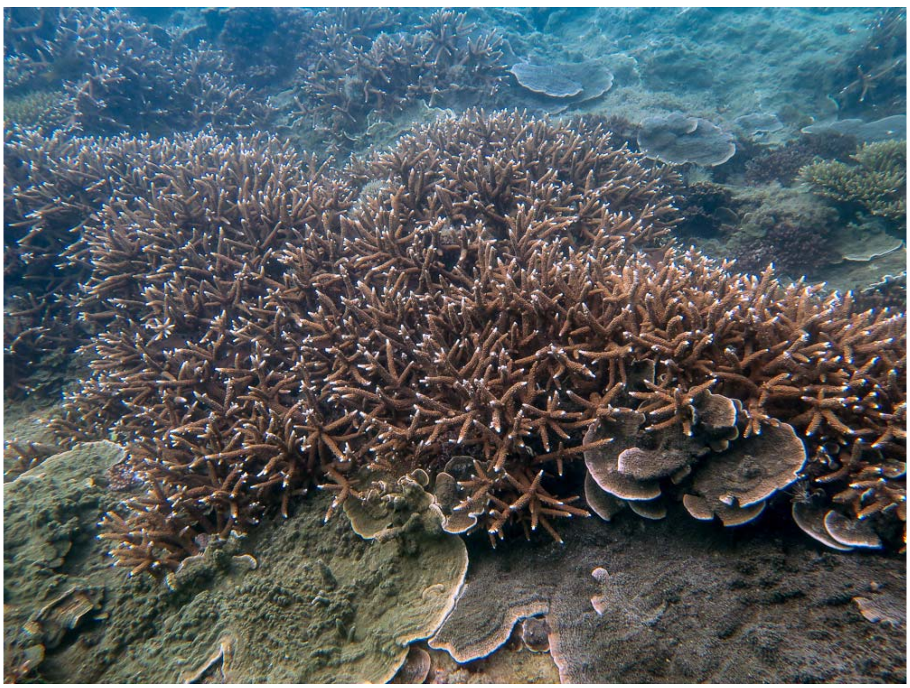


Figure 30. Large *Acropora* staghorn colony (centre), surrounded by encrusting *Montipora* corals at Victor Islet Site 2 in June 2019.

Figure 31. Heavy sediment cover on a *Montipora* colony and on the surrounding algae at Victor Islet (Site 6) in Jan 2019.

Figure 32. Heavy sediment cover on *Lobophora* algae at Victor Site 5 during the Jan 2019 survey.

Figure 33. A *Porites* colony at Victor Islet Site 5 in June 2019 surrounded by macroalgae. Note that the heavy cover on sediment recorded on everything in Jan 2019 had reduced markedly by this survey.

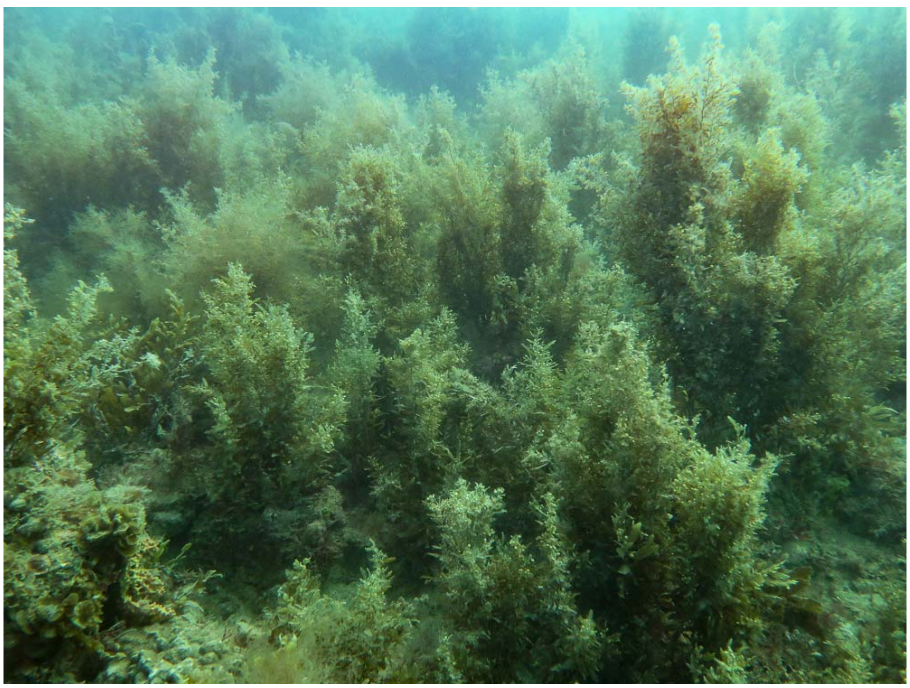


Figure 27. Dense forest of *Sargassum* macroalgae on Victor Islet (Site 4) in June 2019.

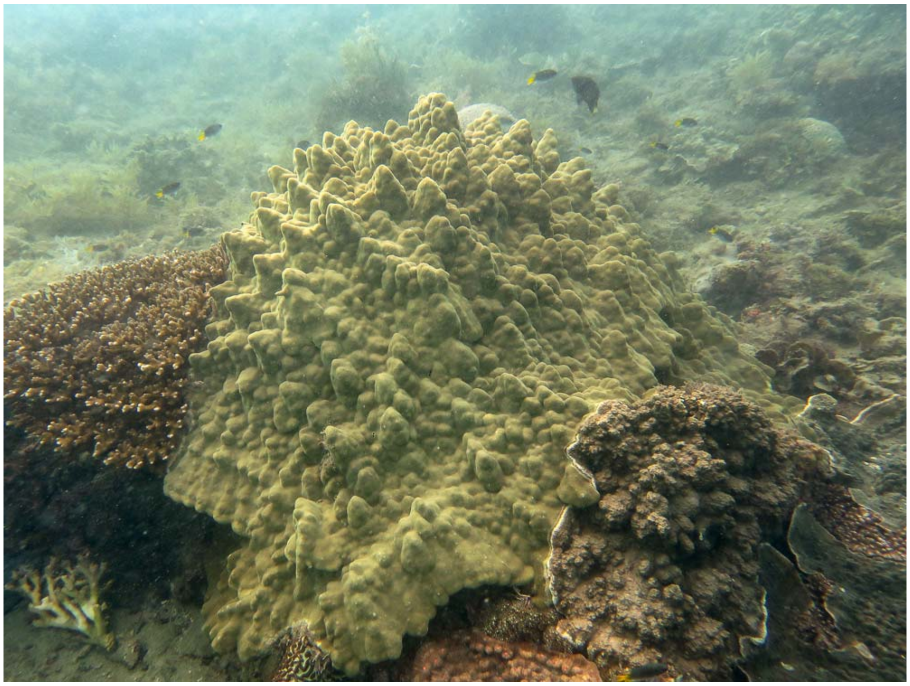


Figure 35. Healthy corals: *Porites* (centre), *Pocillopora* (left) and *Psammocora* (right) on Slade Islet (Site 1) in June 2019.

Figure 36. Explanate *Montipora* corals along with *Pocillopora* (upper left) and *Sargassum* algae (top) at Slade Islet site 5 in June 2019.

Figure 37. Algal cover on Slade Islet was 25% in June 2019, down from 50% during July 2018 in this location: *Lobophora* and *Sargassum* at Site 2.

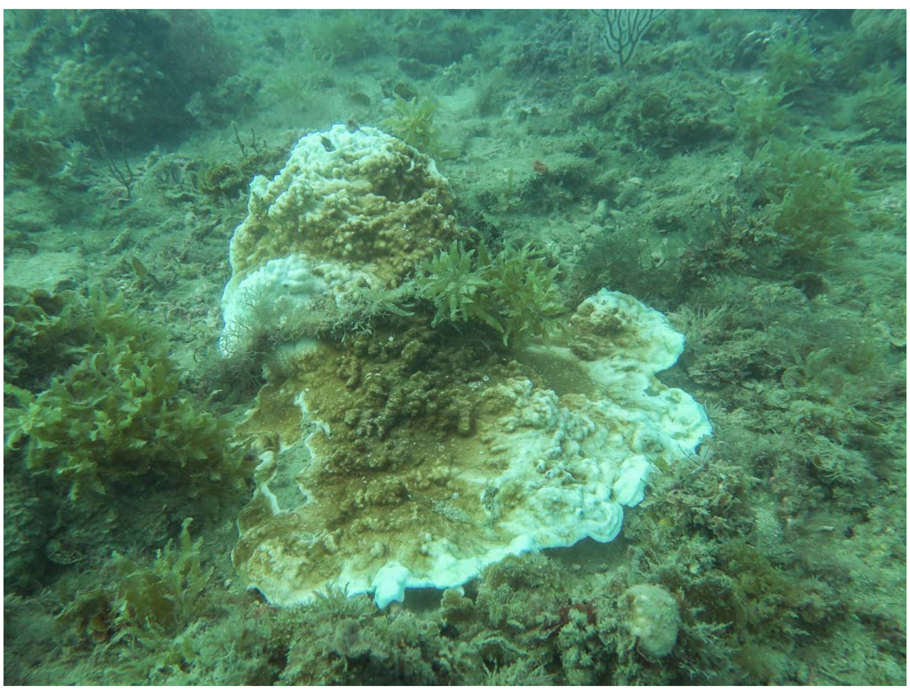


Figure 38. Partially bleached *Montipora* coral colony on Slade Islet Site 1 in June 2019 surrounded by macroalgae.

Figure 28. Four species of *Goniopora* corals at Site 2 on Keswick Island in January 2019.

Figure 29. *Acropora* staghorn corals dominated the benthic community in Homestead Bay, on St Bees Island immediately adjacent to Keswick Island (Site 4) in June 2019.

Figure 30. *Sinularia* soft corals on Keswick Island Site 1 in June 2019.

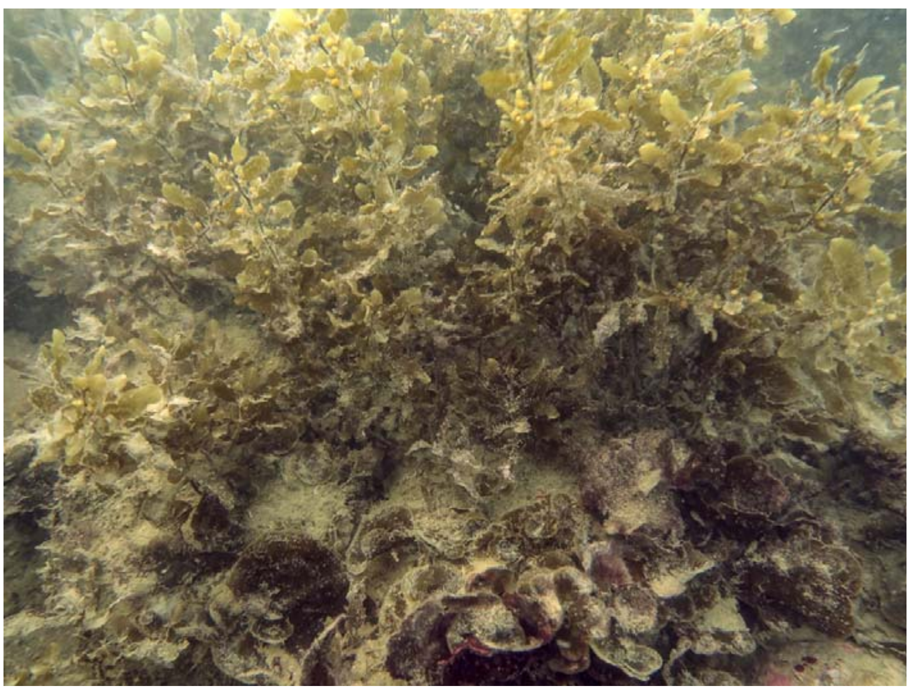


Figure 31. *Sargassum* macroalgae at Site 5 on Keswick Island in Jan 2019. Macroalgae covered 30-35% of the substratum at this location during the 2019 ambient surveys.

Figure 32. Brown-band disease had affected the *Acropora* staghorn corals on St Bees Island following Cyclone Debbie but this outbreak had mostly stopped by June 2019.

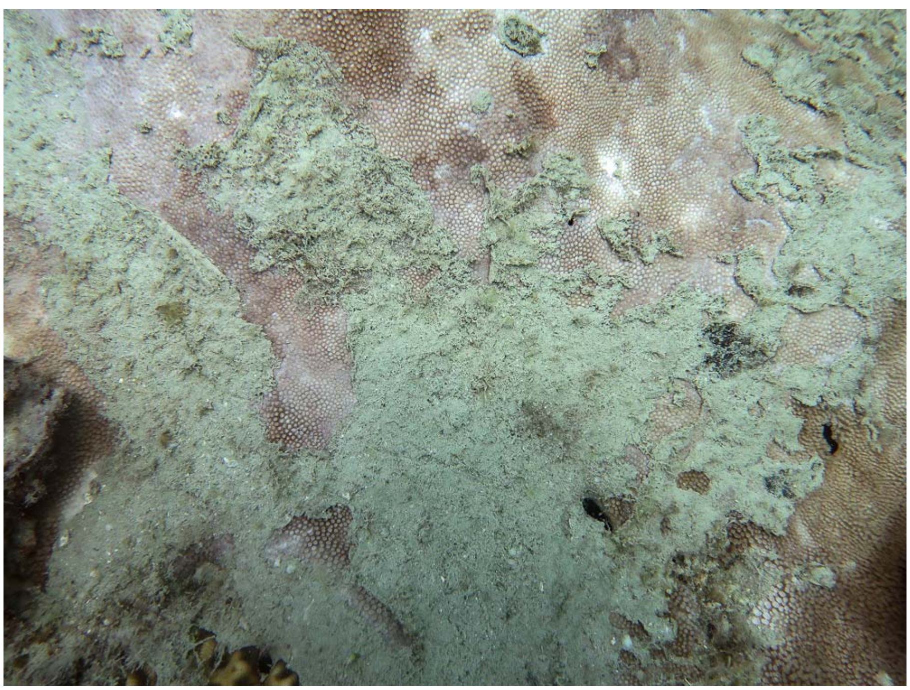


Figure 33. Heavy sediment accumulation causing partial mortality on a *Goniopora* colony at Keswick Island Site 2 during the June 2019 survey.

4 DISCUSSION

4.1 Benthic Cover during the 2019 Ambient Surveys

The major change recorded during the 2018/2019 ambient surveys covered in this report was the decrease in macroalgal cover at the three inshore locations compared to the July 2018 survey. There had been concern that the huge increase in macroalgal cover relative to pre-Cyclone Debbie levels represented a shift in community structure. However, over the past 12 months macroalgal cover has reduced to levels similar to those recorded before Cyclone Debbie. The reason for the strong spike in macroalgal cover in mid 2018 is not clear but may be related to a nutrient peak in the coastal water mass. Water quality monitoring in 2018/19 period indicated the highest nutrient levels in inshore waters since JCU TropWater began monitoring in the area (Waltham et al. 2018).

There had been no change in hard coral cover at any of the locations in the first 18 months following Cyclone Debbie (ie to July 2018). Previous fringing reef surveys have suggested that there is rapid recovery of hard coral cover following cyclone events (Sato et al. 2018; Ayling and Ayling 2005), with damaged corals putting on a growth spurt to recover lost space. This has not happened on these fringing reefs, either following Cyclone Ului or Cyclone Debbie. Declines in coral cover caused by extreme events have rather caused a permanent change in the community structure. It is worth noting that neither of these events resulted from a direct cyclone hit with the associated very destructive winds but from gale force winds on the outer fringes of the cyclones. Reef damage would have been far more severe and recovery far longer from a direct cyclone impact. Overall, the declines in hard coral at these inshore locations are consistent with documented impacts on inshore reefs from acute storm events (Lam et al. 2018). While cyclones are responsible for driving acute losses, the complexities of chronic and cumulative pressures including poor water quality, wind driven sediment re-suspension, and sublethal bleaching are more difficult to unpack as drivers of supressed recovery despite their well-documented effects on coral reefs worldwide (Lam et al. 2018; Ortiz et al. 2018). By the time of the latest survey there had been some slight recovery in overall coral cover. Grand mean coral cover pre Cyclone Debbie was 27.3% for the three inshore locations. This was reduced to 22% immediately after the cyclone and was still 21.8% in July 2018 but had increased to 24% by June 2019. The reduction in macroalgal cover over the past 12 months may have helped corals to begin recovery.

Soft coral cover was also slow to recover following Cyclone Debbie. At the time of the July 2018 survey soft coral cover was very similar to the immediate post-Cyclone Debbie levels at all locations. It was suggested that this may have been partly due to the huge increase in algal cover over the same time period. During the latest ambient survey macroalgal cover was well down on the July 2018 peak and soft coral cover had increased markedly, especially on Round Top Island. Grand mean soft coral cover was now 4.9% compared to 5.9% pre Cyclone Debbie.

4.2 Long-Term Benthic Cover Changes

Although macroalgal cover on the inshore survey locations has decreased since the very high peak in July 2018 it is still far higher than during most of the past thirteen years and has shown a steady upward trend over that time. This is a worrying sign of a possible shift toward more algal dominated reef communities, especially on Round Top and Slade where algal cover was very low during the 2006 baseline survey (1% and 5% cover respectively). This may hinder recovery of coral cover on the three inshore locations that were most affected by Cyclone Ului and Cyclone Debbie. Such supressed recovery is consistent with chronic impacts of poor inshore water quality due to catchment loads, wind-driven re-suspension, reduction in coral brood stock from sublethal bleaching together with acute storm events documented in other inshore coral communities (Lam et al. 2018; Ortiz et al. 2018; Ostrander et al. 2000).

Benthic communities on these three locations remained relatively stable over the course of the 2006 capital dredging and 2008 maintence dredging and bed levelling operations. After an initial slight decrease in coral cover caused by a coral disease outbreak, coral cover increased slightly due to natural growth. Following this period of stability 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. Note that the majority of damage/cover reduction caused by cyclone events is from water movement physical breakage or colony removal rather than from sedimentation increases. This impact was most severe on the northeast facing sites of Slade Islet where coral cover was reduced by 34%, however Cyclone Ului also reduced cover on Round Top reefs by a mean of 21% and caused an 11% reduction on Victor Islet reefs. Corals were broken up, torn off, 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. Flood and moderate cyclone events during 2011 caused further damage to reefs on Slade Islet and Round Top Island but did not affect Victor Islet. Hard corals on the inshore islands suffered another major coral cover reduction during Cyclone Debbie in March 2017. Although the August 2017 surveys were conducted 4 months after Cyclone Debbie there had not been any strong post-physical-damage coral recovery, possibly due to the extended turbid period following the cyclone when suspended sediment levels were recorded (Waltham et al. 2017). Overall coral cover on these locations dropped to almost half of the pre-Ului peak: from a grand mean of 35% down to a low of 19%. As would be expected the more fragile coral groups *Acropora*, *Montipora* and *Turbinaria* were most impacted by these events. At the time of the latest survey in June 2019 corals had recovered slightly from the post-Debbie low to a grand mean of 21.5% cover on the three inshore locations.

The extent of cyclone damage at each location seemed to be related to the aspect and potential wave fetch of the survey sites; as would be expected damage was highest at sites that were most exposed to the east and the north where the strongest winds originated. Although wind speeds during cyclone Debbie only ranged from 60-80 km/hr the extended time period of the event meant that the damage was equivalent to more intense but shorter duration storms such as Ului. As mentioned above these locations have not been subjected to a direct cyclone impact over the thirteen years of monitoring. Such a direct hit could cause almost total destruction of shallow fringing reef coral communities on the exposed parts of the islands (A.M. Ayling personal observations from other similar locations).

The Keswick Island reefs were not monitored over the period of pre-2017 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 early 2015. Coral cover on Keswick was also not affected by the recent Cyclone Debbie event because all the sites have relatively low wave fetch in most winds. Comparison of coral cover on Keswick from a 2001 survey also conducted by Sea Research that used similar sites to the present ambient survey suggests that there has been little change in coral cover over the past seventeen years in this location. The stability in coral cover on Keswick since Cyclone Debbie probably results from natural growth increases being balanced by reductions caused by disease and sediment damage. In general, Keswick Island is more charactertistic of a mid-shelf reef compared to the other more inshore locations that are part of this monitoring program, which may in part explain these overall differences.

The significant increase in soft coral cover at Round Top Island over the ten years to May 2016 appears to have been due to the natural growth of *Sarcophyton* and *Sansibia* 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. Most of this increase has been wiped out by Cyclone Debbie and soft coral cover at the other three locations is now lower than during the 2006 baseline. Soft coral cover did not recover in the first 18 months following Cyclone Debbie but has increased over the past 12 months, possibly due to the reduction in macroalgal cover.

The major driver of change on these fringing reefs appears to be sporadic cyclone events. Five cyclones have impacted this region over the past twelve years: category 3 Ului in 2010, category 1 Dylan, Ita and Nathan in

2011, 2013, and 2014 respectively, category 4 Debbie in 2017, and category 2 Iris in 2018. Although corals begin to recover slowly between these events the overall trend has been downward over this period. Combined with the upward trend in macroalgal cover that has happened at the same time, reef communities in this region have been changed markedly in a relatively short time period. Although the algal increase may partially reflect the decrease in coral cover (more space available for macroalgae) this increase is greater than the coral cover decrease. These changes are apparently largely due to natural causes but it could be argued that they are partly due to nutrient increases and global warming that are human related. Unless rates of coral recovery improve over what has previously been measured during inter-cyclone periods in this region, or cyclone events become less frequent, it is unlikely that these inshore locations will regain baseline coral condition in the near future. Given best case recovery figures from the period 2006-2008, and no further damage, it will take about three years for Victor to recover to pre-Ului coral cover, four years for Round Top and over five years for Slade.

4.3 Coral Bleaching

The damaging El Nino-driven bleaching events of early 2016 and early 2017 affected reefs north of the Mackay region and did not cause any except very minor partial bleaching of very low numbers of coral colonies in these locations. The highest levels of partial coral bleaching in these locations was observed during the 2006 baseline survey. Even during this event less than 5% of coral colonies were affected and no coral mortality was recorded. Levels of partial bleaching have been very low during the 2019 surveys and only a single bleached or partially bleached coral was recorded during the latest June 2019 survey. Coral bleaching has caused little or no coral mortality throughout the thirteen years covered by surveys in this region.

There have been four mass bleaching events caused by high water temperatures that have impacted the GBR. These occurred in 1998, 2002, 2016 and 2017 but did not impact reefs in the inshore Mackay region or further south. There is a possibility that increasing average sea temperatures associated with climate change will start to impact reefs in the Mackay region during future bleaching events but to date this has not been an issue for the study locations.

4.4 Sedimentation and Coral Damage

The coastal GBR sediment budget has been estimated in a recent study (BMT 2018). Sediments have accumulated in the near-shore region over thousands of years and it is estimated that there is presently about 2 billion tonnes of sediment in the vicinity of the Ports of Mackay and Hay Point. There is less than 200,000 tonnes of new sediment input from river catchments into these ports areas each year or about 0.01% of existing material. The major contributor to sediment levels in inshore waters is resuspension of existing seafloor sediments by wave action and tidal currents. It is estimated that there is about 9.7 million tonnes of sediment resuspended every year within the combined Mackay/Hay Point Port areas. Most resuspension occurs during strong wind events (ie when the wind is 18 knots or higher) with an average of around 25 such events a year. Cyclone events resuspend an order of magnitude more sediment than these regular strong wind events with an estimated 7.5 million tonnes of sediment moved within the combined ports region by an average cyclone. For comparison maintenance dredging for the combined ports is about 250,000 tonnes every three years or about 83,000 tonnes per year. In contrast, the major 2006 capital dredging project moved about 9 million tonnes of sediment, substantially more than a typical cyclone and about equivalent to the total annual resuspension budget but over a much shorter time period.

As a result of these natural processes corals on fringing reefs must deal with heavy sedimentation as part of normal environmental conditions. Inshore waters become very turbid from resuspended sediment during any strong wind event and this sediment settles on all fringing reef corals. These corals are able actively to remove surface sediment unless rates remain very high for long periods. It takes extreme events like cyclones or prolonged rough weather to overwhelm coral colonies natural sediment removal mechanisms. These mechanisms may also be overwhelmed during prolonged dredging operations such as the 9 million cubic metre 2006 capital dredging program. In these cases sediment may accumulate in depressions on the surface of vulnerable coral colonies and eventually cause small patches of mortality. Such dead patches occur naturally on most fringing reefs and are usually repaired, once sediment levels decrease, by regrowth from the edges of the damaged patch.

Cyclone events have caused partial, sediment-driven damage of up to 5% of coral colonies in this region on several occasions over the past decade but the actual decrease in coral cover due to such sediment damage has been much less than 1%. The 2006 capital dredging program caused similar levels of sediment damage to corals and also resulted in a coral cover reduction of much less than 1%. The maintenance dredging for Port of Mackay in 2013 coincided with a strong wind event and sedimentation from these combined events caused significant damage to encrusting *Montipora* corals on the NE face of Slade Islet. During the post-dredging survey following this maintenance dredging over 60% of coral colonies had surface sediment around Slade Islet with mean sediment depth of about 1mm. This event only resulted in a reduction of *Montipora* cover from 18.1% to 16.6% and is the only significant sediment damage to corals we have ever recorded (Ports and Coastal Environmental 2013).

The level of sediment damage to hard coral colonies caused by major cyclone events such as Ului and Debbie is comparable or greater than that caused by large port-related activities such as capital dredging but this sediment damage is orders of magnitude less than the physical damage caused to benthic communities by wave action during these cyclone events.

4.5 Mortality and Coral Disease

Levels of coral disease during the 2019 ambient surveys were in line with levels recorded over the thirteen years spanned by the long-term surveys. Less than 2% of hard corals were affected by disease on these locations at any one time and trends have been down or flat over this thirteen 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). Disease affects all major coral groups but rarely causes complete colony mortality.

Studies in the GBR region indicate that activities such as fishing may increase levels of coral disease (Lamb et al. 2015) and that disease can be more prevalent following warmer than normal sea temperatures (Bruno et al. 2007). However, there is no evidence that stress caused by past dredging operations has increased the susceptibility of corals in this region to disease outbreaks and disease levels have been stable or trending slightly downward.

4.6 Coral Recruitment

Coral recruit numbers have been low and have not fluctuated much on Keswick Island, probably because coral cover and algal cover have been relatively consistent here compared to the inshore locations. Recruit numbers on the inshore locations have been lowest when algal cover has been very high, suggesting that it is the ability to detect the recruits that is changing rather than the actual recruit numbers fluctuating. When there is a dense, multi-layer algal community even a careful search may miss small recruits. The significant drop in recruit numbers caused by Cyclone Debbie is probably a real change and the major impact recorded during these surveys.

Turbinaria corals were by far the dominant component of the recruit population on the inshore locations, accounting for a grand mean of about 75% of the recorded recruits. This group of corals are inshore, turbid water specialists and are relatively tough and slow growing. Larval input would probably be from adult corals either in the local area or from nearby similar habitats rather than from distant or offshore reefs. Recruitment to these inshore locations is probably not affected by distant, large-scale events such as the 2016 and 2017 coral bleaching episodes.

4.7 Implications for Coral Assessment

Keswick Island is an outlier in this survey, being further offshore and having better water quality. Algal cover was more consistent in this location and the hard coral community composition was markedly different from the three inshore locations. Soft coral cover was also higher and the species composition different on Keswick than the inshore locations. This location is not a suitable distant reference site for the three inshore locations which are all potentially affected by operations at either Hay Point or Mackay Ports. It is suggested that either this location be removed from the on-going ambient program or several more offshore locations be added eg Brampton Island and/or Scawfell Island.

It is also suggested that future surveys on the inshore locations be reduced to four sites per location rather than six. This would make the surveys more efficient and by dropping the sites that are most algal dominated and have the lowest coral cover would also improve the power of future statistical tests. For instance sites 2 and 5 could be dropped on Round Top, Sites 1 and 4 on Victor and sites 3 and 6 on Slade.

Water quality is monitored throughout the Port of Mackay and Hay Point and provides valuable insights into seasonal and inter-annual dynamics (Waltham et al. 2018). In order to better understand how inshore water quality may be influencing the trajectory and fluctuations of coral, macroalgae and sediment on these inshore reef communities, it is recommended to relocate some water quality loggers closer to the ambient coral monitoring locations.

Recent natural cyclonic impacts have reduced coral cover significantly on all three inshore island reefs and coral cover is now similar at these locations. Coral cover has changed least at Victor Islet during these events in spite of this location being the most affected by sediment during dredging operations over the past thirteen years. This suggests that although many coral colonies on the protected back sites at Victor Islet are still recovering from previous sediment damage the coral communities are still resilient enough to deal with continued natural impacts. Coral cover impacts have been greatest on Slade Islet where potential dredge impacts were limited to the small Port of Mackay maintenance program in 2013. Slade Islet was the most impacted of the inshore locations by both major cyclone events because it is the furthest north, hence closer to both major cyclones paths, and has the shallowest, most vulnerable reefs. Victor Islet is furthest south of the inshore locations and has been further from the path of the major cyclones, with the lowest level of cyclone impact on coral communities. The slow rate of recovery of hard coral communities on these fringing reefs in the 30 months since Cyclone Debbie is a cause for concern.

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