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SEA RESEARCH

JAMES COOK UNIVERSITY
AUSTRALIA



Ports of Mackay and Hay Point Ambient Coral Monitoring Surveys: 2017-2018

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

Report No. 18/54
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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 2017/2018 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.

2. The three inshore survey locations were severely impacted by Cyclone Debbie in late March 2017, between the January 2017 and August 2017 ambient surveys.

3. 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). Overall, the significant reduction and resulting similar coral cover at all three locations has been driven by cyclonic impacts.

4. In the 18 months since Cyclone Debbie, there has been no recovery evident in hard and soft coral cover at any location. In contrast, macroalgal cover has increased dramatically at the three inshore locations. The lack of any recovery of hard coral communities on these fringing reefs in the 18 months since Cyclone Debbie is a cause for concern.

5. The cover of macroalgae has increased from a mean of 9% cover in 2006 to a peak of 47% at the time of the latest July 2018 ambient survey. This increase has occurred gradually over this 12-year period but also sharply post-Cyclone Debbie.

6. 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.

7. Over the twelve years of monitoring these locations, coral community composition overall has only slightly changed, however, the percentage of *Acropora* corals in the inshore locations has decreased.

8. New coral recruits significantly decreased in 2018 from previous years, a likely result of Cyclone Debbie in 2017 and the increased macroalgae cover smothering recruits or causing a bias in the counts by making it hard to detect the small colonies.

9. 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 2018 surveys both the number of corals with sediment and sediment depth were at very low levels.

10. 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.

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 of these parameters 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 instigated an ambient coral monitoring program 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 such as dredging. Advisian, in association with Sea Research, carried out these ambient surveys at all four locations on three occasions: March 2015, November 2015 and May 2016. Sea Research was asked to continue this program in 2016/2017, making surveys in January and August 2017. TropWATER, in association with Sea Research, continued this program in 2017/2018, carrying out surveys in January 2018 and July 2018.

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 extreme 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 18 months since Cyclone Debbie hard and soft coral cover has not changed, with no recovery evident at any location. Macroalgal cover has 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%.

Coral community composition was different at the four locations. At Round Top Island *Turbinaria* corals were dominant, accounting for almost 40% of hard coral cover, with *Montipora* and siderastreids also important. At Victor Islet *Montipora* corals were dominant (40% of coral cover), with *Turbinaria* and faviids also important. At Slade Islet *Montipora* corals were dominant, accounting for 52% 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 twelve 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. Peak levels have been around 30% of corals affected and mean sediment depths of around 1 mm. This sediment deposition on living coral colonies caused patches of mortality, especially on Victor and Round Top, with over 5% of coral colonies partially damaged in severe events. However, the resulting coral cover reductions have 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 measured to date.

Coral bleaching has affected corals in these locations on a number of occasions over the past twelve 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. A disease outbreak during the 2006 summer caused a short-term but significant reduction in coral cover at all inshore locations and yet the impact of disease on hard corals has been an order of magnitude less than physical cyclone damage over the last 12 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 more than a decade covered by these surveys. The cover of macroalgae has increased from a mean of 9% cover in 2006 to a peak of 47% at the time of the latest July 2018 ambient survey. 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 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. Recovery times are estimated to be 3-6 years given best-case recovery scenarios and no further impacts.

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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 both 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. NQBP's vision is to maintain the Port of Mackay and Hay Point as two of Queensland's premier bulk materials handling ports and to act as a supply-chain partner for commodities and goods including servicing coal mines in the central Queensland coal fields.

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 this 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 2017/2018 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 most recent two ambient surveys at all four locations over the 12 months between mid-2017 and 2018 and 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

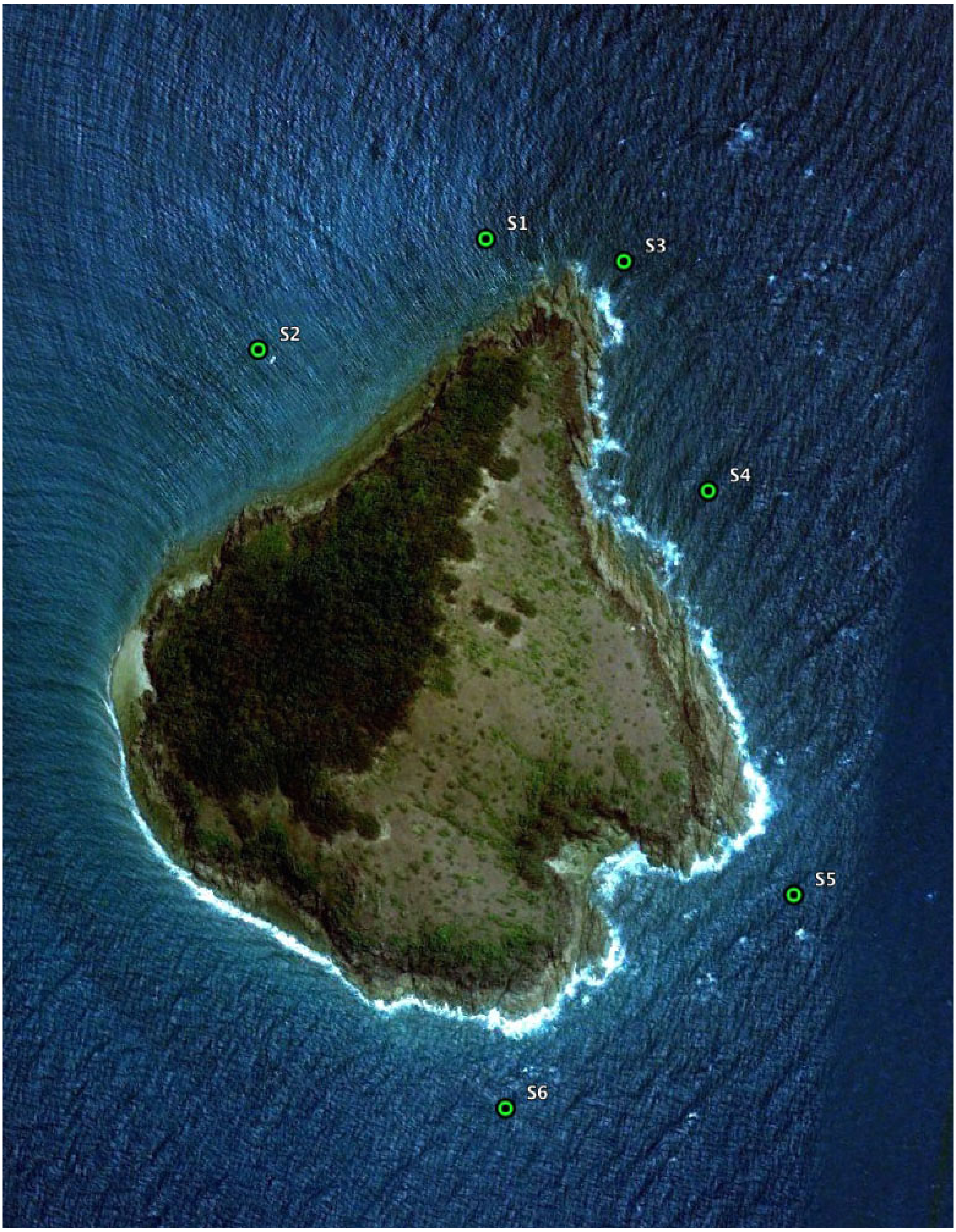


Figure 2. Round Top Island Location Showing Position of the Six Coral Monitoring Sites

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

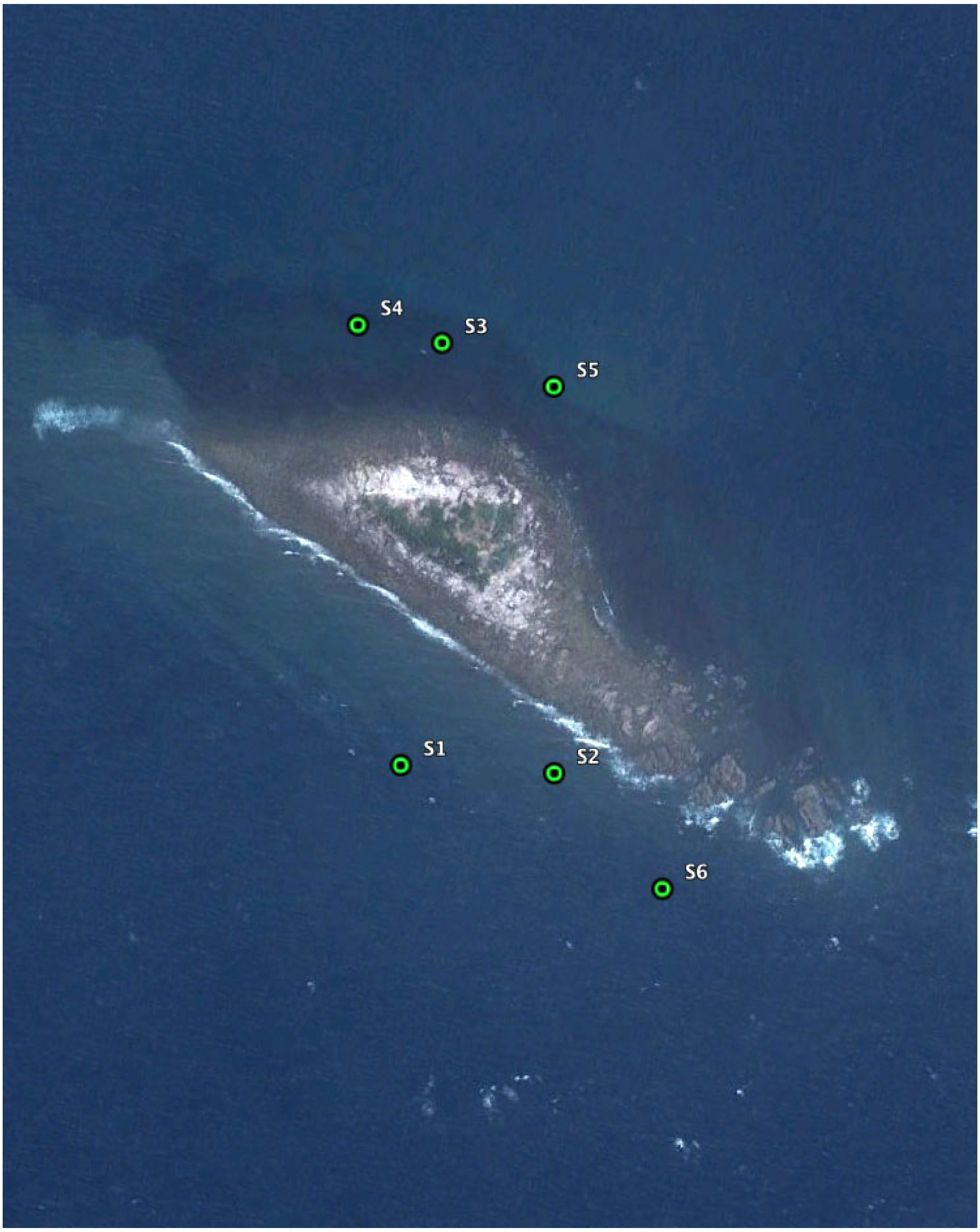


Figure 4. Slade Islet Location Showing Position of the Six Coral Monitoring Sites

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

2 METHODS

2.1 Locations

Fringing reefs were surveyed around four island locations (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

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 reef locations over the period January/February 2018 to July 2018. The two survey periods were 'pre-wet', from 21-23 January and 24-25 February 2018 (henceforth referred to as January 2018) and post-wet from 15-18 July 2018.

The pre-wet survey was delayed from the ideal October/November time period due to poor weather and pre-existing commitments by Sea Research. However, the January/February survey was well prior to the major wet season event caused by Cyclone Iris in early April 2018 and hence can still be considered pre-wet. The post-wet survey was also delayed due to rough weather and poor underwater visibility. The surveys cannot be conducted accurately if water visibility is less than about 2 m.

During rough weather underwater visibility in the study areas can be zero due to high levels of turbidity. During the January/February pre-wet survey visibility ranged from 3-10 m. During the July post-wet survey underwater visibility ranged from 4-10 m.

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 (Aug 2017, Jan 2018, July 2018) was tested with one series of anovas (Table 3) 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 seventeen 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 September 2017 to July 2018 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 2017) 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 2016) 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). The 2017/2018 wet season was below average in terms of rainfall, with only 657mm recorded for the January-April period compared to the 1,080mm average. More than 50mm in 24hr rainfall was only recorded on three days during this wet season period (Figure 6A).

Water discharges from the Pioneer River were also well below average for the 2017/2018 period (Figure 6B). Only two short peaks of over 10,000 ML/day were recorded and the maximum flow of about 25,000 ML/day occurred during the offshore passage of Cyclone Iris in early April 2018. This is very low compared to previous rainfall events, with river flows of over 100,000 ML per day recorded on at least ten occasions throughout the past decade.

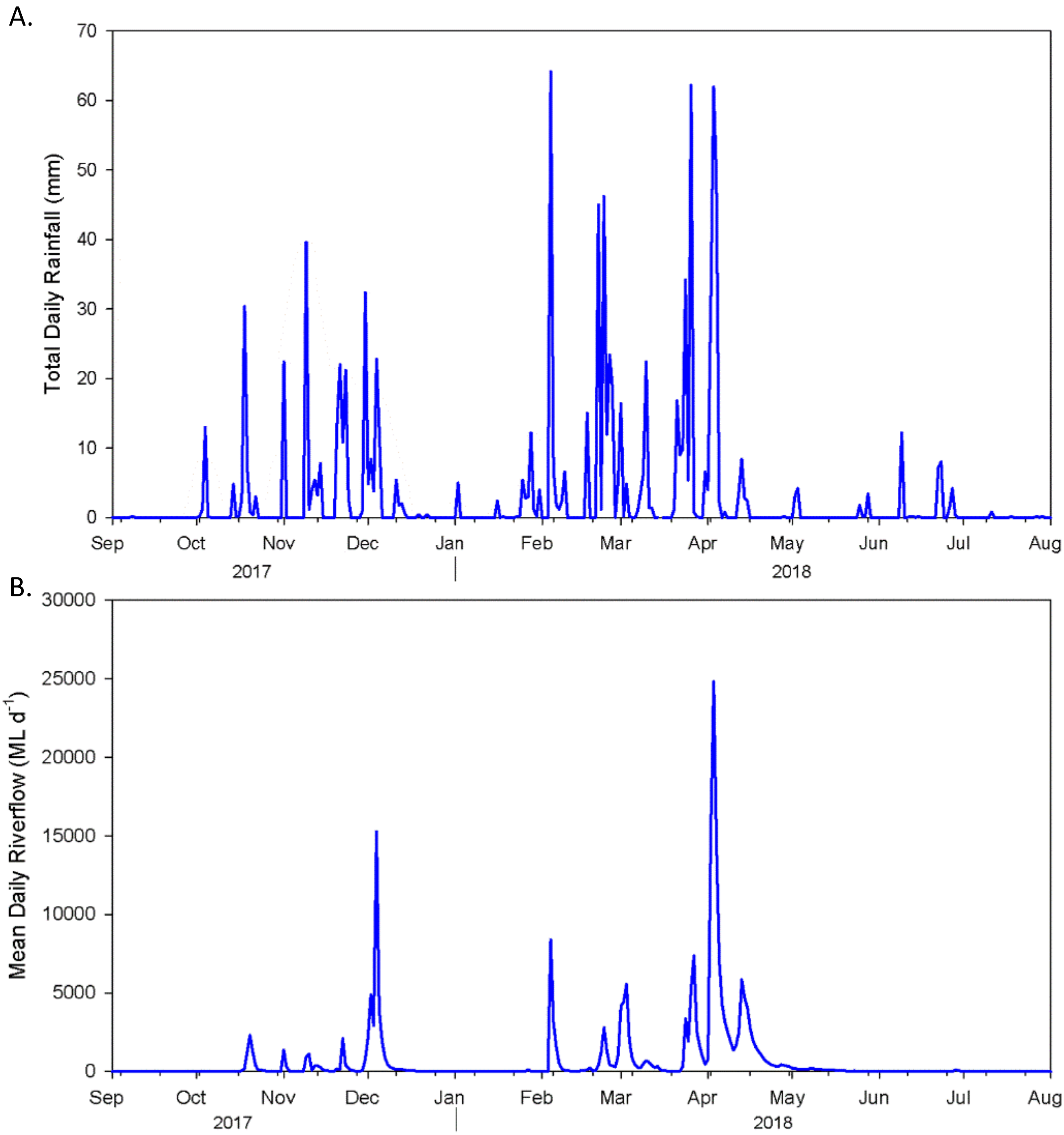


Figure 6. A. Daily rainfall measured at the Mackay Airport, B. the Pioneer River discharge at Dumbleton Weir

3.1.2 Cyclones

During the 2018 ambient monitoring period only one cyclone passed near Mackay: Tropical Cyclone Iris (Figure 7). This cyclone steered a zig-zag course offshore from Mackay over a period of about five days in early April, reaching a maximum intensity of category 2. Iris did not cross the coast but generated winds over 50 km/hr from the SE quarter for over 24 hours at Hay Point. Maximum sustained winds were about 65 km/hr with gusts of over 80 km/hr. Almost 150mm of rain fell at Mackay Airport during this event but daily river flows peaked at only 25,000 ML (Figure 6B).

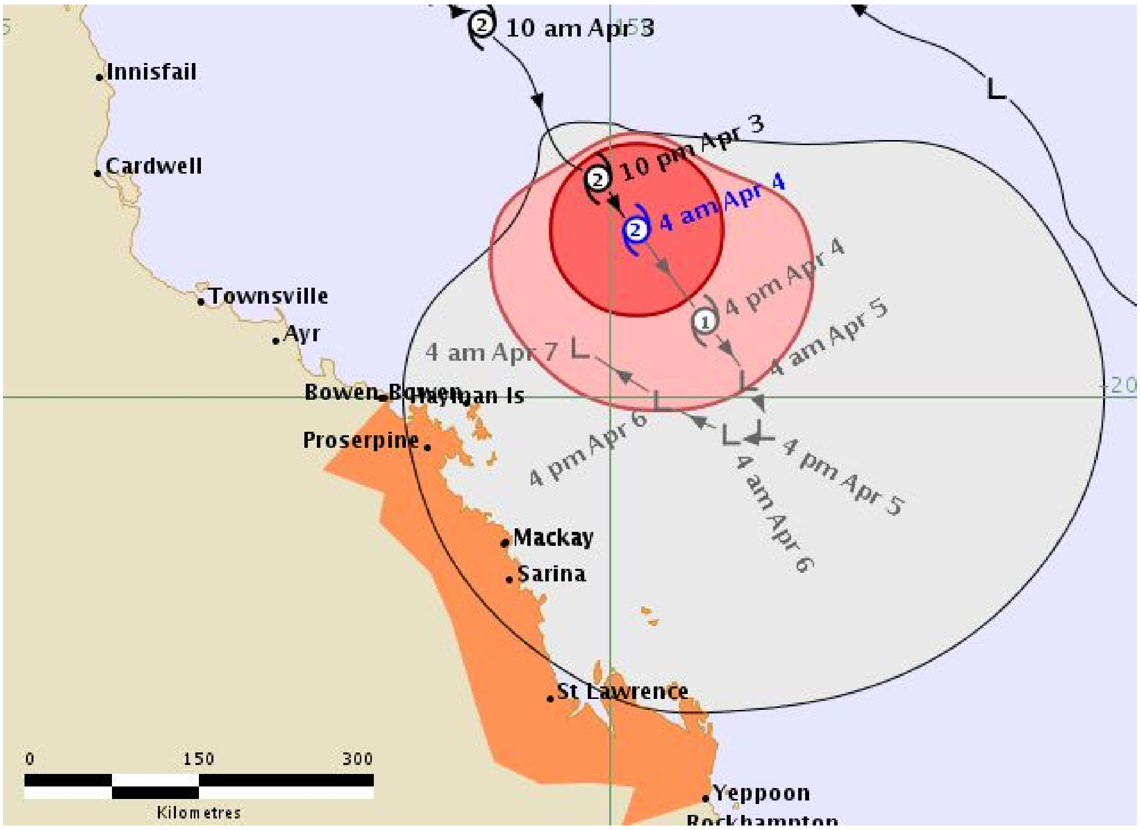


Figure 7. Partial Track of Tropical Cyclone Iris

Prior to 2018 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 2017/2018 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 2017/2018 ranged from 29.0°C to 30.2°C at Round Top Island and Keswick Island respectively (Figure 8). Water temperatures during the July 2018 survey were at the annual minimum and ranged from 19.6 to 21.7°C, 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 9).

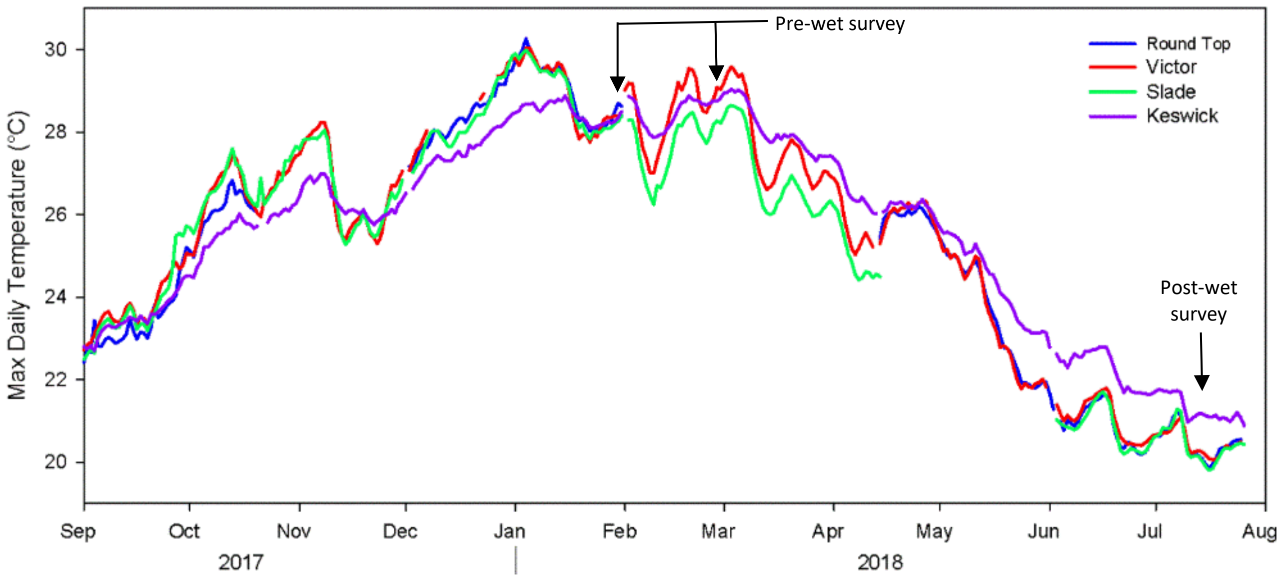


Figure 8. Maximum daily temperature recorded at monitoring locations in 2017-2018.

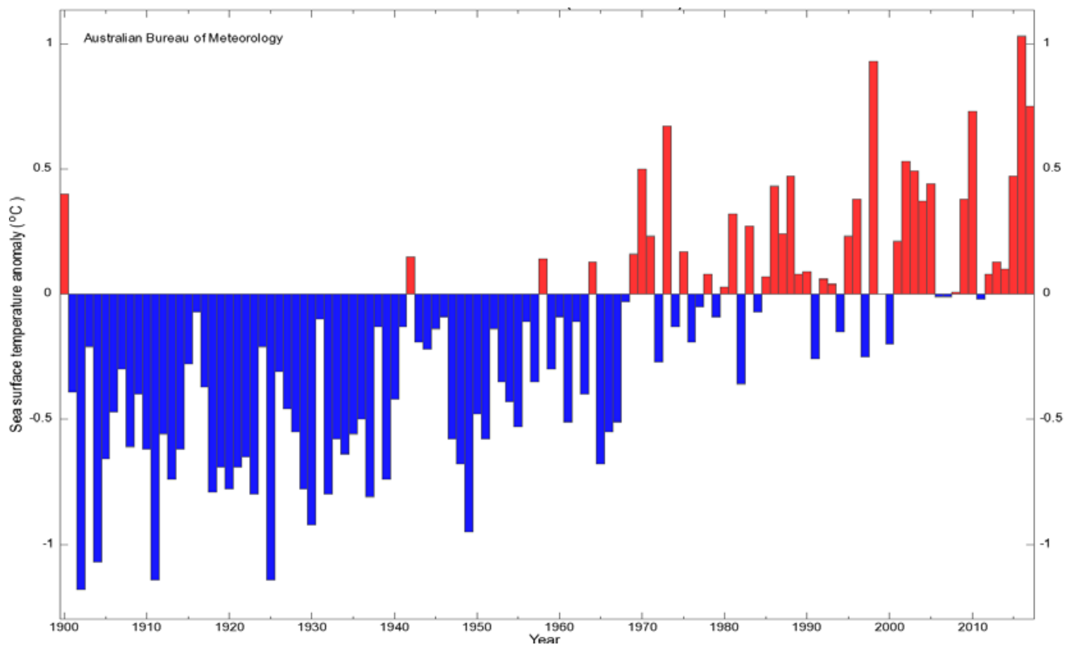


Figure 9. Annual sea surface temperature anomaly for the Great Barrier Reef (1900 to 2017) based on 1961 – 1990 climatology; Bureau of Meteorology

† 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, although this benthic group had been reduced at all locations by Cyclone Debbie in March 2017. During the January 2018 survey algal cover ranged from 18% to 24% on the inshore locations and was 38% on Keswick Island. There was a strongly 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 July 2018 survey algal cover had increased to around 50% on the inshore locations but decreased slightly to 32% on Keswick Island (Figure 10, 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.

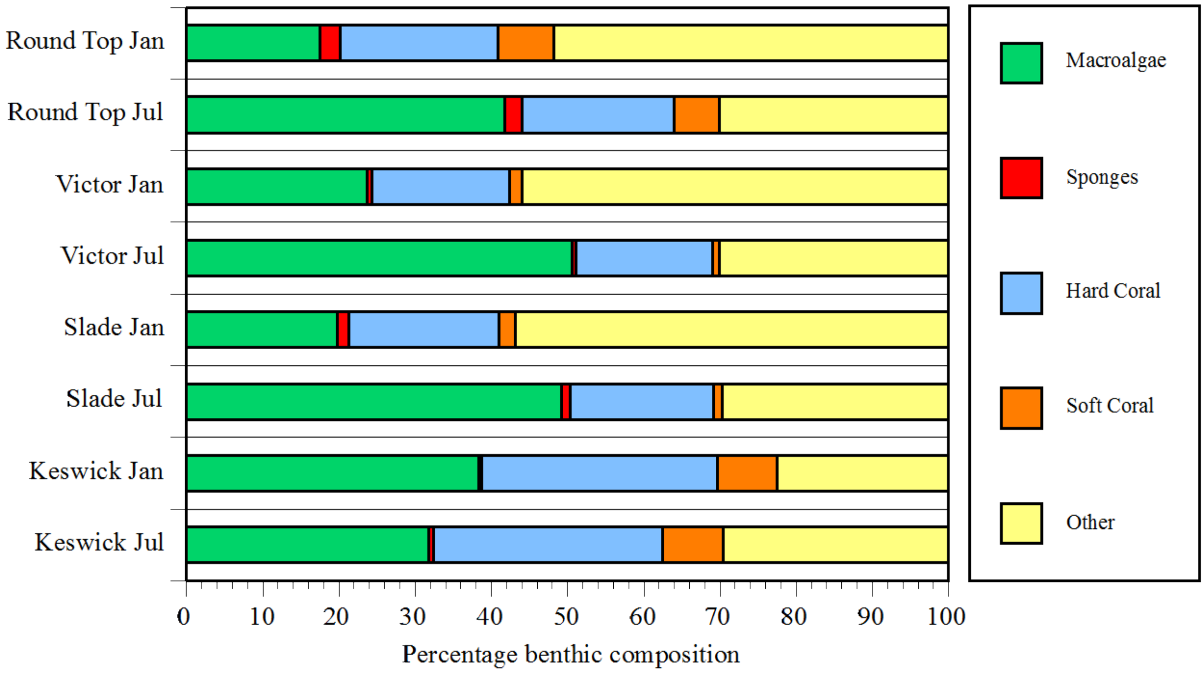


Figure 10. Changes in benthic composition in the four locations between January and July 2018. Plot shows mean percentage benthic composition from the latest ambient survey at each location. Benthic category 'Other' = sand + bare reef + crustose corallines + algal turf.

Sponges were not common in any of these locations (Figure 10) but were most abundant on Round Top Island where the cover of this benthic group was 2.3% during the July 2018 ambient survey. (Table 6). The most abundant sponge was *Turpios* sp. that takes over living coral.

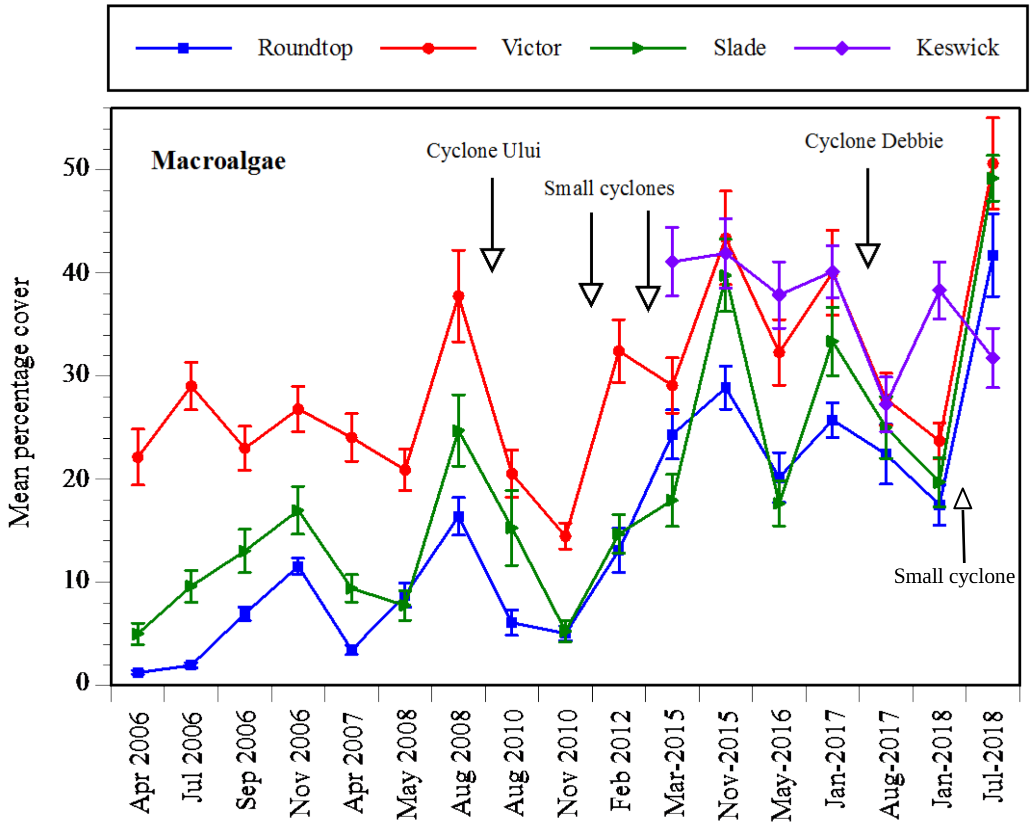


Figure 11. Changes in percentage cover of macroalgae.
Graphs show grand mean percentage algal cover from the 2018 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors.

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

Family/Group	August 2017		Jan 2018		July 2018	
	mean	***sd***	**mean**	***sd***	**mean**	***sd***
ROUND TOP						
Total algae	22.4	*14.2*	17.5	*9.6*	41.7	*19.6*
Total sponges	2.5	*2.4*	2.6	*2.5*	2.3	*2.4*
Total hard corals	19.7	*13.9*	20.7	*14.7*	19.9	*13.7*
Acropora spp.	0.6	*1.9*	0.6	*1.7*	0.5	*1.5*
Montipora spp.	3.5	*6.1*	4.0	*7.5*	3.9	*6.3*
Pocilloporidae	0.1	*0.3*	0.2	*0.5*	0.2	*0.4*
Siderasteridae	3.6	*3.2*	3.2	*3.2*	3.1	*2.9*
Turbinaria spp.	7.4	*6.8*	7.7	*6.9*	7.2	*6.8*
Faviidae	2.4	*1.5*	2.4	*1.8*	2.6	*2.4*
Poritidae	1.6	*2.1*	2.0	*2.5*	1.8	*2.5*
Total soft corals	6.0	*6.2*	7.3	*7.2*	5.9	*5.7*
VICTOR						
Total algae	27.8	*12.4*	23.7	*8.5*	50.6	*21.7*

Total sponges	0.4	*0.8*	0.6	*0.9*	0.4	*0.7*
Total hard corals	18.3	*18.2*	18.0	*18.9*	17.9	*20.5*
Acropora spp.	0.8	*2.2*	1.0	*2.5*	0.9	*2.2*
Montipora spp.	7.4	*14.5*	8.2	*15.9*	8.3	*17.3*
Pocilloporidae	1.0	*3.1*	0.4	*1.9*	0.4	*1.7*
Siderasteridae	1.7	*2.6*	1.9	*2.7*	1.7	*2.5*
Turbinaria spp.	2.9	*3.9*	2.5	*3.7*	2.8	*4.1*
Faviidae	2.7	*2.5*	2.4	*2.6*	2.3	*2.7*
Poritidae	1.2	*3.5*	1.1	*3.2*	1.2	*3.2*
Total soft corals	1.0	*1.5*	1.7	*1.9*	0.9	*1.6*
SLADE						
Total algae	25.0	*14.6*	19.7	*11.7*	49.2	*10.9*
Total sponges	1.2	*1.5*	1.6	*1.7*	1.1	*1.7*
Total hard corals	18.5	*12.0*	19.7	*13.6*	18.9	*12.9*
Acropora spp.	1.2	*2.0*	1.1	*1.9*	1.1	*1.9*
Montipora spp.	9.6	*9.6*	10.4	*11.2*	10.5	*10.7*
Pocilloporidae	0.7	*1.9*	0.8	*2.2*	0.7	*1.9*
Siderasteridae	2.0	*2.4*	2.1	*2.3*	1.7	*2.0*
Turbinaria spp.	1.5	*2.0*	1.3	*1.5*	1.1	*1.2*
Faviidae	1.3	*1.7*	1.6	*2.0*	1.5	*1.9*
Poritidae	1.7	*2.3*	1.8	*2.6*	1.8	*2.6*
Total soft corals	1.3	*1.6*	2.1	*2.7*	1.1	*1.3*
KESWICK						
Total algae	27.3	*13.0*	38.3	*13.6*	31.8	*14.0*
Total sponges	0.5	*0.6*	0.4	*0.7*	0.6	*0.9*
Total hard corals	31.3	*13.8*	30.9	*13.2*	30.1	*12.5*
Acropora spp.	12.1	*17.8*	12.4	*17.7*	11.4	*16.1*
Montipora spp.	6.2	*7.5*	6.5	*8.3*	6.4	*8.1*
Pocillopridae	1.0	*1.2*	0.8	*1.3*	0.7	*1.1*
Siderasteridae	0.2	*0.4*	0.1	*0.3*	0.5	*0.8*
Turbinaria spp.	0.5	*1.1*	0.5	*1.1*	0.4	*0.9*
Faviidae	2.3	*1.6*	2.2	*1.5*	2.4	*1.6*
Poritidae	5.0	*5.5*	4.6	*6.1*	4.3	*5.3*
Total soft corals	7.5	*6.4*	7.8	*6.2*	8.0	*6.8*

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 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	***	***	NS	NS	***
Acropora spp.	***	***	NS	NS	***
Montipora spp.	***	***	***	NS	***
Pocilloporidae	NS	***	NS	**	**
Siderasteridae	***	***	NS	*	NS
Turbinaria spp.	***	***	NS	NS	**
Faviidae	*	***	NS	NS	NS
Poritidae	***	***	NS	NS	NS
Total soft corals	***	***	***	NS	*

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

Table 8. Benthic changes between all seventeen 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	**	***	NS	***
Turbinaria spp.	***	***	***	***	***
Faviidae	*	***	***	**	NS
Poritidae	NS	**	**	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 2018 ambient surveys (Table 7, Figure 12). Mean coral cover during these surveys was between 18% and 20% on Round Top, Victor and Slade and around 30% on Keswick. Hard coral cover did not change significantly since Cyclone Debbie in any of the four locations (Table 7, Figure 12) and the Time x Location interaction was also not significant for total hard coral cover.

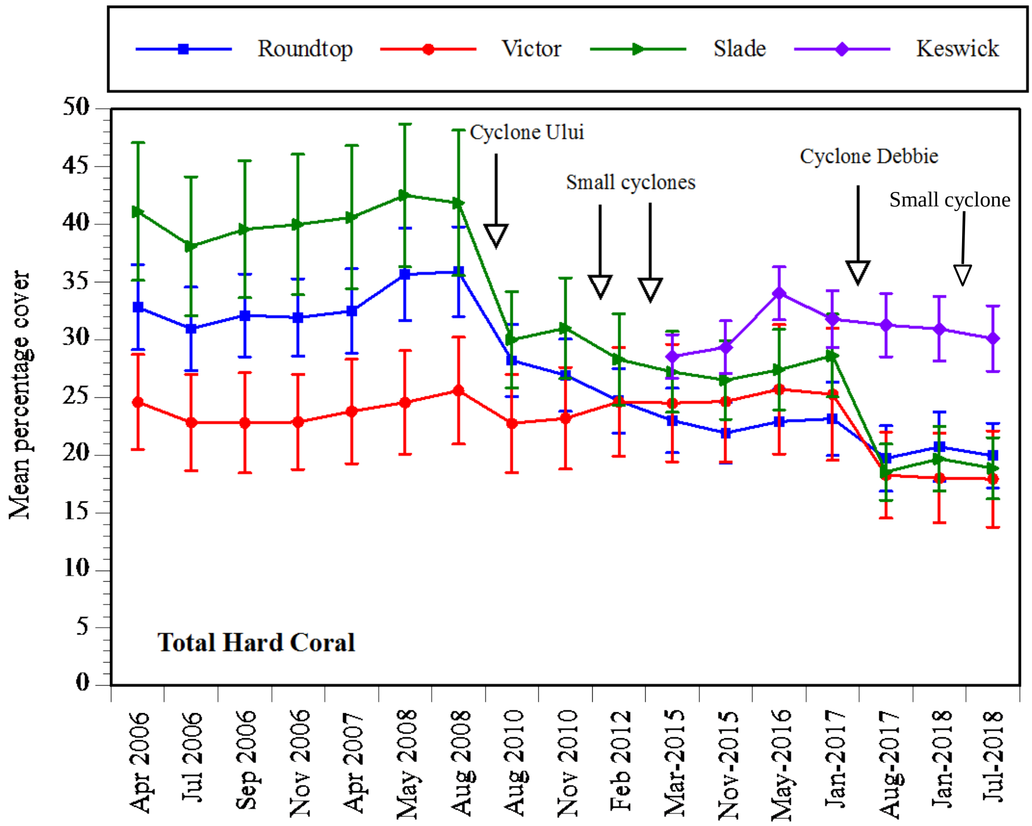


Figure 12. Changes in the cover of total hard coral.
Graphs show grand mean percentage benthic cover from the 2018 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors.

Hard coral community composition was different in each location (Figure 13). During the 2018 surveys coral communities at Round Top Island were dominated by *Turbinaria* spp. (36% of total coral cover) with siderasterids, *Montipora* spp., faviids and poritids also common. Victor Islet reefs were dominated by *Montipora* spp. corals (46% of coral cover), with *Turbinaria* spp., faviids and siderasterids also common. On Slade Islet spreading *Montipora* spp. corals accounted for 56% of all hard coral cover, with siderasterids and poritids also common. Keswick Island coral communities were dominated by *Acropora* spp. corals (38% 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.

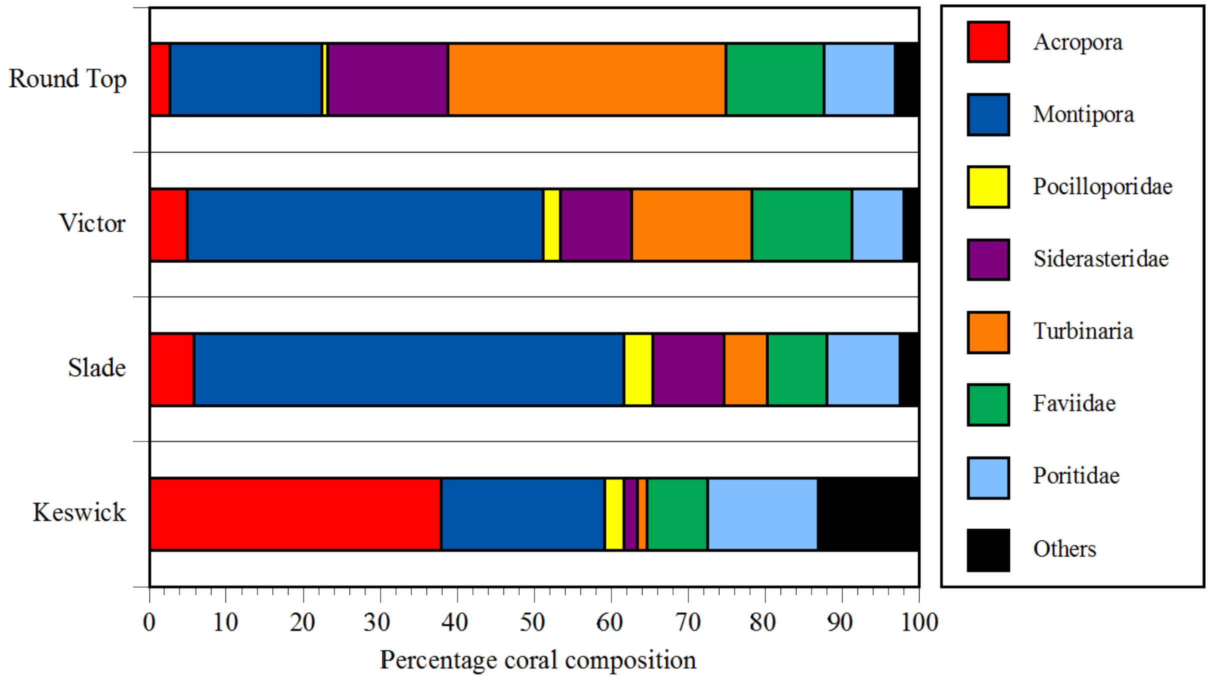
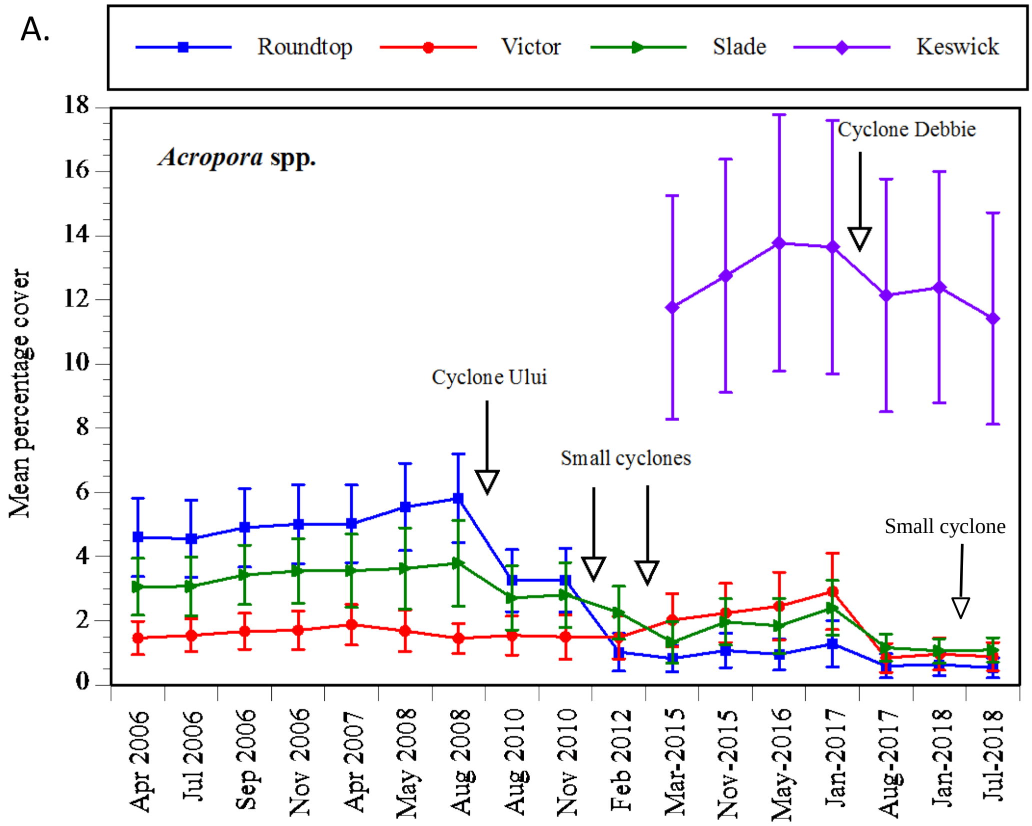


Figure 13. Coral community composition at the four locations for the last ambient survey. Graphs show mean percentage composition of the major coral groups from the four locations. Composition is shown for the latest, July 2018 survey.

All but the pocilloporid coral group showed significant location differences during the two 2018 ambient surveys (Table 7). *Acropora* corals were significantly more abundant on Keswick than in the three inshore locations (Figure 14A). *Montipora* was highest on Slade and lowest on Round Top (Figure 14B). 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 15). 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 16). Over the eleven months spanned by the last three ambient surveys significant changes in cover were only recorded for *Montipora* spp. corals (Figure 14B). Although *Montipora* corals increased slightly in cover on the three inshore locations 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*) decreased nominally at all three inshore locations since Cyclone Debbie, possibly due to disease, but the decrease was significantly larger on Round Top giving a significant Time x Location interaction.

A.



B.

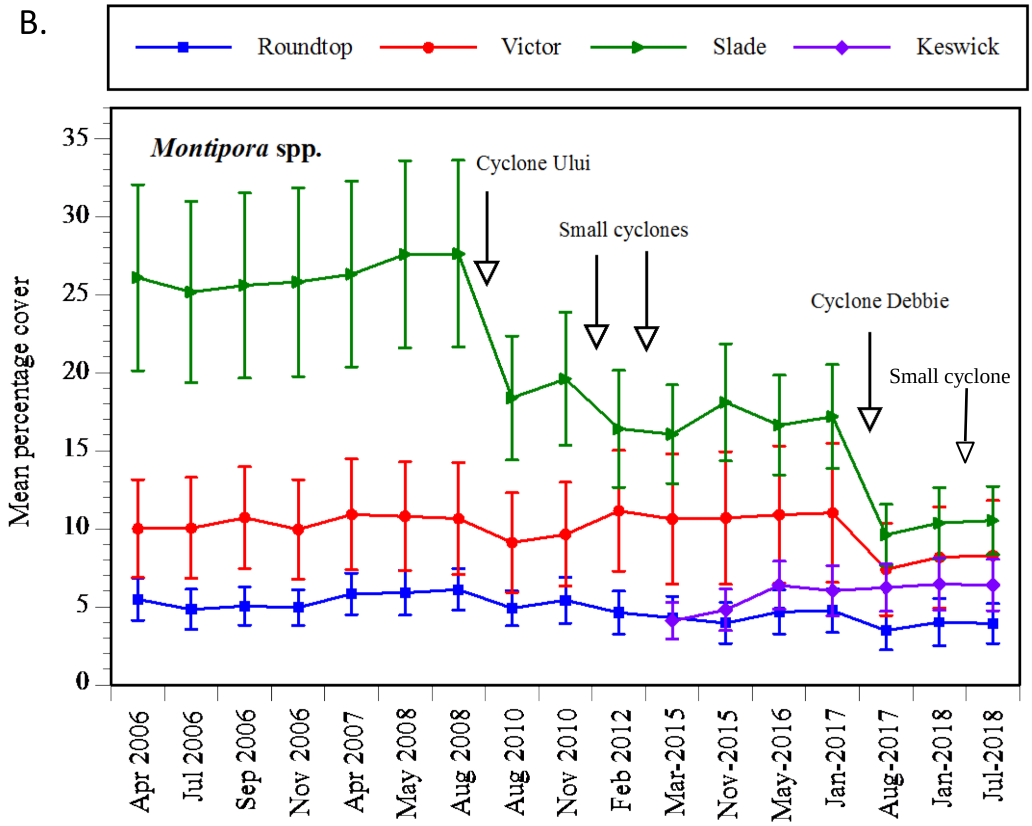


Figure 14. Changes in the cover of coral groups: *Acropora* corals and *Montipora* corals. Graphs show grand mean percentage benthic cover from the 2018 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors. Roundtop = Round Top Island.

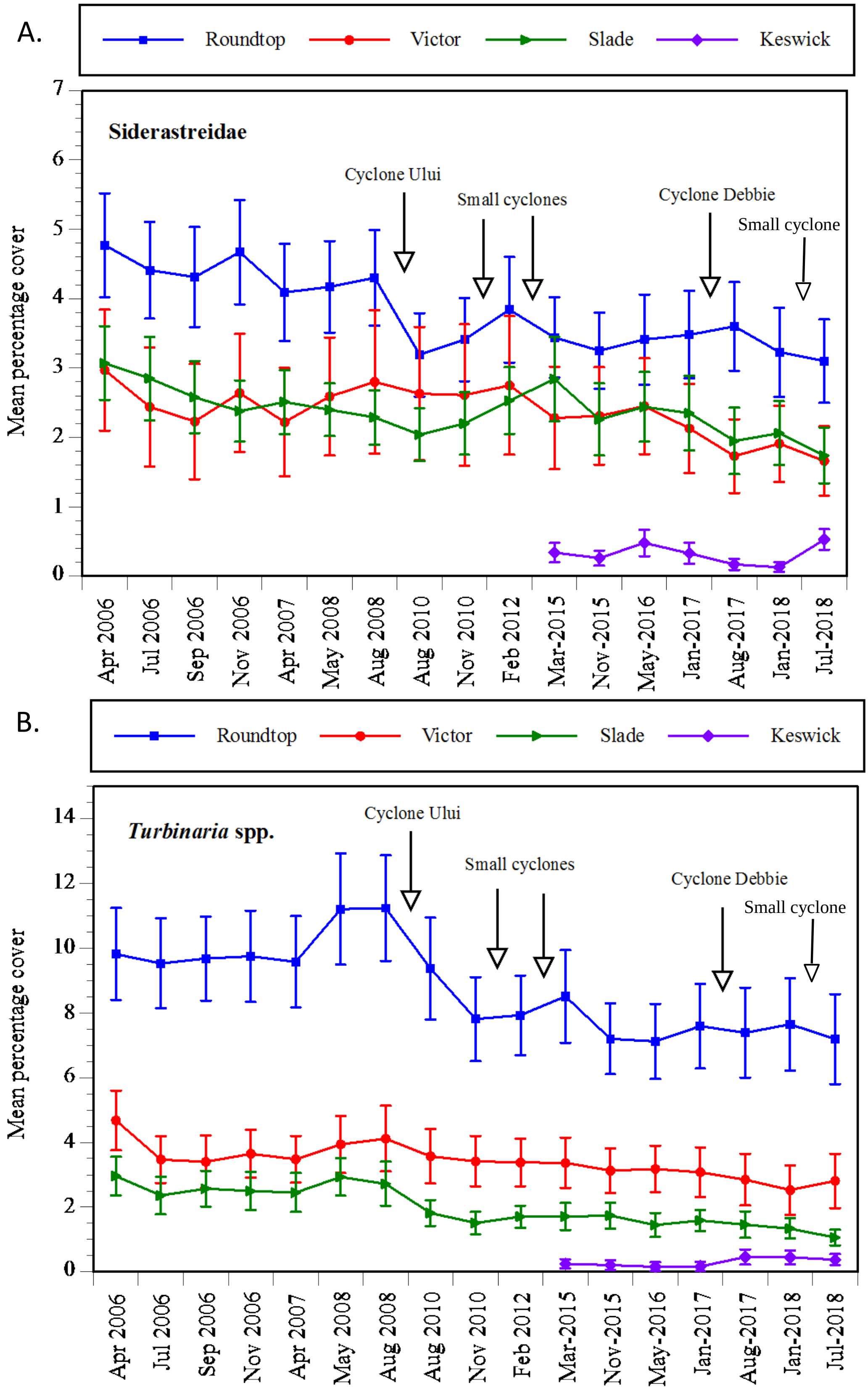
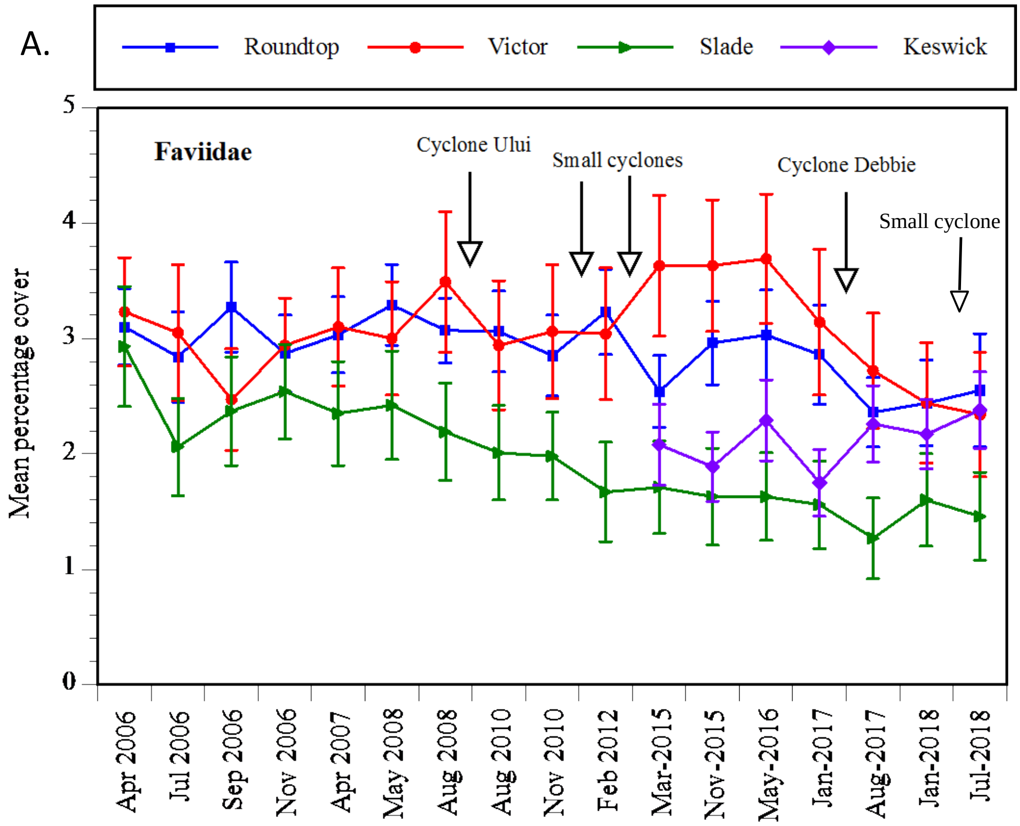


Figure 15. Changes in the cover of coral groups: *Siderastreid* corals and *Turbinaria* corals. Graphs show grand mean percentage benthic cover from the 2018 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors. Roundtop = Round Top Island.



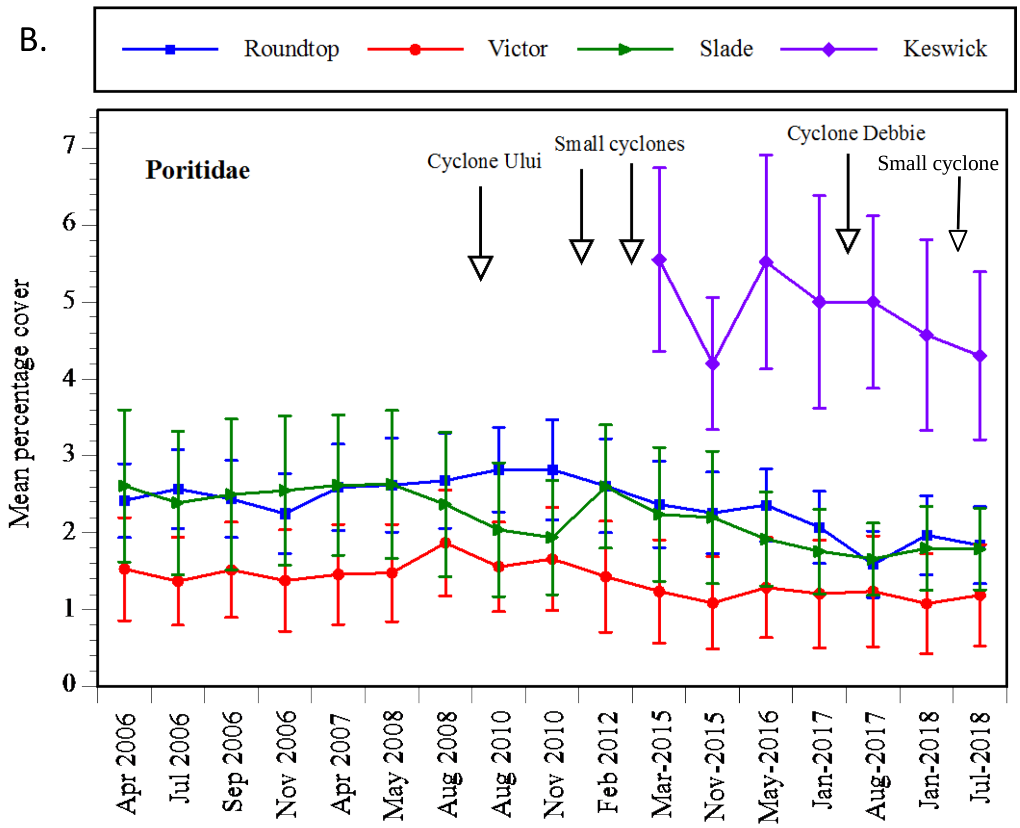


Figure 16. Changes in the cover of coral groups: *Faviid* corals and *Poritid* corals.
Graphs show grand mean percentage benthic cover from the 2018 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors. Roundtop = Round Top Island.

Soft corals were significantly more abundant on Round Top Island and Keswick Island during the 2018 ambient surveys, where this group covered a mean of around 6-8% of the substratum, than in the other two locations (Table 6, Table 7, Figure 17). Soft coral cover increased at all locations between August 2017 and Jan 2018 but had decreased again by the time of the latest survey and these fluctuations were significant.

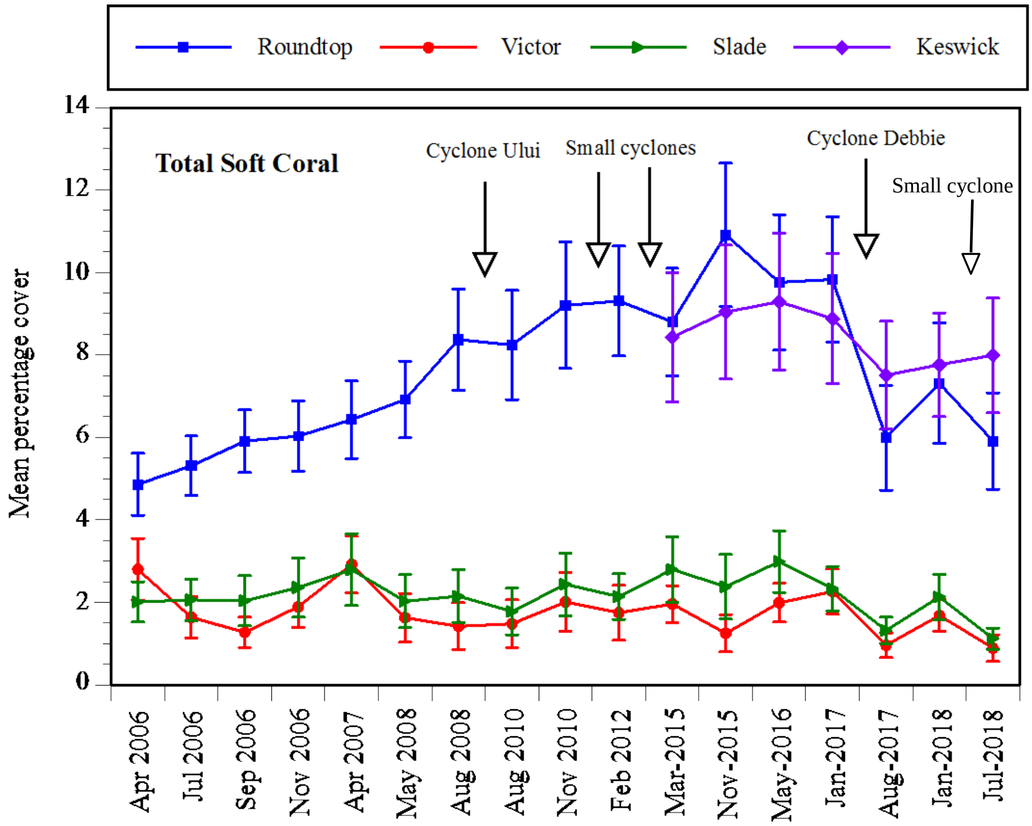


Figure 17. Changes in the cover of total soft coral.
Graphs show grand mean percentage benthic cover from the 2018 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at six sites for each location). Error bars are standard errors. Roundtop = Round Top Island.

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

Seventeen surveys spanning more than twelve 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 11). 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 twelve years, especially on Round Top Island and Slade Islet. Since the 2006 baseline algal cover increased from about 1% to 42% on Round Top, 5% to 49% on Slade and 22% to 51% 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%, very similar to the 32% recorded during the latest survey in July 2018. 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 twelve years at all three inshore locations (Table 8, Figure 12). 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 12), 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 12). 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 has not increased in the 18 months since Cyclone Debbie in these three locations and at between 18-20% is now a mean of 42% lower than it was during the 2006 baseline.

Mean coral cover on Keswick Island during the 2001 survey mentioned above (Ayling and Ayling 2002) was 32%, the same as the coral cover of 32% recorded during the July 2018 ambient survey seventeen years later.

There have been significant changes in the cover of all major coral groups over the past twelve 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 14A). 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. *Acropora* cover did not decline on Victor Islet and hence the Location x Time interaction was significant (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 0.8%, a quarter of the pre-Ului peak (Figure 14A). The cover of these fast-growing corals has not increased in the 18 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 14B). 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. During the most recent survey *Montipora* cover on Slade Islet was only a third of pre-Ului levels. The decline in *Montipora* cover on Slade was much higher than in the other inshore locations giving a strongly significant Location x Time interaction for *Montipora* cover changes (Table 8).This change is likely due to both site aspect and species composition. Three of the northeast oriented sites at Slade Islet are dominated by *Montipora* spp. (77% of total coral cover) and were also the sites most exposed to the TC Debbie winds. As for *Acropora*, the cover of these fast-growing corals has not increased in the 18 months since Cyclone Debbie.

There were significant fluctuations in the cover of siderasterid corals caused by disease episodes and the two major cyclone events but these patterns were similar in all three locations and the time x location interaction was not significant (Figure 15A, Table 8). *Turbinaria* corals in the family Dendrophylliidae were the dominant benthic group on Round Top Island where they covered about 7% of the substratum during the most recent surveys (Figure 15B). 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 twelve years spanned by these surveys (Table 8, Figure 16A). 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 twelve years of these surveys (Table 8, Figure 16B).

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 17). Soft coral cover has fluctuated since Cyclone Debbie but has not increased significantly.

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). Very few soft corals were bleached during the March 2015 or August 2017 hard coral bleaching peaks whereas around 50% of soft coral colonies on Round Top showed partial bleaching in April 2006 (GHD 2006).

During the 2018 ambient surveys coral bleaching levels were very low at all four locations (Table 9). The number of coral colonies partially bleached reduced significantly on the inshore locations over the past three ambient surveys (Table 10). No partially bleached corals were recorded during the latest ambient survey in July 2018 (Table 9).

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

Location	Aug 2017	Jan 2018	Jul 2018
ROUND TOP			
Mean total coral colonies per 40 sq m	95	ns	ns
Healthy coral colonies (%)	92.3%	98.9%	99.3%
Partially bleached colonies (%)	2.2%	0.5%	0.0%
Disease damaged colonies (%)	0.1%	0.2%	0.3%
Sediment damaged colonies (%)	5.4%	0.4%	0.4%
VICTOR			
Mean total coral colonies per 40 sq m	98	ns	ns
Healthy coral colonies (%)	91.9%	98.3%	98.4%
Partially bleached colonies (%)	1.7%	0.1%	0.0%
Disease damaged colonies (%)	0.7%	0.4%	0.2%
Sediment damaged colonies (%)	5.7%	1.2%	1.4%
SLADE			
Mean total coral colonies per 40 sq m	88	ns	ns
Healthy coral colonies (%)	96.3%	97.9%	99.7%
Partially bleached colonies (%)	0.8%	0.0%	0.0%
Disease damaged colonies (%)	0.2%	0.5%	0.2%
Sediment damaged colonies (%)	2.7%	1.6%	0.1%
KESWICK			

Location	Aug 2017	Jan 2018	Jul 2018
Mean total coral colonies per 40 sq m	82	ns	ns
Healthy coral colonies (%)	96.0%	95.6%	97.4%
Partially bleached colonies (%)	0.3%	1.0%	0.0%
Disease damaged colonies (%)	1.6%	0.7%	0.9%
Sediment damaged colonies (%)	2.1%	2.7%	1.7%

Healthy and damaged corals are recorded as a percentage of the total number of colonies; ns=not surveyed.

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	***	***	***	***	***
Coral disease changes	***	***	NS	**	***
Sediment damage changes	***	***	***	***	***

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

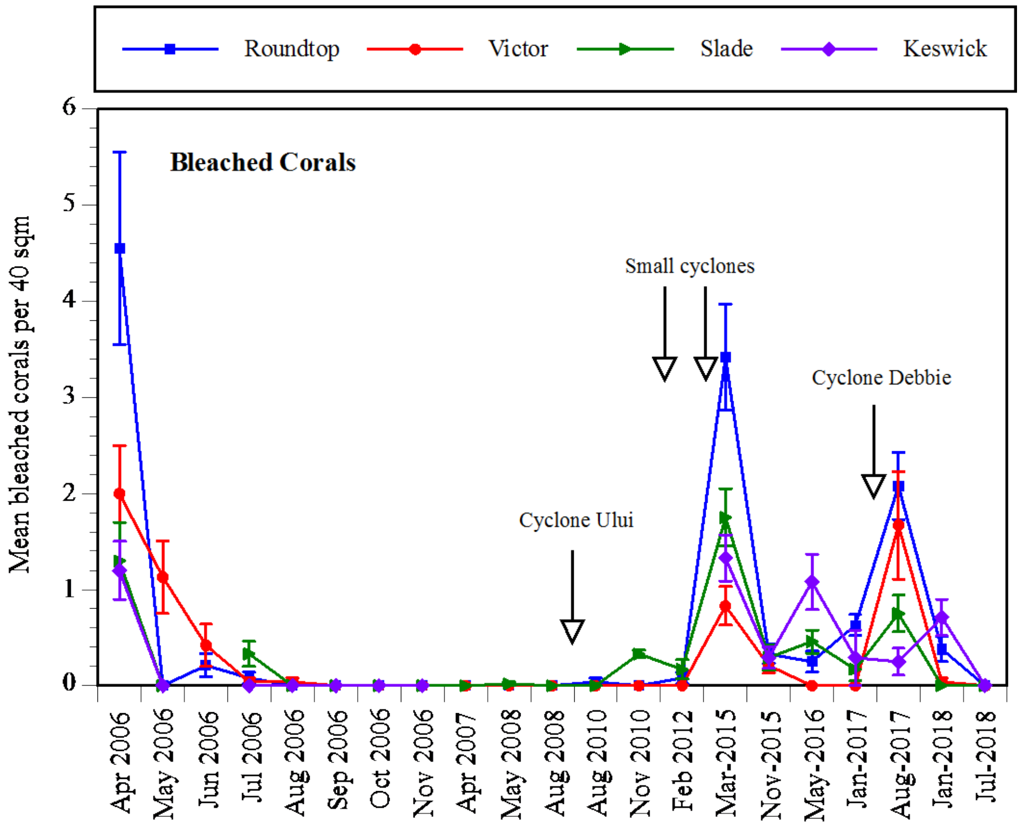


Figure 18. Changes in Density of Bleached and Partially Bleached Hard Coral Colonies. Graphs show grand mean density of bleached and partially bleached corals per 40sq m from six sites of four 20 x 2m transects in each location from the 2018 ambient surveys and all previous surveys. Error bars are standard 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 but no port related activities of this sort occurred during the 2017/18 period and with no dredging activities at the Port of Hay Point since 2011 and at Port of Mackay since 2013. During the 2018 ambient surveys a grand mean of only 11% of coral colonies had recordable sediment on at least part of their surface (Table 11). The percentage of colonies with surface sediment during these ambient surveys was higher on Victor Islet and Keswick Island than on Slade Islet or Round Top Island. Mean depth of these patches of sediment on living coral colonies showed a similar pattern (Table 11, Table 12). Coral sediment depth decreased markedly on Victor Islet and Round Top Island between August 2017 and Jan 2018 and remained low in July 2018 but did not decrease on Keswick Island and hence 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 (Figure 19). 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 19A). 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 19B). 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 19B). During the 2018 surveys both the number of corals with sediment and sediment depth were at very low levels.

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								
Aug 2017	36.3%		30.4%		13.8%		12.1%	
Jan 2018	9.0%		13.3%		8.5%		12.5%	
Jul 2018	6.9%		13.8%		6.3%		17.3%	
MEAN MAXIMUM SEDIMENT DEPTH (mm)								
Aug 2017	0.56	*1.61*	0.44	*1.22*	0.12	*0.37*	0.16	*0.78*
Jan 2018	0.08	*0.36*	0.11	*0.44*	0.05	*0.19*	0.13	*0.48*
Jul 2018	0.08	*0.47*	0.13	*0.54*	0.03	*0.13*	0.24	*0.96*

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

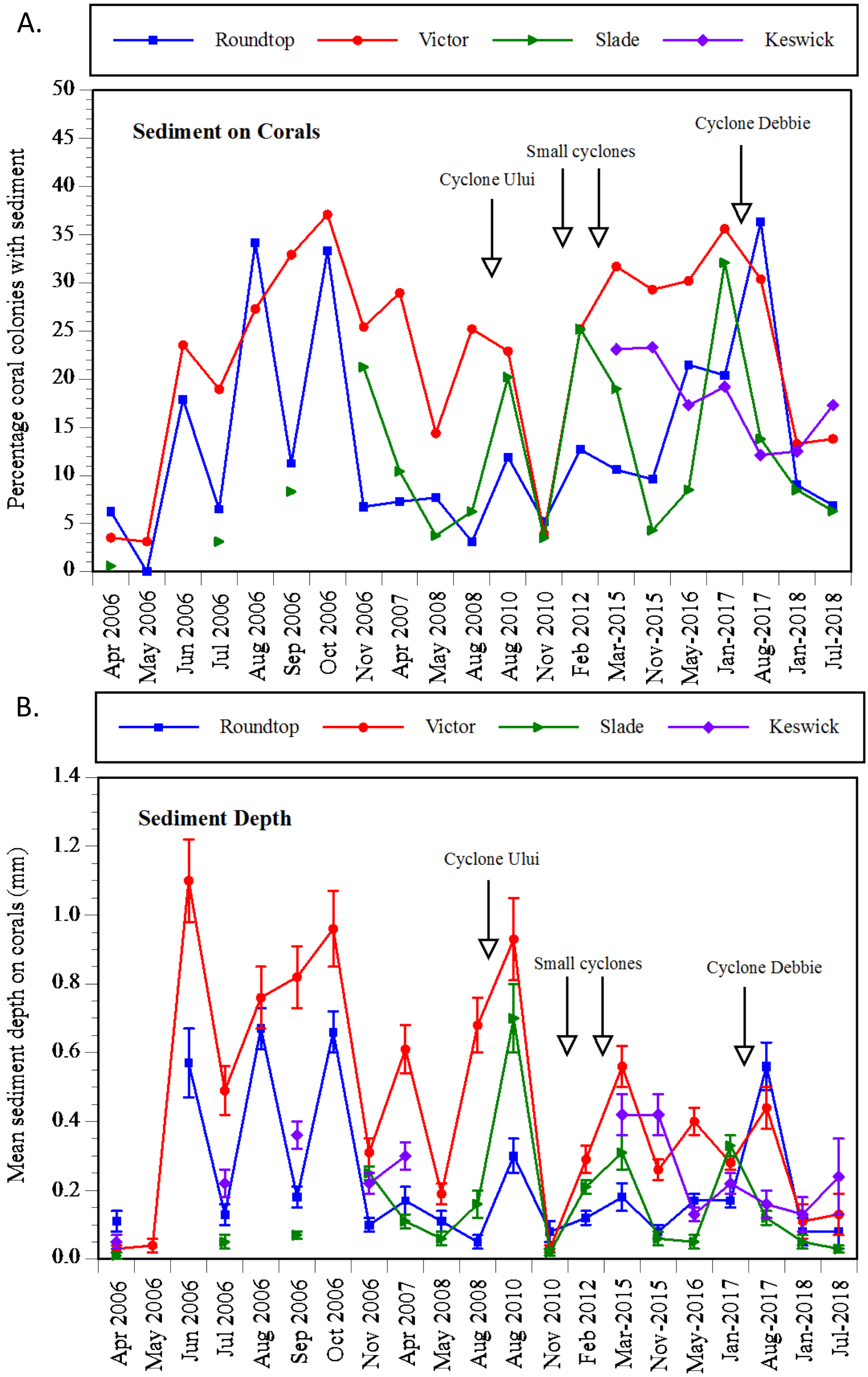


Figure 19. Changes in Number of Corals with Sediment Load and Sediment Depth.
Graphs show percentage of the 480 coral colonies examined in each location that had measurable sediment on part of the surface during each survey and the mean depth in mm of that sediment for the 2018 ambient surveys and for all previous surveys. Error bars where appropriate are standard errors. Roundtop = Round Top Island.

3.6 Sediment Damage and Disease in Coral Colonies

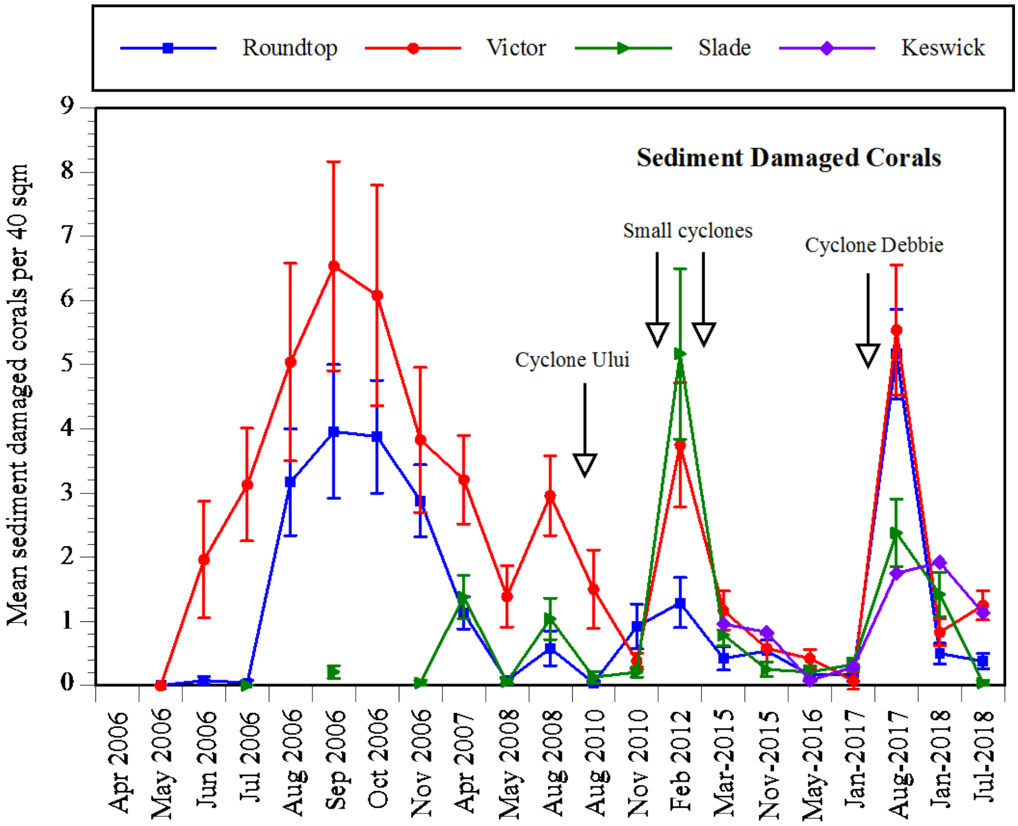
Heavy sediment deposition on living coral can cause patches of mortality on the coral surface. Numbers of sediment damaged corals have reduced significantly since the Cyclone Debbie event. This drop in sediment induced mortality was significantly higher on Round Top and Victor than in the other two locations and the Location x Time interaction was significant (Table 10, Figure 20).

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 20A). There was another much smaller peak in damage levels during the 2008 bed-levelling event. 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 20A). 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 twelve years but this was ended by sediment resuspension during Cyclone Debbie with damage at all locations and unprecedented damage at Round Top Island (Figure 20A). Sediment damage levels were relatively low during the 2018 ambient 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 below average during the 2018 ambient surveys with a grand mean of about 0.5% of corals affected (Table 9). There were significantly more diseased corals in the Keswick location than in the other three locations during the 2018 ambient surveys (Table 10). Changes in disease levels over the last three ambient surveys were different in all locations and the Location x Time interaction was also significant (Table 10).

There were significant fluctuations in the density of diseased corals over the twelve years spanned by the surveys reported here, with order of magnitude changes at each location (Figure 20B). Disease affected corals were present at all four locations and there were no overall trends in abundance at any location (Figure 20B). Small colonies sometimes died completely when affected by disease but usually disease only caused partial colony mortality.

A.



B.

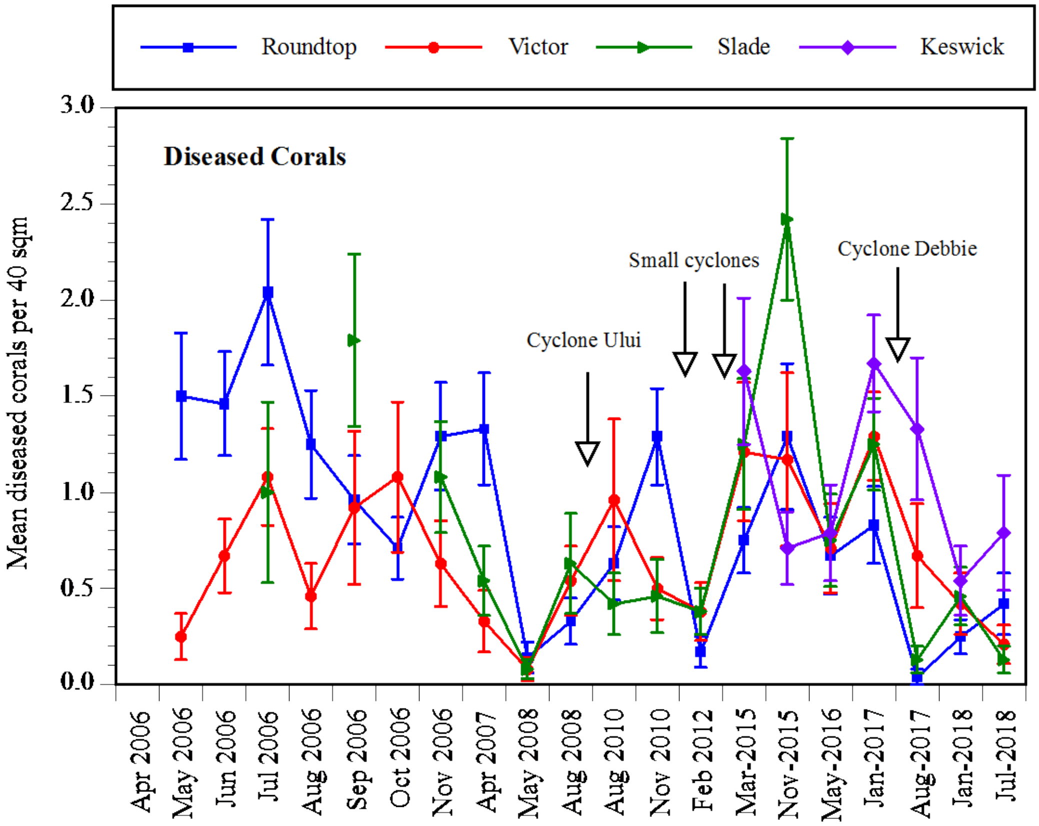


Figure 20. Changes in density of sediment damaged and diseased coral colonies.
Graphs show grand mean density of diseased coral colonies and sediment damaged corals per 40sq m from six sites of four 20 x 2m transects in each location from the 2018 ambient surveys and all previous surveys. Error bars are standard errors. Roundtop = Round Top Island.

3.7 Coral Demography Patterns

Numbers of hard coral recruits less than 10 cm in diameter reduced on these reefs during the 2018 ambient surveys, from a grand mean over all locations of about 1.1 per square metre to 0.6 per square metre (Figure 21). This is on the low side of means ranging from 0.7 to 1.8 per sq m from surveys of other 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 21). 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.

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 66% and 77% of total coral recruits in these locations (Figure 22). Faviids also recruited well on these inshore locations. The recruit population on the offshore Keswick Island was different, with faviids accounting for over 36% of recruits and Acropora (13%) 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 36% 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

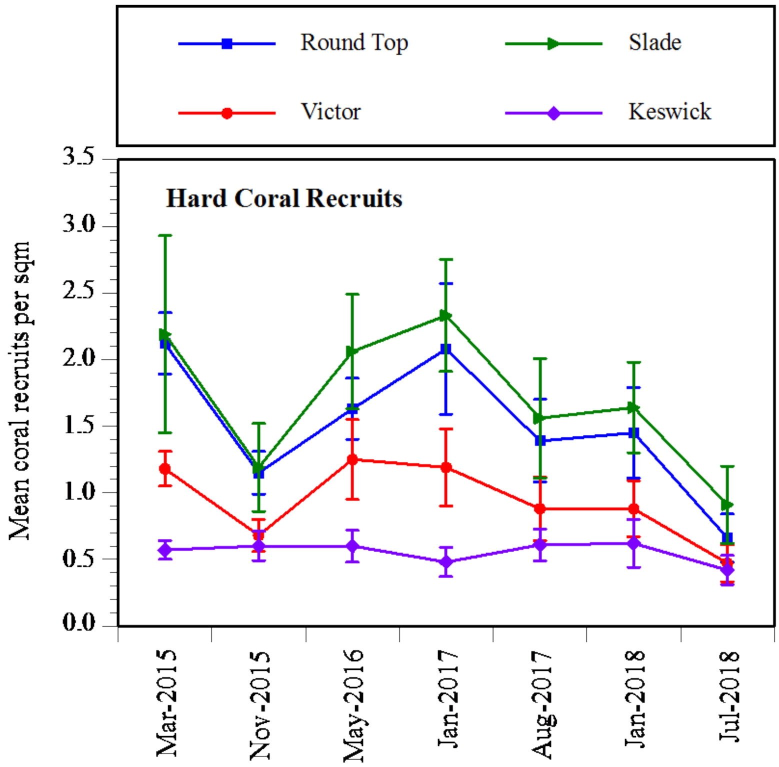


Figure 21. Changes in density of hard coral recruits over the ambient surveys. Graphs show mean density of hard coral recruits per m^{-2} from six sites in each location for the past seven ambient surveys. Error bars are standard errors.

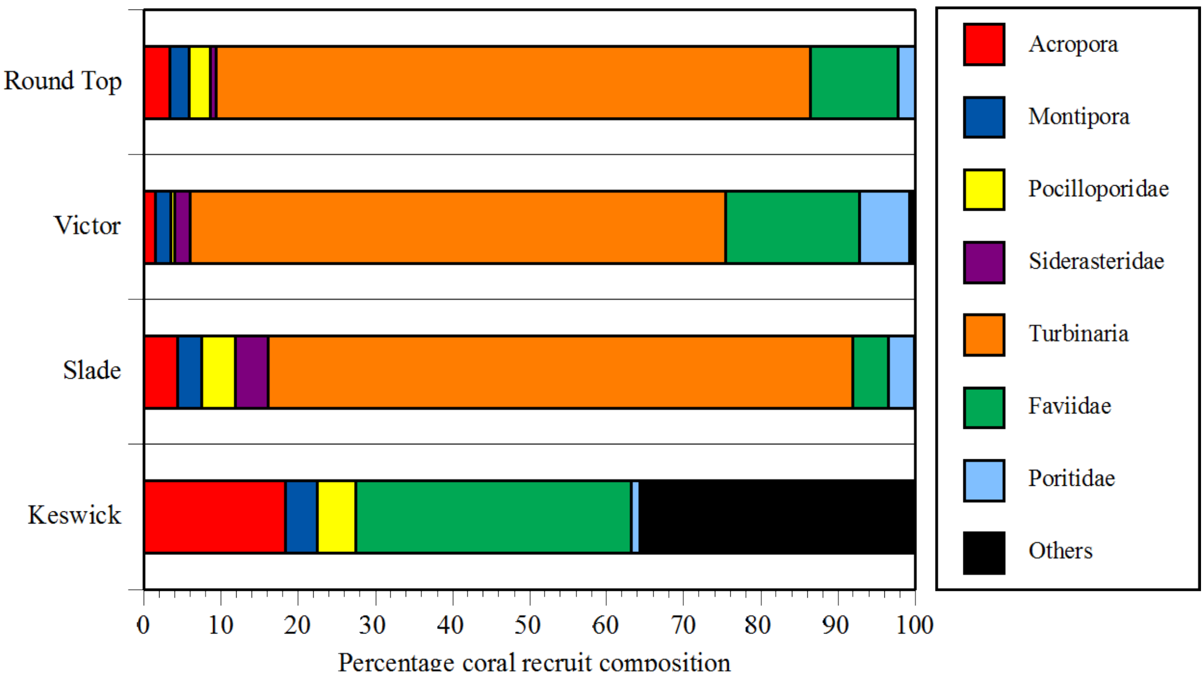


Figure 22. Composition of the hard coral recruit population in the four locations over the ambient surveys. Graphs show mean percentage composition of the major groups of coral recruits from the four locations. Composition is averaged across both 2018 ambient surveys.

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. *Turbinaria* spp. corals were dominant at Round Top Island (Site 5), along with *Psammocora* (centre right) and dense growth of macroalgae.

Figure 24. Disease causing mortality of a *Turbinaria* colony on Round Top Island (Site 3) during January 2018.

Figure 25. Algae, including *Sargassum*, had increased markedly on Round Top Island over the past six months from 18% to over 40% (Site 2).

Figure 26. The *Acropora* thickets at Round Top Site 1 were badly damaged by Cyclone Debbie but had started to recover by January 2018.

Figure 27. Healthy corals on Victor (Site 2), including *Turbinaria* (right), *Favia* (lower right), *Goniopora* (centre left), *Platygyra* (brown colony on left) and *Psammocora* (top).

Figure 28. A variety of hard corals, including *Pocillopora* (left), *Turbinaria* (centre left and right) and *Psammocora* (bottom), surrounded by algae at Victor Islet Site 2 in July 2018.

Figure 29. Thick patch of sediment causing partial mortality of a *Montipora* colony at Victor Islet (Site 2) in July 2018.

Figure 30. Active disease patch on a large *Montipora* colony at Victor Site 2 during the July 2018 survey.

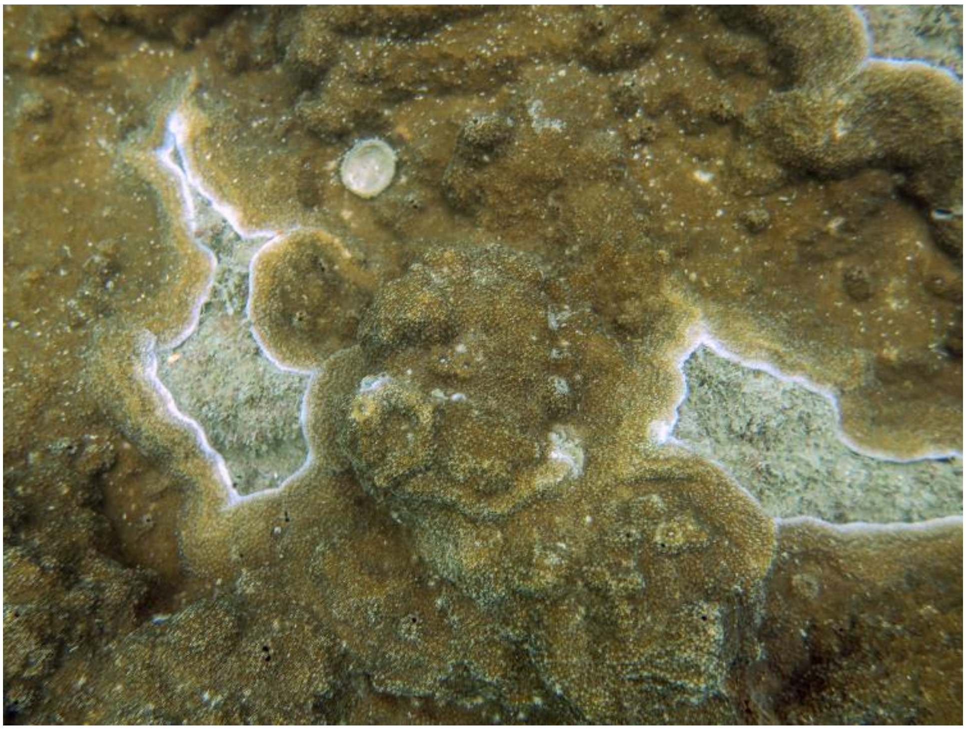


Figure 31. A *Montipora* colony actively growing over dead patches caused either by disease or sediment accumulation. Victor Islet: Site 2 January 2018.

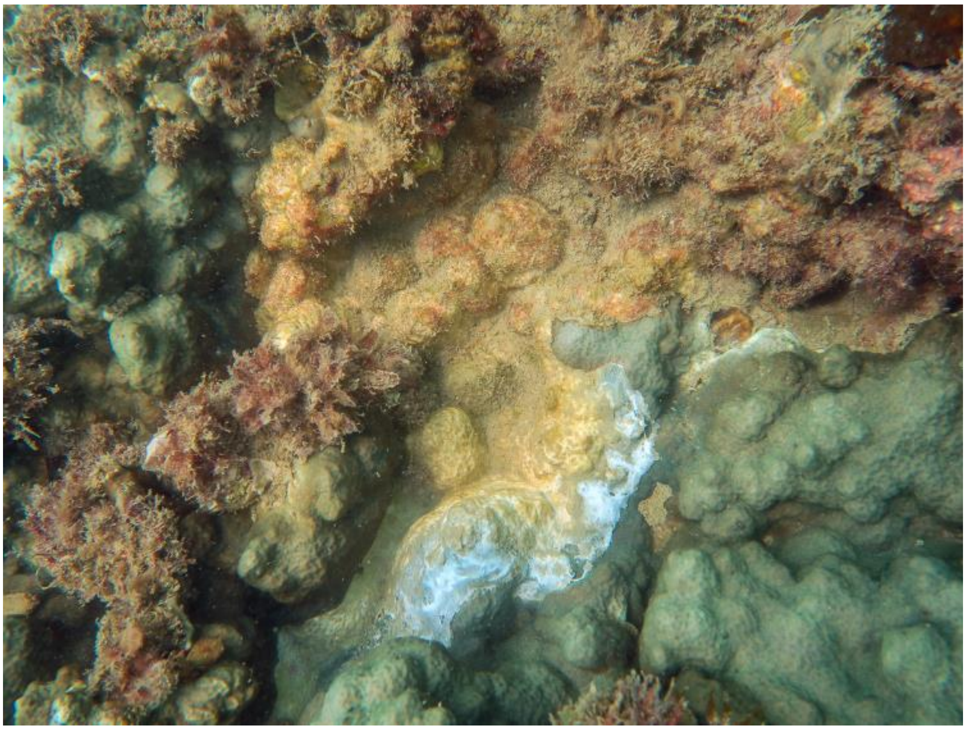


Figure 32. An active patch of disease on a *Psammocora* colony on Victor Islet (Site 2) in January 2018.

Figure 33. Healthy corals: *Montipora* (left) and *Pocillopora* (right) surrounded by algae on Slade Islet (Site 2) in July 2018.

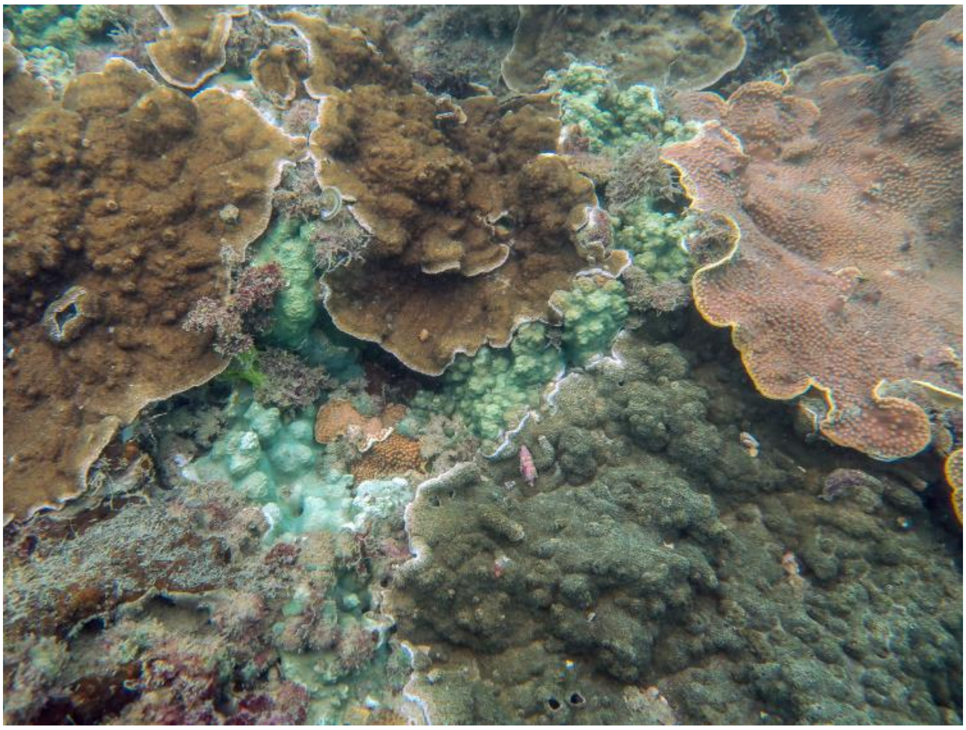


Figure 34. Explanate *Montipora* corals (left, lower right and centre), along with *Turbinaria* (upper right) and *Psammocora* (greenish) at Slade Islet site 5 in July 2018.

Figure 35. Dense, high growth of *Sargassum* algae on Slade Islet (Site 5) in July 2018. Algal cover had increased from 20% to 50% during 2018 in this location.

Figure 36. Large *Porites* colony on Slade Islet Site 6 surrounded by new, dense algal growth in July 2018.

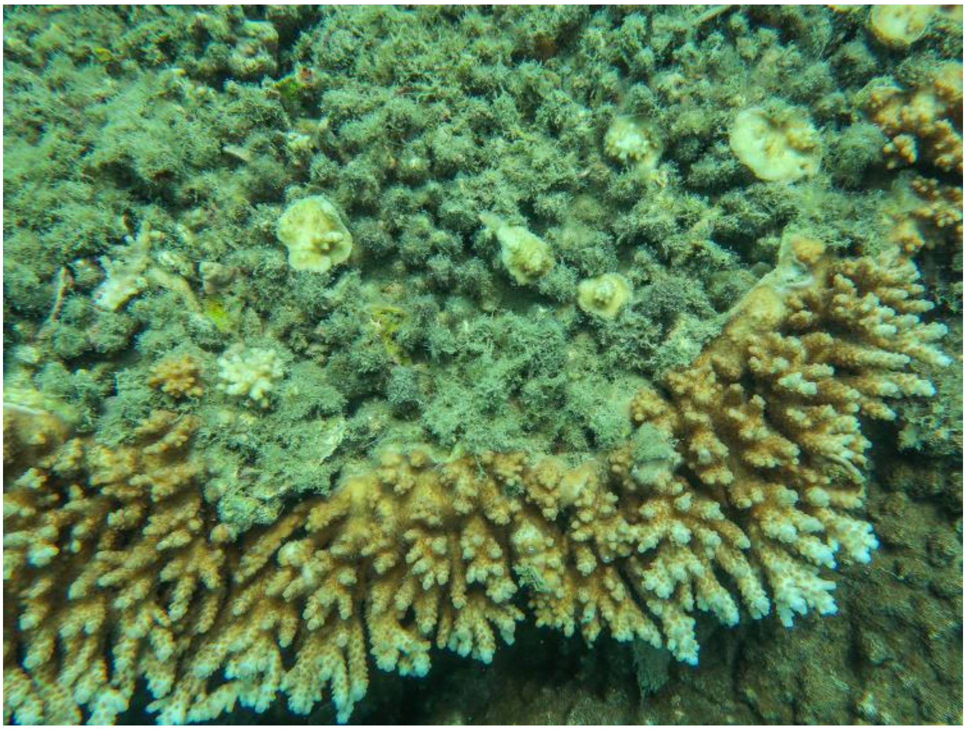


Figure 37. Recovery of an *Acropora* coral colony following disease induced mortality on Slade Islet (Site 4) in July 2018.

Figure 38. A cluster of newly recruited *Turbinaria* corals on Slade Islet (Site 5) in January 2018.

Figure 39. A variety of healthy hard and soft corals at Site 5 on Keswick Island in January 2018.

Figure 40. *Acropora* staghorn corals dominated the benthic community in Homestead Bay, on St Bees Island immediately adjacent to Keswick Island (Site 4) in July 2018.

Figure 41. *Sargassum* and *Lobophora* algae on Keswick Island Site 5 during July 2018. Algal cover on Keswick has not increased markedly following Cyclone Debbie.

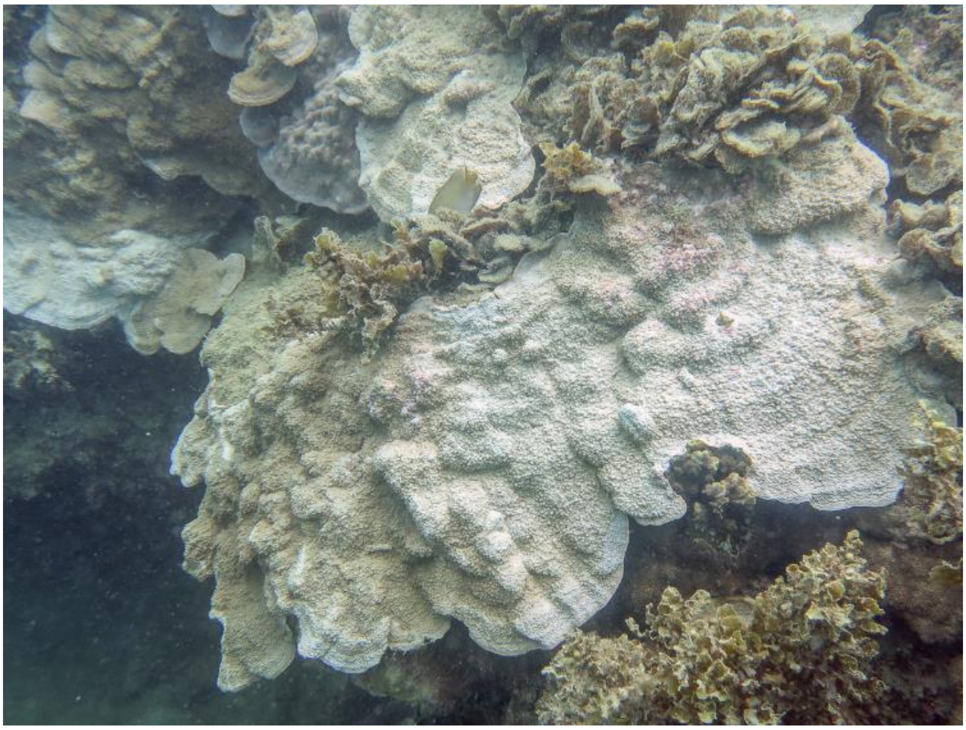


Figure 42. Partial bleaching of a *Montipora* colony on Keswick Island Site 6 during the January 2018 survey. Around 1% of corals were bleached on Keswick at this time.

Figure 43. Sediment deposition on a massive *Porites* colony on Keswick Island (Site 5) during the January 2018 survey. Although patches of mortality may occur beneath this sediment most of the colony will survive.

Figure 44. Heavy sediment accumulation causing partial mortality on a *Goniopora* colony at Keswick Island Site 2 during the July 2018 survey.

4 DISCUSSION

4.1 Benthic Cover during the 2018 Ambient Surveys

The major change recorded during the 2017/2018 ambient surveys covered in this report was the increase in macroalgal cover between January and July 2018 on the three inshore locations. This increase in macroalgae is also well above macroalgae cover reported for the inshore coral reef Marine Monitoring Program (Thompson et al. 2018). Although algal cover reduced nominally at Keswick Island over this time there was a mean 2.4x increase in algal cover on the inshore locations, from 20% cover to over 47% cover. It is possible that this marked increase in algal cover was a delayed response to the TC Debbie release of free space and nutrient release from disturbed sediment. The slow recovery of hard and soft coral cover following the cyclone may have given macroalgae the opportunity to increase in cover. Higher than average sea surface temperatures together with substantial post-European nutrient and sediment loading from local catchments (Kroon et al. 2012) can drive shifts in community composition, particularly after major disturbance events such as cyclones. It will be interesting to see whether algal cover eventually reduces to more normal levels.

There has been no change in hard coral cover at any of the locations in the 18 months since Cyclone Debbie. 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 such 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).

Soft coral cover has also been slow to recover following Cyclone Debbie. Although there had been an increase in soft coral cover between August 2017 and January 2018 this had decreased again to immediate post-cyclone levels by the July 2018 survey. The *Sansibia* soft corals that have been responsible for the large increase in soft coral cover on Round Top Island since the 2006 baseline are relatively fast growing but they have further decreased in cover at this location over the past six months. This has possibly been a result of the huge increase in algal cover at this location over the same time period.

4.2 Long-Term Benthic Cover Changes

Algal cover on the inshore survey locations is presently far higher than at any other time during the past twelve 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. 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. Overall coral cover on these locations has dropped to almost half of the pre-Ului peak: from a grand mean of 35% down to 19%. As would be expected the more fragile coral groups *Acropora*, *Montipora* and *Turbinaria* were most impacted by these events. There has been no recovery of hard coral cover at any of these locations in the 18 months since Cyclone Debbie.

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 twelve years of monitoring. Such a direct hit could cause almost total destruction of shallow fringing reef coral communities (A.M. Ayling personal observations).

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 since Cyclone Debbie coincides with the lower macroalgae cover observed at this location.

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 has not recovered to any extent in the 18 months since Cyclone Debbie.

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

As has already been mentioned 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 2018 surveys and no bleached or partially bleached corals were recorded during the latest July 2018 survey. Coral bleaching has caused minimal coral mortality throughout the twelve years covered by surveys in this region.

4.4 Sedimentation and Coral Damage

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 caused significant damage to encrusting *Montipora* corals on the NE face of Slade Islet. During the post-dredging survey 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 actual sources of the sediment impacting these benthic communities are likely to be both local and regional and may include:

- Sediments from local and regional riverine inputs (Pioneer River, Plane Creek) into the nearshore environment every year during the wet season.
- Sediment remobilised during the daily tidal cycle (especially during spring tides) travelling up the coastline with the prevailing currents and winds from Broadsound in the south.
- Re-suspended sediments due to the macrotidal environment at Mackay.
- Potential remobilisation of sediments from the nearby existing spoil grounds.
- Mobilisation of sediments due to dredge or bed levelling operations.

Recent studies have identified 150,000,000t yr^{-1} of sediment is naturally resuspended through tides, wind and waves within Great Barrier Reef marine environment and a further 9,000,000t yr^{-1} of new sediment arrives annually from catchment systems (Teakle 2018). GBR-wide, port related resuspension from maintenance dredging is estimated at 0.4% of this at 600,000t yr^{-1} during years where such campaigns are required in order to maintain the operation of the shipping berths and channels. There have been no dredging activities at the Port of Hay Point since 2011 and at Port of Mackay since 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 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 2018 ambient surveys were in line with levels recorded over the twelve years spanned by the long term surveys. Less than 1% of hard corals were affected by disease on these locations at any one time and trends have been down or flat over this twelve year period. Diseased corals are often present on fringing reefs especially during the warmer summer months and rarely cause significant coral mortality (Ayling and Ayling 2005). There is no evidence that stress caused by past dredging operations has increased the susceptibility of corals in this region to disease outbreaks.

4.6 Implications of Coral Assessment

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 dredging operations over the past eleven 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 program in 2013. Slade Islet was the most impacted of the inshore locations by both major cyclone events. The Round Top Island sites were on average deeper than the other locations but cyclone damage was higher than any location except Slade Islet. The lack of any recovery of hard coral communities on these fringing reefs in the 18 months since Cyclone Debbie is a cause for concern.

5 REFERENCES

Advisian. 2016. Port of Mackay and Hay Point Ambient Coral Monitoring: March 2015 – May 2016. Prepared on behalf of Ports Corporation of Queensland.

Ayling, A. M. and Ayling, A. L. 1995. A preliminary survey of benthic communities on fringing reefs in the middle Cairns Section. Unpublished report submitted to the Great Barrier Reef Marine Park Authority.

Ayling, A. M. and Ayling, A. L. 2002. Long term monitoring program for marine benthos in the vicinity of Keswick Island development (Whitsunday Island Group): baseline survey, Unpublished report to the Great Barrier Reef Marine Park Authority. 18 pp.

Ayling, A. M. and Ayling, A. L. 2005. The Dynamics of Cairns and Central Section Fringing Reefs, Unpublished report to the Great Barrier Reef Marine Park Authority. 81

BOM. 2017. Daily rainfall measured at the Mackay Airport (Station number 033045).

GHD. 2006. Port of Hay Point Apron Areas and Departure Path Capital Dredging Environmental Management Plan. Prepared on behalf of Ports Corporation of Queensland.

Jonker, M. M., Johns, K. K. and Osborne, K. K. 2008. Australian Institute of Marine Science Standard Operational Procedure Number 10 - Surveys of benthic reef communities using underwater digital photography and counts of juvenile corals. AIMS.

Lam, V. Y., Chaloupka, M., Thompson, A., Doropoulos, C. and Mumby, P. J. 2018. Acute drivers influence recent inshore Great Barrier Reef dynamics. Proceedings of the Royal Society B, **285**: 20182063

Mapstone, D. D., Choat, J. H. and Cumming, R. L. 1989. The fringing reefs of Magnetic Island: Benthic biota and sedimentation – a baseline survey. Unpublished report to the Great Barrier Reef Marine Park Authority, 88 pp.

Ortiz, J.-C., Wolff, N. H., Anthony, K. R., Devlin, M., Lewis, S. and Mumby, P. J. 2018. Impaired recovery of the Great Barrier Reef under cumulative stress. Science Advances, **4**: eaar6127

Ostrander, G. K., Armstrong, K. M., Knobbe, E. T., Gerace, D. and Scully, E. P. 2000. Rapid transition in the structure of a coral reef community: the effects of coral bleaching and physical disturbance. Proceedings of the National Academy of Sciences, **97**: 5297-5302

Ports and Coastal Environmental. 2013. Port of Mackay Dredging 2013: Coral Monitoring Program. Prepared on behalf of North Queensland Bulk Ports Corporation.

Sato, Y., Bell, S. C., Nichols, C., Fry, K., Menéndez, P. and Bourne, D. G. 2018. Early-phase dynamics in coral recovery following cyclone disturbance on the inshore Great Barrier Reef, Australia. Coral Reefs, 1-13

Sea Research. 2017. Ports of Mackay and Hay Point Ambient Coral Monitoring Surveys: 2016-2017. Unpublished report to North Queensland Bulk Ports Corporation.

Teakle, I. 2018. GBR Quantitative Sediment Budget Assessment. BMT WBM. 89 pp.

Thompson, A., Costello, P., Davidson, J., Logan, M., Coleman, G. and Gunn, K. 2018. Marine Monitoring Program. Annual Report for inshore coral reef monitoring: 2016 – 2017. Great Barrier Reef Marine Park Authority, Townsville, 148 pp.

Waltham, N., McKenna, S., York, P., Devlin, M., Campbell, S., Rasheed, M., Da Silva, E., Petus, C. and Ridd, P. 2015. Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program (July 2014 to July 2015). Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) Publication 15/16, James Cook University, Townsville, 96 pp.

WIMP. 2016. Queensland Government Water Monitoring Information Portal for The Pioneer River at Dumbelton Weir (Station Id: 125016A)