Centre for Tropical Water and Aquatic Ecosystem Research

SEA RESEARCH

Ports of Mackay and Hay Point Ambient Coral Monitoring Surveys: 2020-2021

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Report No. 21/44

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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, and Slade Islet was completed in 2020/2021 as part of an ambient monitoring program for the Ports of Mackay and Hay Point to measure benthic cover, coral health, sedimentation and coral recruitment. The majority of these locations have been surveyed over two dozen times since 2006.

2. Macroalgal cover has continued to remain dramatically lower with a mean of 12% during the latest May 2021 surveys, possibly a continued effect of the high water temperatures experienced in early 2020. Macroalgal cover has generally followed a gradual increase on the three inshore locations since the 2006 baseline and reached a peak of 47% in July 2018. This was more than 5x baseline means of 9% macroalgal cover. Victor Islet does appear to be the exception with a long term increasing trend as of May 2021.

3. The Mackay region reefs went through a mass bleaching event during the April 2020 survey with a mean of 56% of hard coral cover bleached and 20% of soft coral cover. Hard coral mortality has resulted in the last 12 months, especially at Slade Islet sites with a drop in dominant *Montipora* by >50%. Round Top soft corals have started to recover after a 50% loss was recorded in April 2020 likely due to the warm water event. Broad-scale GBR surveys confirmed bleaching throughout the central and southern GBR sectors at inshore and mid-shelf reefs but with relatively low mortality observed as a result of this regional event.

4. The mean relative decrease in hard coral cover on the three inshore locations between the 2006 baseline and the post-Cyclone Debbie (August 2017) coral cover low has been 45% (from 38% down to 21% coral cover). Overall, the significant reduction and resulting similar low coral cover at all three locations has been driven by cyclonic impacts over the longer term with significant further declines from the 2020 mass bleaching at Slade Islet.

5. In the 50 months since Cyclone Debbie there has been no sustained recovery evident in hard and soft coral cover at any location. Mean coral cover was 22.0% following the cyclone and 23.3% during the latest survey. The slow recovery of hard coral communities on these fringing reefs since Cyclone Debbie continues to be a cause for concern.

6. There were a significant number of coral recruits, particularly at Round Top, in 2020/2021 ambient surveys following the significant drop recorded in 2018 related to Cyclone Debbie acute impacts. Coral recruits were dominated by *Turbinaria* across all three locations.

7. Over the 15 years of monitoring, coral composition has only slightly changed at these locations with mainly a decrease in the proportion of *Acropora* corals, most notably at Round Top, and the most recent loss of *Montipora* at Slade Islet.

8. During the 2020/2021 ambient surveys, both the number of corals with sediment and sediment depth were at relatively low levels. Victor continued to have relatively high numbers of colonies with surface sediment during November 2020 surveys but had reduced during May 2021 to similar levels at Round Top and Slade.

9. Overall, the 2020 mass bleaching event did have a significant effect locally on the coral communities in the Mackay/Hay Point area with some hard and soft coral loss. However, overall impact on coral cover has been low and strong recruitment is a positive sign of local recovery processes. The warmer water and parallel dieback of some macroalgae may have inadvertently created greater open substrate and reduced macroalgal inhibitory chemical cues for corals to recruit.

IN BRIEF

Coral monitoring sites were set up 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. A recent review of the program has led to the reduction in the program to three locations with Keswick Island considered a more mid-shelf reef rather than an appropriate indicator of inshore coral communities. Six sites of four permanently marked 20 m survey transects were originally 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.

The current realigned program continues to monitor four of the six sites at each location following a review of the program in 2019/2020 to align with other inshore coral monitoring in the Abbot Point region. All datasets reviewed in the current report have been back calculated to account for trends at the current four transects to ensure current and future trends in the program are comparable with the historical record.

Surveys occurred for various monitoring needs from the April 2006 baseline through September 2013. In March 2015, North Queensland Bulk Ports began the biannual ambient coral monitoring program to gain a greater understanding of background coral condition and the main drivers of change in these communities. This program enables greater management and mitigation capacity during periods of Port related activities.

Hard coral cover during the 2006 baseline ranged from 33% on Victor Islet to 40% on Round Top Island and at Slade Islet. Macroalgae were also characteristic of the benthos at some of these locations during the baseline survey with <1% cover at Round Top Island, 6% on Slade Islet, and 18% on Victor Islet. Soft corals were not common, ranging from 2% cover on Slade Islet to a high of 5% at Round Top. Sponges were rare covering only 0.8-2.1% of the substratum.

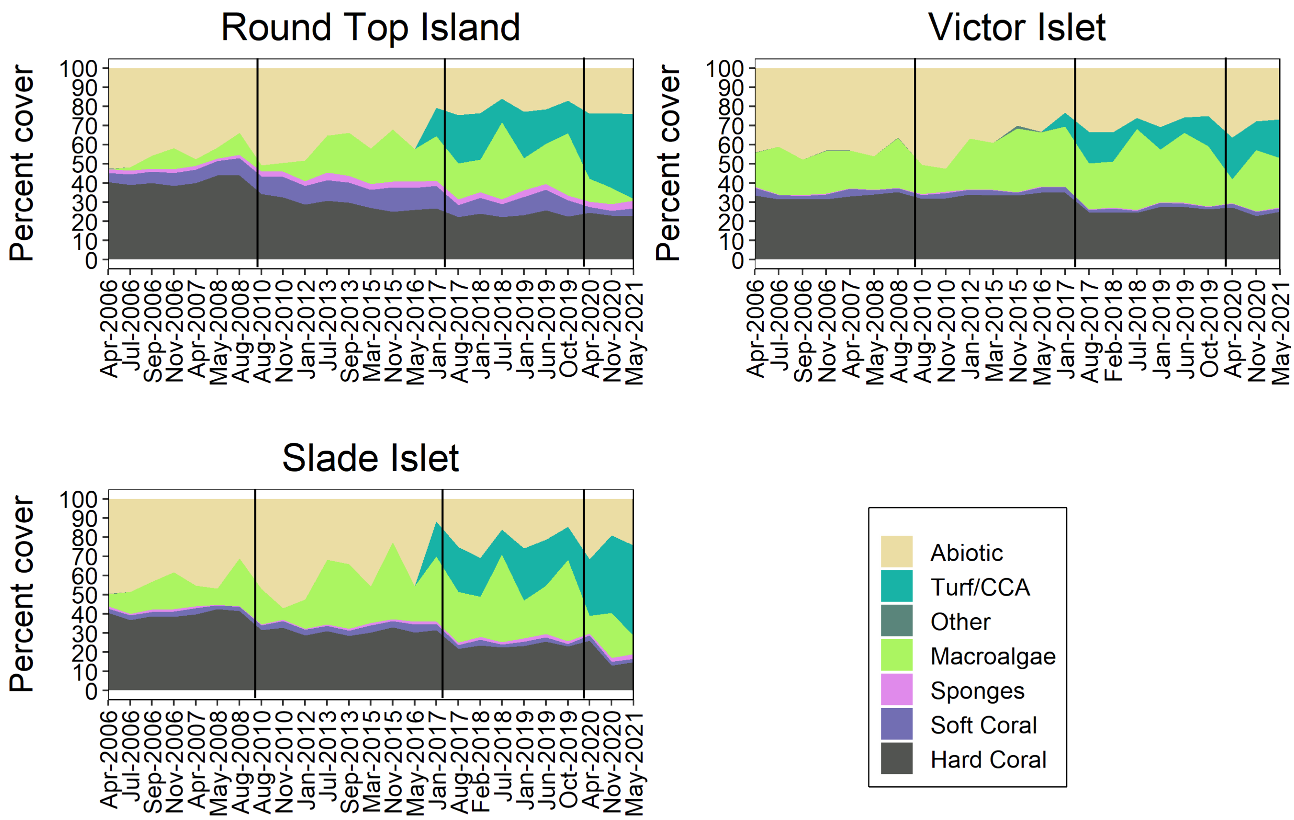

Figure i Summary of changes in the major benthic categories at the three Mackay - Hay Point locations. Graphs show cumulative percent cover from all ambient surveys. Solid vertical lines indicate the times of Cyclone Ului (Mar 2010) and Cyclone Debbie (Mar 2017) and the 2020 warm water event (March 2020). 'Other' is comprised of fire coral and zoanthids. Turf algae was not recorded independently prior to 2016 and was previously considered part of 'abiotic'.

Four cyclonic weather events, two of which had major local impacts, crossed over these locations between 2010 and 2015, reducing hard coral cover from 42% to 30% on Slade Islet and from 44% to 25% on Round Top Island. Hard coral cover was not affected on Victor Islet, remaining around 33%. Sponge cover and soft coral cover remained similar over this time period but macroalgae increased markedly at all locations: from <1% to 28% on Round Top Island, from 8% to 30% on Slade Islet and from 26% to 33% on Victor Islet.

These inshore survey locations were severely impacted by Cyclone Debbie in late March 2017. Extensive physical damage caused hard coral cover to drop from 27% to 22% on Round Top Island, from 35% to 25% on Victor Islet and from 31% to 22% on Slade Islet. In the time following Cyclone Debbie there has been minimal recovery of hard coral cover. Grand mean coral cover was 22.0% following the cyclone and only 23.3% in May 2021. Macroalgal cover increased and peaked dramatically at the three inshore locations during the July 2018 and October 2019 surveys at a grand mean of around 42% cover prior to the early 2021 warm water event.

Sediment levels on living hard corals were relatively low during 2020/2021 surveys. The 2006 baseline found less than 4% of coral colonies having any surface sediment and a mean sediment depth of only 0.05 mm. Sediment levels have fluctuated by more than an order of magnitude over subsequent surveys with increases associated either with natural sediment resuspension events or with dredging campaigns. Peak levels have been around 30-50% of corals affected and mean sediment depths of around 1 mm. Sediment deposition can cause patches of mortality but rarely are significant. Physical damage to corals from cyclonic events is more than an order of magnitude higher than any sedimentation damage.

Reefs in the Mackay region experienced a mass bleaching event in early 2020. A grand mean of 58% of hard coral cover was bleached at the time of the April 2020 survey. Hard coral mortality from bleaching was minimal during the April 2020 surveys, however, the most recent 2020/2021 surveys have found some mortality, particularly in the *Montipora* community at Slade Islet by November 2020. Soft corals were also bleached during the 2020 event. There was a 50% reduction in soft coral cover at Round Top Island between October 2019 and April 2020 probably resulting from bleaching mortality of *Sansibia* soft corals. The soft coral cover has begun to somewhat increase as of May 2021 but without the return of *Sansibia*. Prior to this event, coral bleaching had only occasionally affected about 1-3% of hard coral colonies and had caused no measurable changes to coral cover in the Mackay/Hay Point region. In line with these local impacts, widespread bleaching both at inshore and mid-shelf reefs was most prevalent in the central and southern sectors in early 2020. Despite the severity of the mass bleaching event, widespread coral mortality has not eventuated (Townsville to Gladstone; ARC Centre of Excellence for Coral Reef Studies).

There was a large reduction in macroalgal cover recorded during the April 2020 survey which has continued in November 2020 and May 2021 surveys. The macroalgal loss is likely due to the high summer water temperatures in early 2020. The macroalgae decline at Round Top and Slade may in fact provide a reprieve for coral to potentially recruit into open substrate which was created from this macroalgal loss. Macroalgae is known to also have a chemical inhibitory effect on coral recruitment which would have diminished with the decline. Coral recruitment did inversely correlate with this macroalgal decline showing some positive outcomes for potential hard coral recovery.

Disease sometimes affects hard coral colonies and may cause partial or occasionally total mortality. Only 1-2% of coral colonies are affected at any one time and disease levels are usually higher in summer when the water is warmer and lower during the winter months. Disease levels were close to absent at Slade in 2020/2021 surveys with similar albeit average levels for Round Top and Victor.

Physical cyclone damage has been the major impact on hard coral cover at these inshore locations, with the 2020 mass bleaching event significantly reducing hard coral only at Slade Islet. Soft coral was also impacted by the bleaching event at Round Top and macroalgal cover reduced at Round Top and Slade. Unless rates of coral recovery improve over what has previously been measured during inter-cyclone periods in this region, or cyclone and bleaching 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 at least 10 years given best-case recovery scenarios and no further impacts which is unlikely given climate trajectories.

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ACRONYMS AND ABBREVIATIONS

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

1 INTRODUCTION

1.1 Project Background

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

Mackay Port's throughput tonnage for 2019-2020 financial year was almost 3.2 million tonnes. The current export capacity through both existing coal terminals in the Port of Hay Point is approximately 106 Mtpa.

Beginning in 2006 extensive coral monitoring has been undertaken for NQBP (previously known as Ports Corp Queensland) at key locations surrounding the Ports of Hay Point and Mackay (Figure 1): Round Top Island (Figure 2), Victor Islet (Figure 3) and Slade Islet (Figure 4). These previous investigations were focused around port dredging activities and, whilst some temporary increase in sedimentation was identified, there was minimal overall recorded impact as a result of this (<1% coral cover loss). The development of the present ambient coral monitoring program was triggered in order to gain a greater understanding of ambient conditions and the drivers of these conditions which would also allow for a greater capacity to manage potential influences during periods of Port related activities. Advisian (formerly WorleyParsons), in association with Sea Research, conducted surveys at all established monitoring locations in March 2015, November 2015 and May 2016. Sea Research were asked to continue these ambient surveys with two surveys of these four locations during the 2016/2017 period. TropWATER and Sea Research have continued these surveys during the 2017-2020 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.

Surveys considered:

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

This report documents the findings of the two most recent ambient surveys at the three Hay Point/Mackay locations over the 12 months between mid-2020 and mid-2021 that have not been included in previous reports, but makes comparisons with the results from previous surveys. Changes to the monitoring program design were agreed to prior to the commencement of field surveys in order to align the program with other inshore monitoring locations and to better characterise coral communities at each location. The most significant adjustments to the program include the decommissioned monitoring sites at Keswick Island and the reduction of sites per location at Slade Islet, Round Top Island, and Victor Islet to four sites per location. All changes were made based on the guidance and expertise of Sea Research who setup and maintained all transect sites since their inception. Keswick Island in particular, was dropped due to its more mid-shelf reef benthic composition compared to the inshore locations which are more representative of the inshore port environment.

Figure 1. Map of the Port of Mackay (Mackay Harbour), Port of Hay Point and the coral monitoring locations

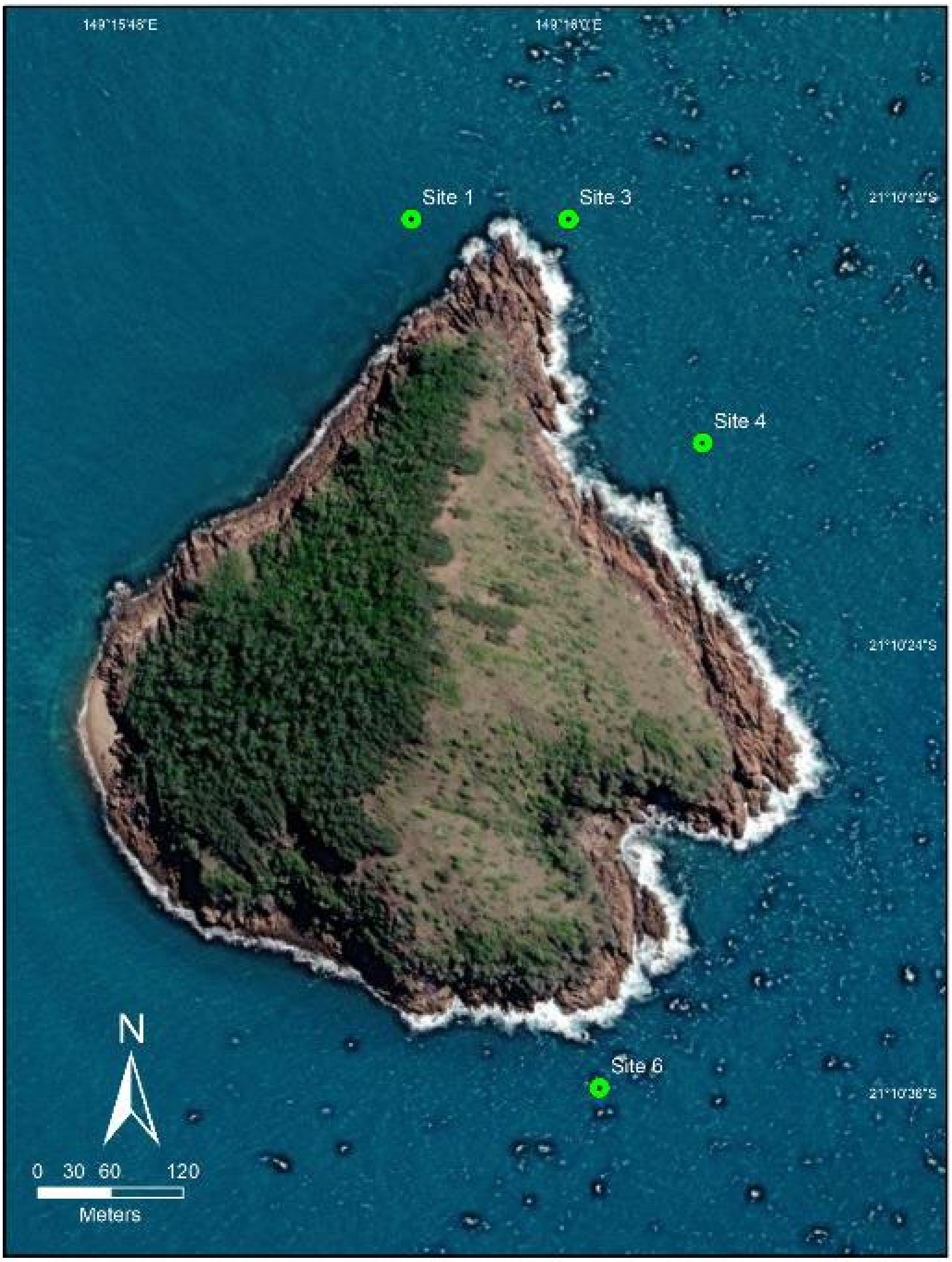

Figure 2. Round Top Island location showing position of the four coral monitoring sites

Figure 3. Victor Islet location showing position of the four coral monitoring sites

Figure 4. Slade Islet Location showing position of the four coral monitoring sites

2 METHODS

2.1 Mackay/Hay Point Locations

Fringing reefs were surveyed around three island locations in the Mackay/Hay Point region (Figure 1). Two near-shore islands close to the Port of Hay Point were incorporated (Round Top Island and Victor Islet), along with another inshore island (Slade Islet) 18 km north of the Port of Hay Point and directly adjacent to the Port of Mackay.

Table 1. GPS coordinates of each monitoring site*.

Location	Ambient monitoring site ID	Historical site ID	Latitude	Longitude
Slade Islet	S1	S1	-21.0989	149.2440
Slade Islet	S2	S2	-21.0988	149.2450
Slade Islet	S4	S4	-21.0961	149.2431
Slade Islet	S5	S5	-21.0966	149.2450
Round Top Island	S1	S1	-21.1699	149.2656
Round Top Island	S3	S3	-21.1702	149.2668
Round Top Island	S4	S4	-21.1719	149.2675
Round Top Island	S6	S6	-21.1769	149.2665
Victor Islet	S2	S2	-21.3223	149.3267
Victor Islet	S3	S3	-21.3232	149.3276
Victor Islet	S5	S5	-21.3197	149.3215
Victor Islet	S6	S6	-21.3223	149.3191

* Two sites dropped from the program in October 2020 to align with the modified program design but sites numbering kept for historical reference.

Six monitoring sites were previously established at each location at the start of the 2006 capital dredging monitoring program but were reduced to four of the original six in November 2020 (Figures 2-5). These sites 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.

Table 2. Summary of all coral surveys made at the four Hay Point survey locations.

Survey date:	Round Top	Victor	Slade
Apr 2006	X	X	X
Jul 2006	X	X	X
Sep 2006	X	X	X
Nov 2006	X	X	X
Apr 2007	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
Nov 2015	X	X	X
May 2016	X	X	X
Jan 2017	X	X	X
Aug 2017	X	X	X
Jan 2018	X	X	X
Jul 2018	X	X	X
Jan 2019	X	X	X
Jun 2019	X	X	X
Oct 2019	X	X	X
Apr 2020	X	X	X
Nov 2020*†	X	X	X
May 2021*	X	X	X

X indicates locations that were included during each survey. * Surveys covered by this report. †From Nov 2020 onwards, each location is comprised of four sites instead of six.

2.2 Survey Period

This report provides a summary of coral conditions observed during two different surveys undertaken at the three Mackay reef locations over the period June 2020 to June 2021. The two survey periods were pre-wet, from 22 October and 24-25 November 2020 and post-wet from 7-9 May 2021. Two small rainfall events (<25mm each) occurred in late October and early November while significant wet season rainfall began in late December 2020 (Figure 5). For clarity in this report, the pre-wet survey period is referred to as November 2020 despite one day completed in late October 2020.

During rough weather, underwater visibility in the study areas can be zero due to high levels of turbidity. During the November pre-wet survey visibility was good ranging from 5-6 m at the Round Top sites and generally poor at Slade and Victor with 1-4m visibility. During the April post-wet survey, underwater visibility was overall improved ranging from 6-8 m at Round Top and 4-6 m at Slade and Victor.

2.3 Benthic Line Intercept Surveys

Abundance surveys of the marine communities were made at four sites surrounding each island. At each site, cover of major benthic reef organisms was assessed by four 20 m, haphazardly positioned, line 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. All sites were re-located and repaired following major storm activity such as Cyclone Debbie in August 2017. The marker stakes are remarkably resistant to cyclone waves and any missing markers are repaired at each visit to ensure continuity of the survey sites.

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

From pre-wet 2020 surveys November 2020), photoquadrats along each transect were taken approximately 0.5m above the benthos in order to shift from line intercept to a photoquadrat method in line with the Australian Institute of Marine Science (AIMS) methodology for calculating benthic cover of coral reef communities.

For this report, benthic cover based on photoquadrat analysis has been compared against historical line intercept categories in order to determine if a significant effect is detected from the change in methodology. While substantial updates are also made to the statistical analyses in the ambient coral monitoring program's annual report (see Section 2.8), line intercept data is used in all plots and results to avoid uncertainty and ambiguity around the long term trends. All future annual reports will discuss findings with a clear delineation of the changed methodology in place.

2.5 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.

2.6 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.

2.7 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.

2.8 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.

Generalised linear mixed effects models coupled with analysis of variance model output are 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 such analysis after subsequent surveys. Because the transects were fixed within each site and the same bits of the benthic community were assessed during each survey, a transect was incorporated into generalised linear models as a nested random effect to increase the power of the analysis and account for these repeated samplings. This analysis tested the significance of changes in a number of variables that may have influenced benthic abundance at each location over the last four survey periods.

1. The first variable was the four different sites surveyed at each location i.e. to determine whether there were significant differences in benthic abundance among the four sites within each location.

2. The second 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 location.

Interactions between these variables were also determined in the analysis (indicated as Site x Time). If benthic abundance changes caused by ambient conditions are the same at each site then this interaction will not be significant but if benthic abundance decreases at one site and either does not change or increases at another site then the interaction may be significant, even though the mean coral cover may not have changed between the two surveys (the increase at one site could cancel out the decrease at another site and mean coral cover would stay the same).

Changes in sediment depth on coral colonies and the density of damaged and diseased coral colonies were tested for each location using the same analysis. As sediment depth is measured on a different random selection of corals during each survey then repeated measures analysis is not appropriate. The random nested effect term was removed from the generalised linear models for this analysis.

Long-term changes in benthic cover among locations was assessed using generalised additive models (GAMs). A GAM allows for non-linear terms such as time or season to be accounted for inherently in the model design. GAM output is plotted by location over time and with 95% confidence intervals. Differences in locations occur when model output and CIs are non-overlapping. All analyses were performed in R version 4.1.1 (R Core Team) using packages lme4 and mgcv.

3 RESULTS

3.1 Climatic Conditions

One of the key drivers of coral community health is the climatic conditions experienced by that community over time. Major climatic drivers of coral health include local and regional rainfall and river discharges into the nearshore environment, cyclonic conditions, other strong wind episodes and sea water temperatures. The following section deals with the climatic conditions during the present ambient monitoring period from August 2020 to July 2021 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 2021) is provided graphically in Figure 5A. 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 2020) in millions of litres per day (ML/day) (Figure 5B).

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 1,545mm (BOM 2021). Additional rainfall in the catchment areas inland from Mackay contributed to the elevated river discharges. Since then river discharges have been lower than average (Sea Research 2017; Advisian 2016; TropWATER 2018). The 2020/2021 wet season was below average in terms of rainfall, with only 805mm recorded for the January-April period compared to the 1,080mm average. More than 50mm in 24hr rainfall was only recorded on a single day in late December 2020 making this the fourth consecutive year of lower than average rainfall (Figure 5A, see inset).

Water discharge events from the Pioneer River were also mostly well below average for the 2020/2021 period (Figure 5B) with an overall annual river flow of 213,964 ML, a second year well below the 10 year average level (see inset) . Only a single peak of over 10,000 ML/day was recorded in late January 2021 which is low compared to previous extreme rainfall events, with river flows of over 100,000 ML per day recorded on at least ten occasions throughout the past decade.

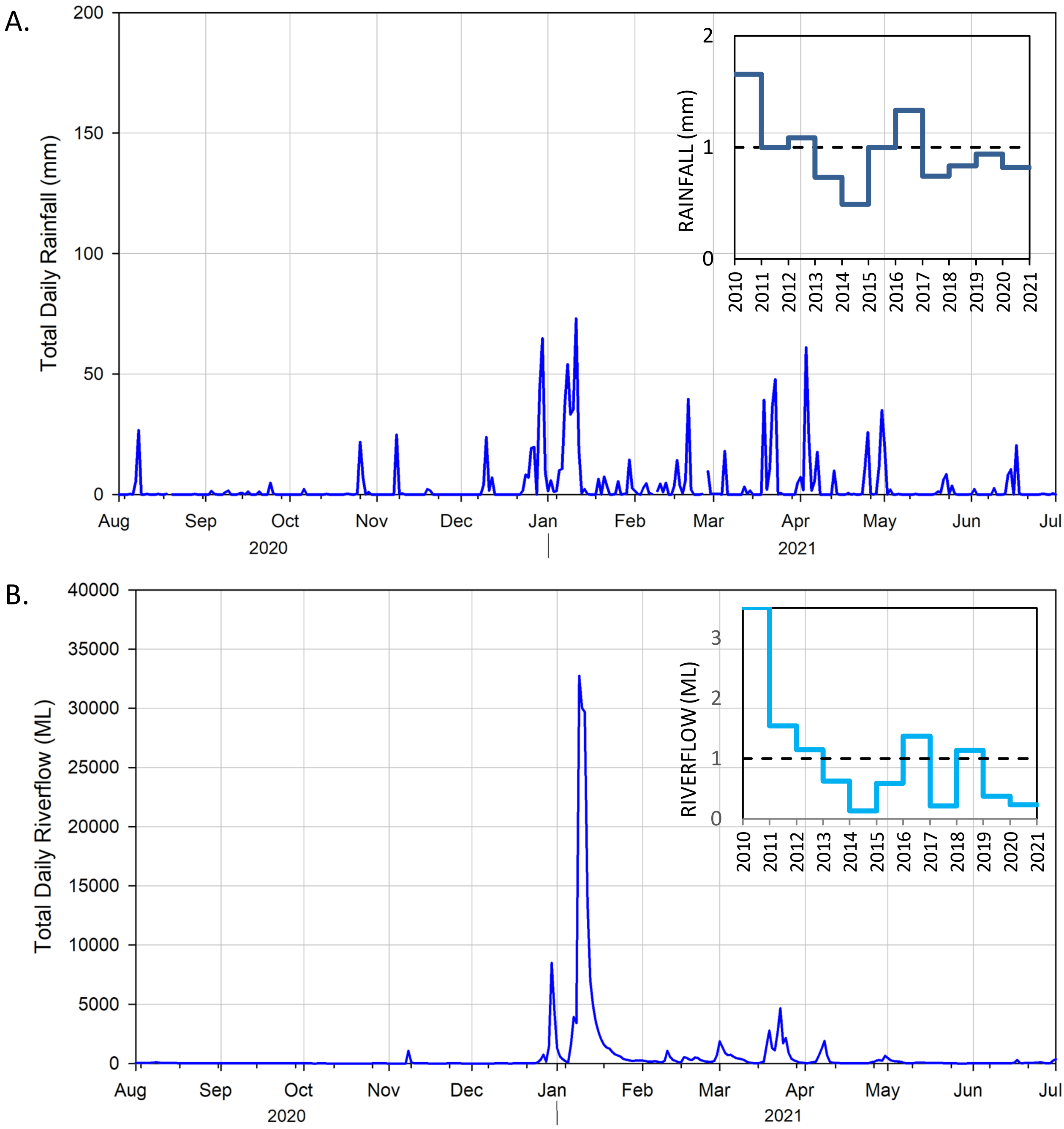

Figure 5. A. Daily rainfall measured at the Mackay Airport with inset of change in rainfall as a proportion of the long-term average, B. the Pioneer River discharge at Dumbleton Weir. Insets represent data as a proportion of long-term average.

3.1.2 Cyclones

During the 2020/2021 ambient monitoring period no cyclones or significant monsoonal event impacted the region with no major rainfall event of the wet season. Strong SE winds impacted the Mackay region between the 10th and 13th of March 2020. Sustained winds at Hay Point were between 45-60 km/hr for the three day event with gusts of between 60-80 km/hr. Over 520mm of rain fell at Mackay Airport between the 23rd February and 13th March and daily river flows peaked at about 52,000 ML (Figure 5B). This was the major weather event of the past 12 months in terms of river flow and accounted for 75% of the total river discharge for the twelve month period.

Prior to 2019 a number of cyclones passed close to Mackay leading to strong or damaging winds and high rainfall that may have impacted the benthic communities in all the coral monitoring locations (Table 3). 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 fourteen years to early 2020.

Table 3. 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 causing mass coral bleaching were recorded during the 2019/2020 summer period in the Mackay region but were generally cooler during the 2020/2021 period (Figure 6). 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 2020/21 were in late December and ranged from 29.3°C at Round Top to 30.1°C at Slade and Victor (Figure 6). This is significantly lower than the peaks during the 2019/20 summer warming event when temperatures reached up to 31.6°C at Slade and Victor in February 2020. Water temperatures during the June 2020 survey were heading towards the coolest temperatures of the year with sites in May 2021 at 24.0°C. Overall, sea surface temperatures have increased from the long term average† in the Great Barrier Reef Marine Park (Figure 7).

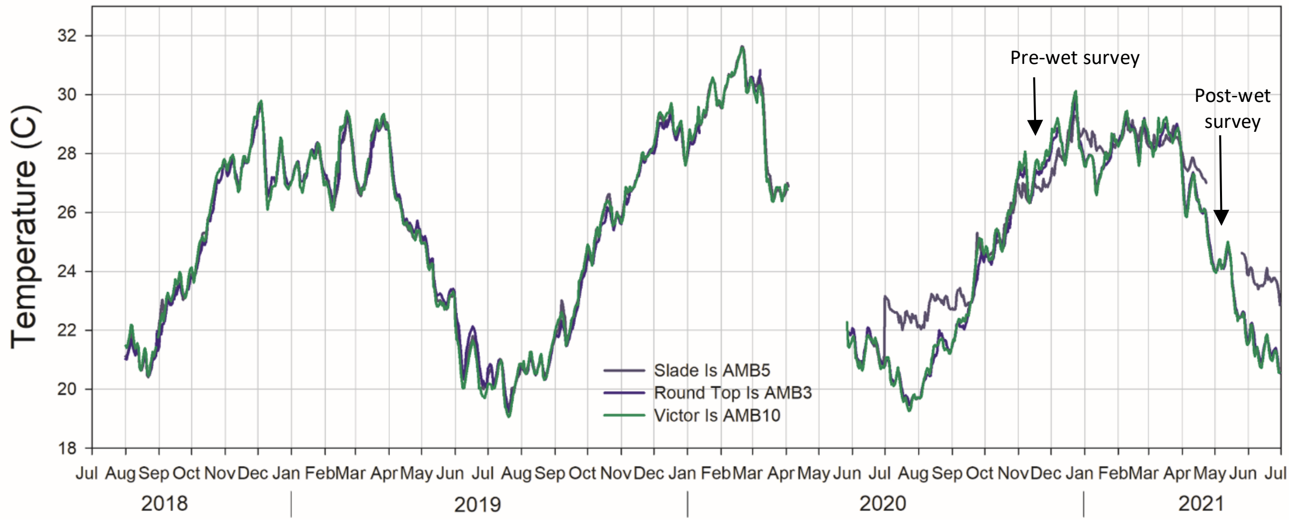

Figure 6. Maximum daily temperature recorded from 2018-2021 by the NQBP water quality monitoring team at nearby logger sites (Waltham et al. 2021).

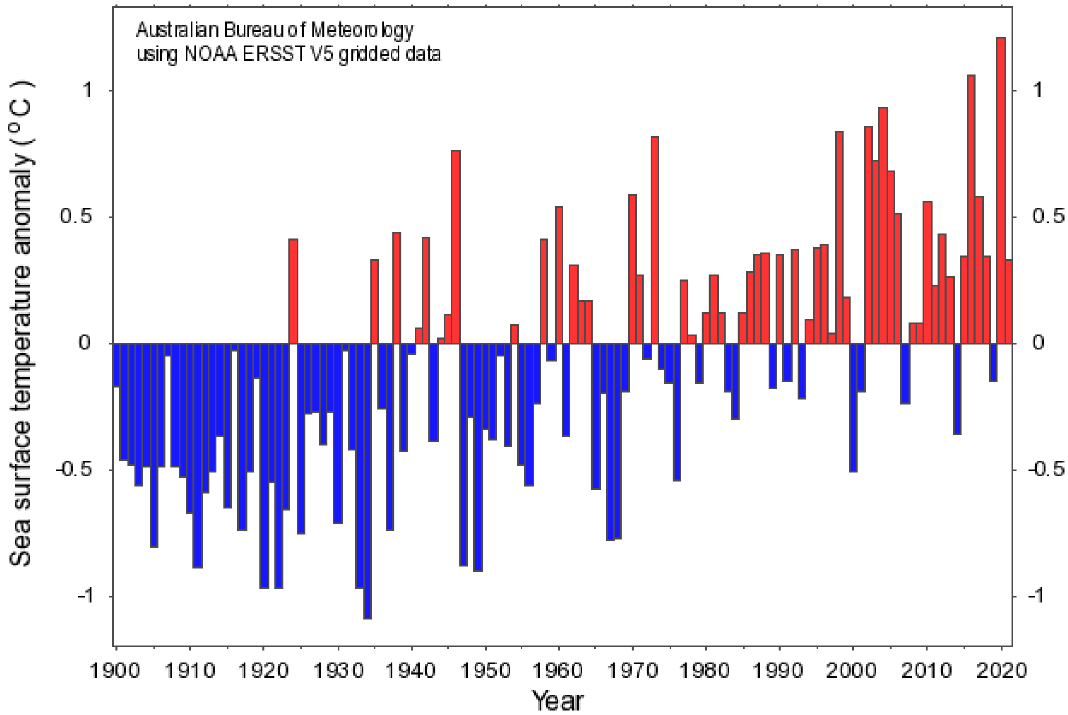

Figure 7. February (1900-2021) sea surface temperature anomaly (deviation from normal) compared to the 1961–1990 average for the Great Barrier Reef†; adapted from Bureau of Meteorology

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

3.2 Benthic cover during the ambient surveys

Macroalgae were common on these fringing reefs. During the November 2020 survey macroalgal cover ranged from 8% to 32% at the three locations, much lower than levels recorded a year before during the October 2019 survey (Figure 9). There was a further significant decrease in macroalgal cover over the six months between the latest two surveys at Round Top and Slade but not at Victor (Figure 9, Table 4). Between November 2020 and May 2021 the overall mean cover of macroalgae had decreased from 21% down to only 12% (Figure 8-9). The genera *Sargassum* and *Lobophora* were usually the most abundant algal groups but a range of other species were usually present including *Padina, Caulerpa* and *Halimeda,* as well as some fast-growing filamentous algae. Most macroalgal species except *Sargassum* had disappeared from Round Top and Slade at the time of the May 2021 survey.

Over the long-term, macroalgae had increased at all locations over the last 8 years following various local impacts, most notable severe cyclones in the region. The decline at Round Top and Slade in macroalgae back to baseline levels is a significant change that is not present at Victor (Figure 9B).

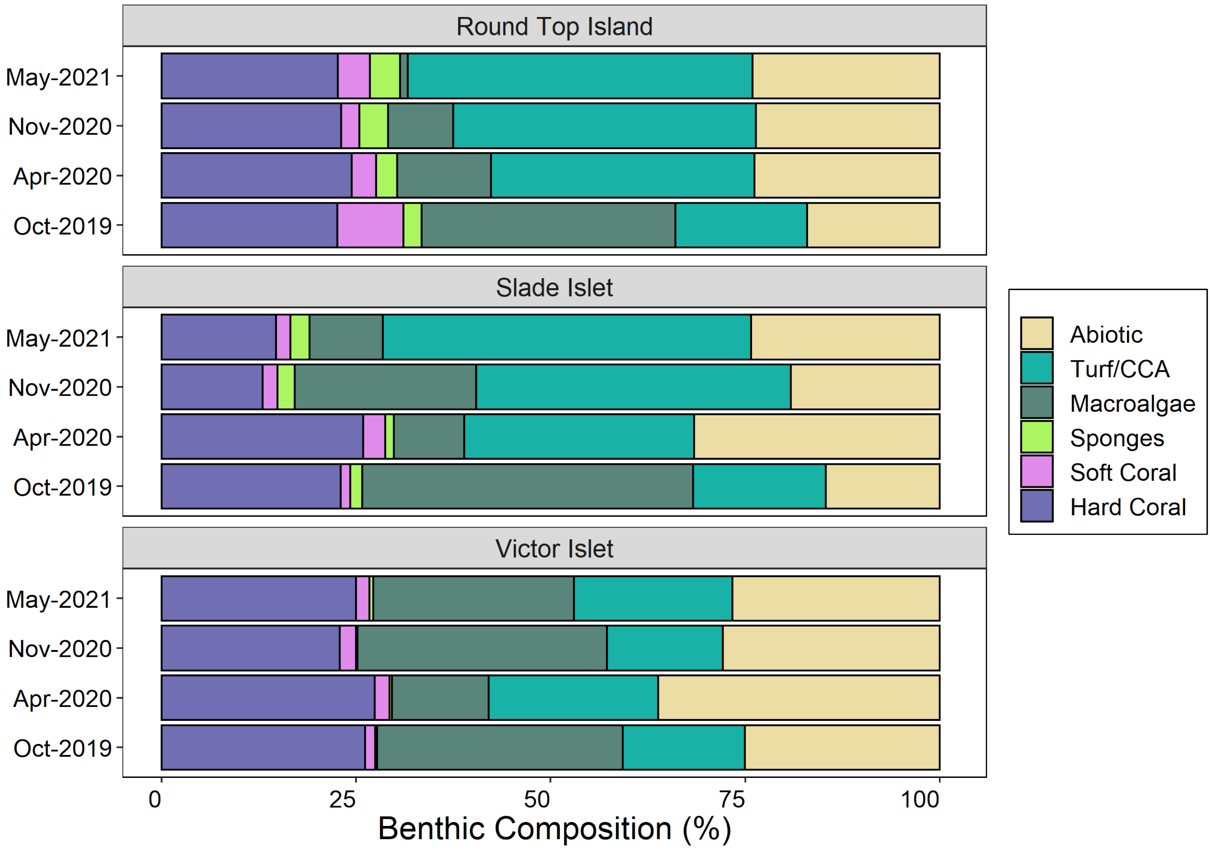

Figure 8. Changes in benthic composition in the four locations between October 2019 and April 2020. Plot shows mean percentage benthic composition from the last two ambient surveys at each location. Benthic category 'Abiotic = sand + rubble + bare reef.

Sponges were not common in any of the locations (Figure 8) but were most abundant on Round Top Island. Sponge cover, while relatively low, has increased during the last two surveys at Round Top to the highest levels for the monitoring program with 3.9% during the May 2021 ambient survey. The most abundant sponge has consistently been brown *Turpios* sp. that takes over living coral. Many of the brown *Turpios* colonies were partially bleached at the time of the April 2020 survey but did not dieback following the warming event.

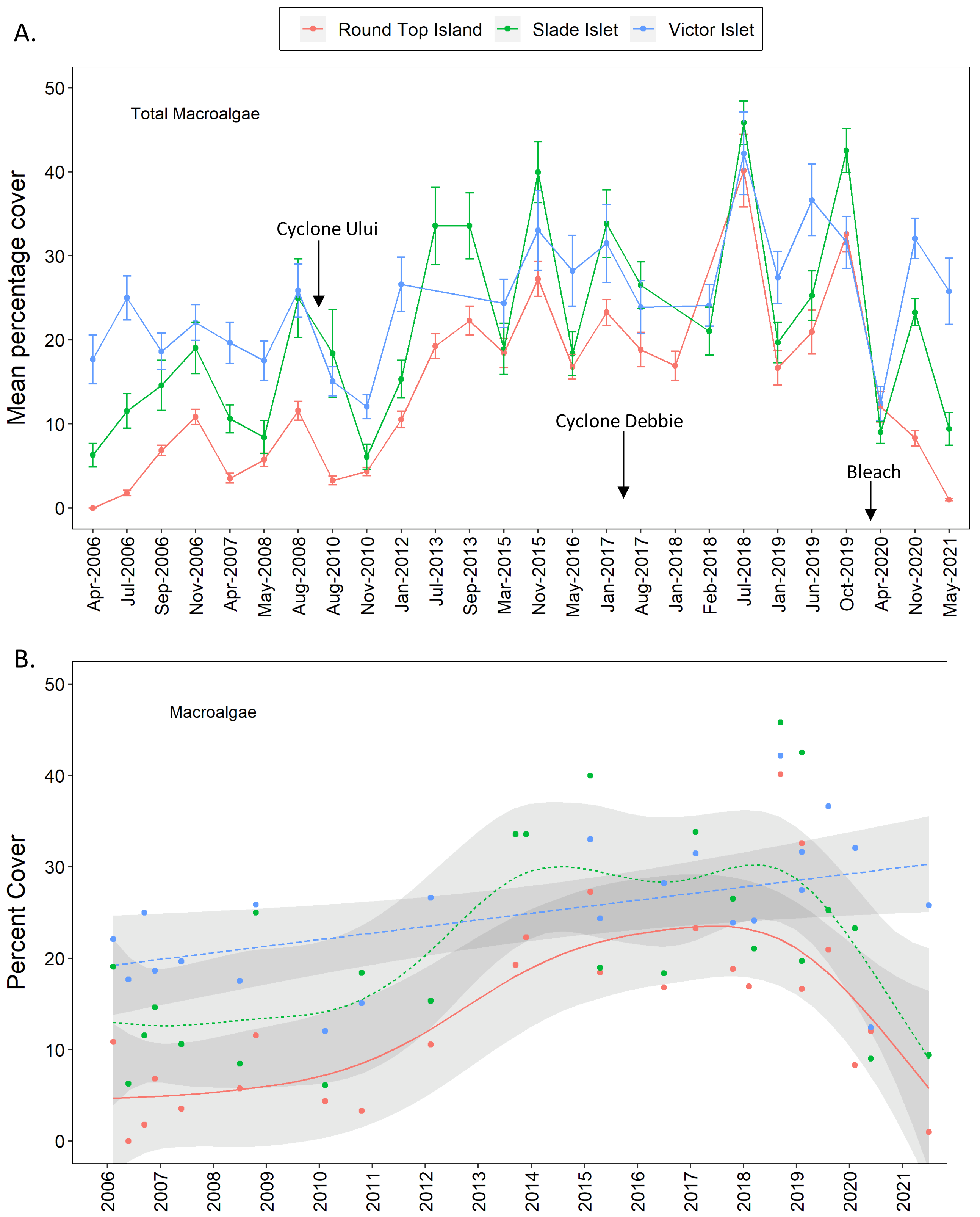

Figure 9. Changes in percentage cover of macroalgae.
Graphs show A) grand mean percentage macroalgal cover from the 2020/2021 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. B) Generalised additive model of trends in mean macroalgae cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

Table 4. Benthic changes between the four most recent surveys (Oct 2019, Apr 2020, Nov 2020 and May 2021) from the site level data of the three locations of the ambient monitoring project. Results are the anova summary results of a generalised linear mixed effects model output with transect as the random effect run for each location separately.

	ROUND TOP			SLADE			VICTOR		
Family/Group	**Site**	**Time**	**S x T**	**Site**	**Time**	**S x T**	**Site**	**Time**	**S x T**
Total macroalgae	**	***	NS	***	***	NS	***	***	**
Total hard corals	***	NS	NS	NS	**	NS	***	NS	NS
Acropora spp.	NS	NS	NS	***	NS	NS	***	NS	NS
Montipora spp.	***	NS	NS	***	***	*	***	NS	NS
Pocilloporidae	NS	NS	NS	***	**	**	*	NS	NS
Siderasteridae	***	NS	NS	***	NS	NS	***	NS	NS
Turbinaria spp.	***	NS	NS	**	NS	NS	***	NS	NS
Faviidae	***	NS	NS	**	NS	NS	***	NS	NS
Poritidae	**	NS	NS	***	NS	NS	**	NS	NS
Total soft corals	***	***	*	***	NS	**	NS	NS	NS

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

Mean coral cover during the 2020/2021 surveys was between 13% and 25% on Round Top, Victor and Slade. Over the past 12 months hard coral cover has been unchanged at Round Top and Victor (Figure 10, Table 4) while Slade had a significant decline (Figure 10, Table 4). Site specific variability was significant across Round Top and Victor but not Slade locations (Table 4).

Long-term ambient monitoring shows no significant differences among locations in hard coral cover (Figure 10B), but an overall downward trend since the inception of monitoring in 2006. The only point in which coral cover significantly differed among locations was early in the program when Round Top and Slade had greater hard coral cover than Victor before declines dampened any location-specific differences (Figure 10B).

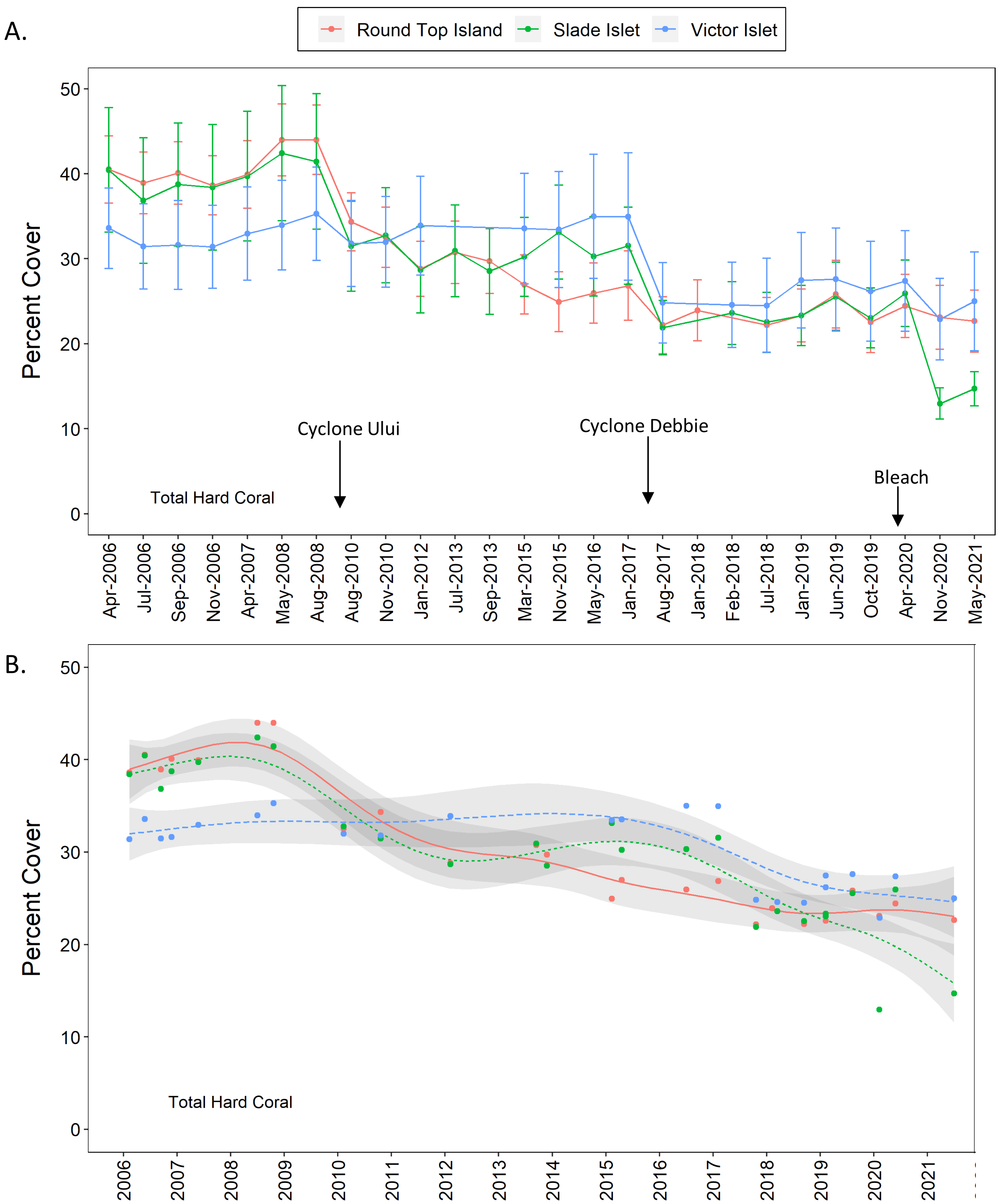

Figure 10. Changes in the cover of total hard coral.
Graphs show A) grand mean percentage benthic cover from the 2020/2021 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

Hard coral community composition was different in each location (Figure 11). During the 2020/2021 surveys coral communities at Round Top Island were dominated by *Turbinaria* spp. (30% of total coral cover) with siderasterids, *Montipora* spp., faviids and poritids also common. Victor Islet reefs were dominated by *Montipora* spp. corals (33% of coral cover), with *Turbinaria* spp. and faviids also common. On Slade Islet *Montipora* spp. corals accounted for only 19% of all hard coral cover, a steep decline from the >50% of the hard coral community in all previous monitoring years. Other Slade Islet corals including *Acropora* spp., siderasterids, *Turbinaria* spp. and poritids now comprise a similar proportion of the hard coral community at this location. Coral composition patterns had remained similar since Cyclone Debbie until the bleaching event affected *Montipora* at Slade Islet. Notably, there was no significant loss of the already low proportion of *Acropora* at any location from the mass bleaching event despite it being a common genus to be affected by bleaching events.

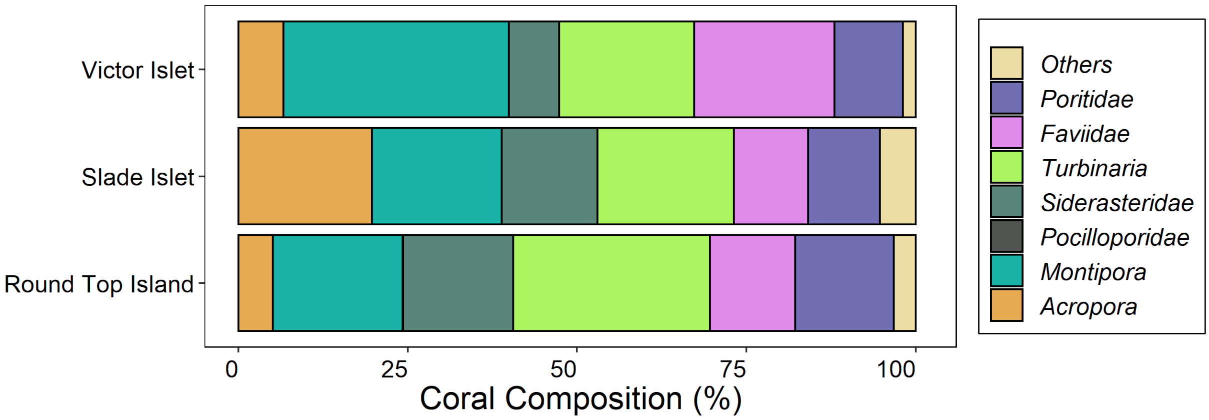

Figure 11. Coral community composition at the four locations for the latest May 2021 ambient survey. Graphs show mean percentage composition of the major coral groups from the four locations.

Location differences among coral groups was apparent in the latest surveys for all coral groups except for *Acropora* and soft corals which were not significantly different among the three inshore locations (Figure 12B-18B). All but the pocilloporid coral group showed significant site differences during the latest four ambient surveys (Table 4). *Montipora* has historically been highest on Slade but dieback following the bleaching event led to significantly greater *Montipora* on Victor Islet compared to the other two locations (Figure 13). *Turbinaria* spp. and siderastreid corals remained significantly higher on Round Top than Slade and Victor (Figure 14B - 15B). Faviid corals had lower cover on Slade than in the other two locations but with an overall declining trend since monitoring began at all locations (Figure 16B). Poritid corals were highest at Round Top Island and cover at all three locations has remained relatively stable since 2006 (Figure 17B).

Soft corals were significantly impacted by the warming event in early 2020 at Round Top Island. Soft corals have historically been significantly higher at Round Top but declined from October 2019 to April 2020 while no major changes occurred at the other two locations during this period. Soft corals did increase significantly from November 2020 to May 2021 at Round Top but are still at much lower levels than pre-bleaching in October 2019 (Figure 18). The soft coral cover decline at Round Top was in large part due to the complete disappearance of the dominant *Sansibia* species; probably due to the high summer water temperatures in early 2020. *Sansibia* has not returned to the sites as of May 2021.

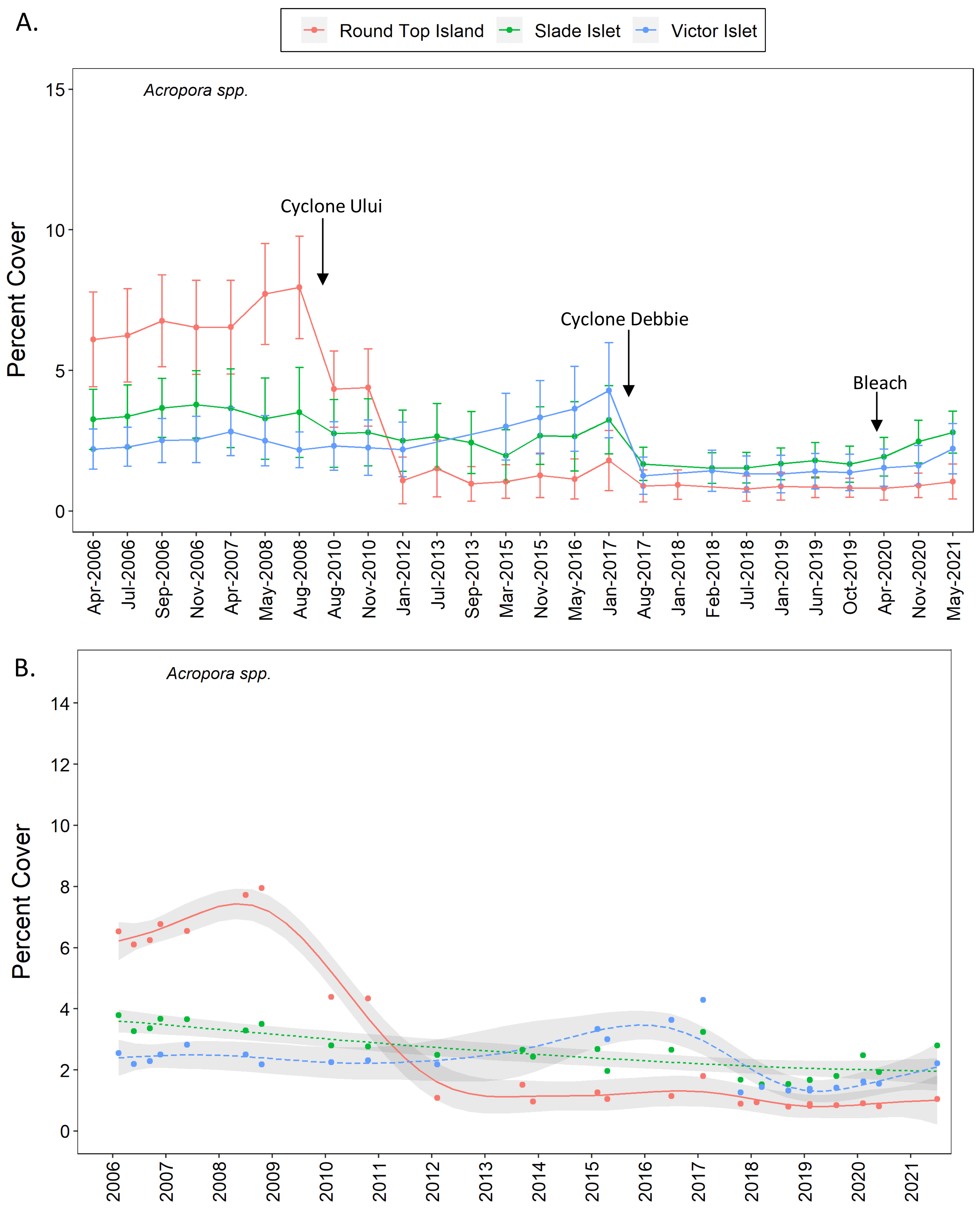

Figure 12. Changes in the cover of *Acropora* corals.

Graphs show A) grand mean percentage benthic cover from the 2020/2021 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

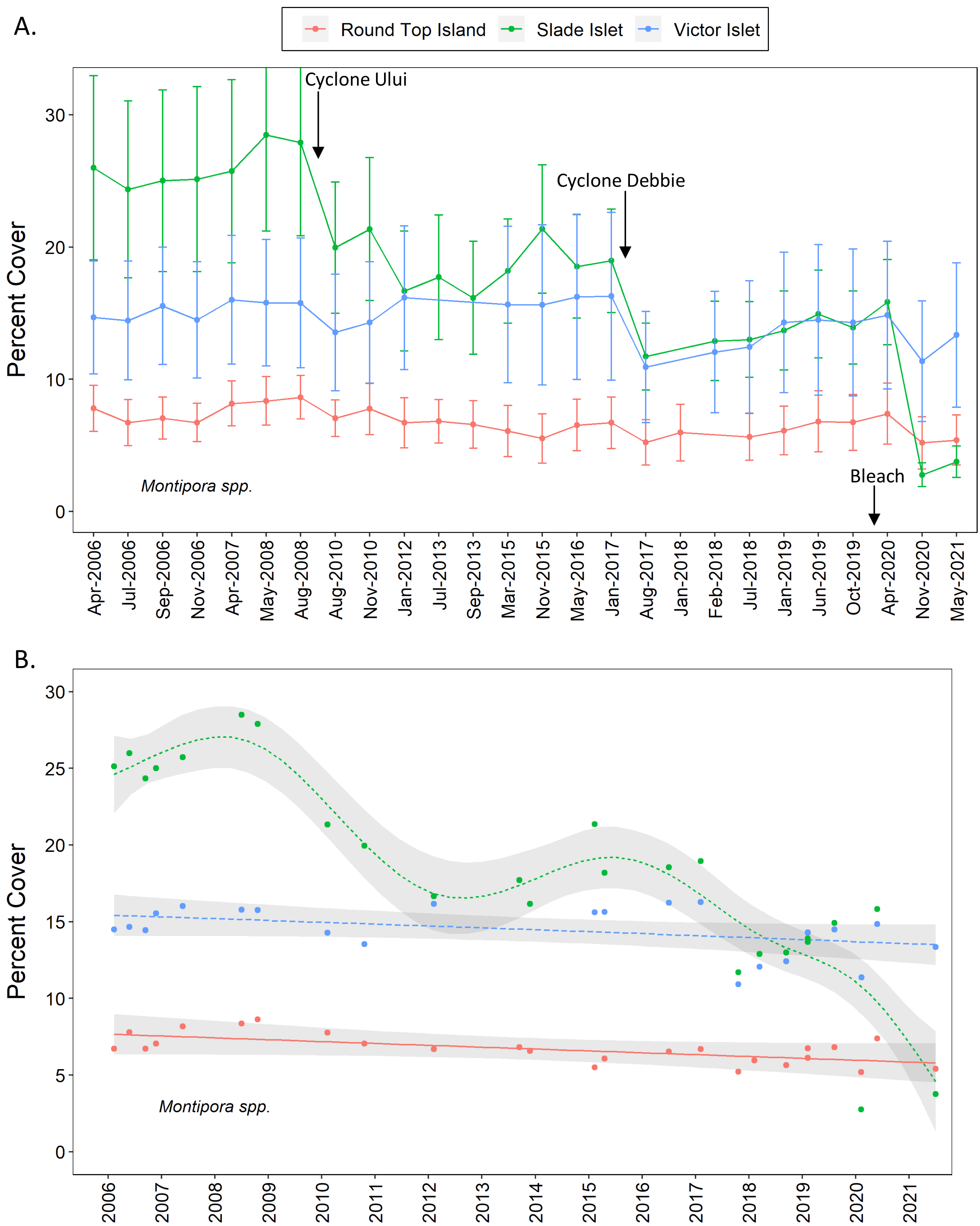

Figure 13. Changes in the cover of *Montipora* corals.
Graphs show A) grand mean percentage benthic cover from the 2020/2021 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

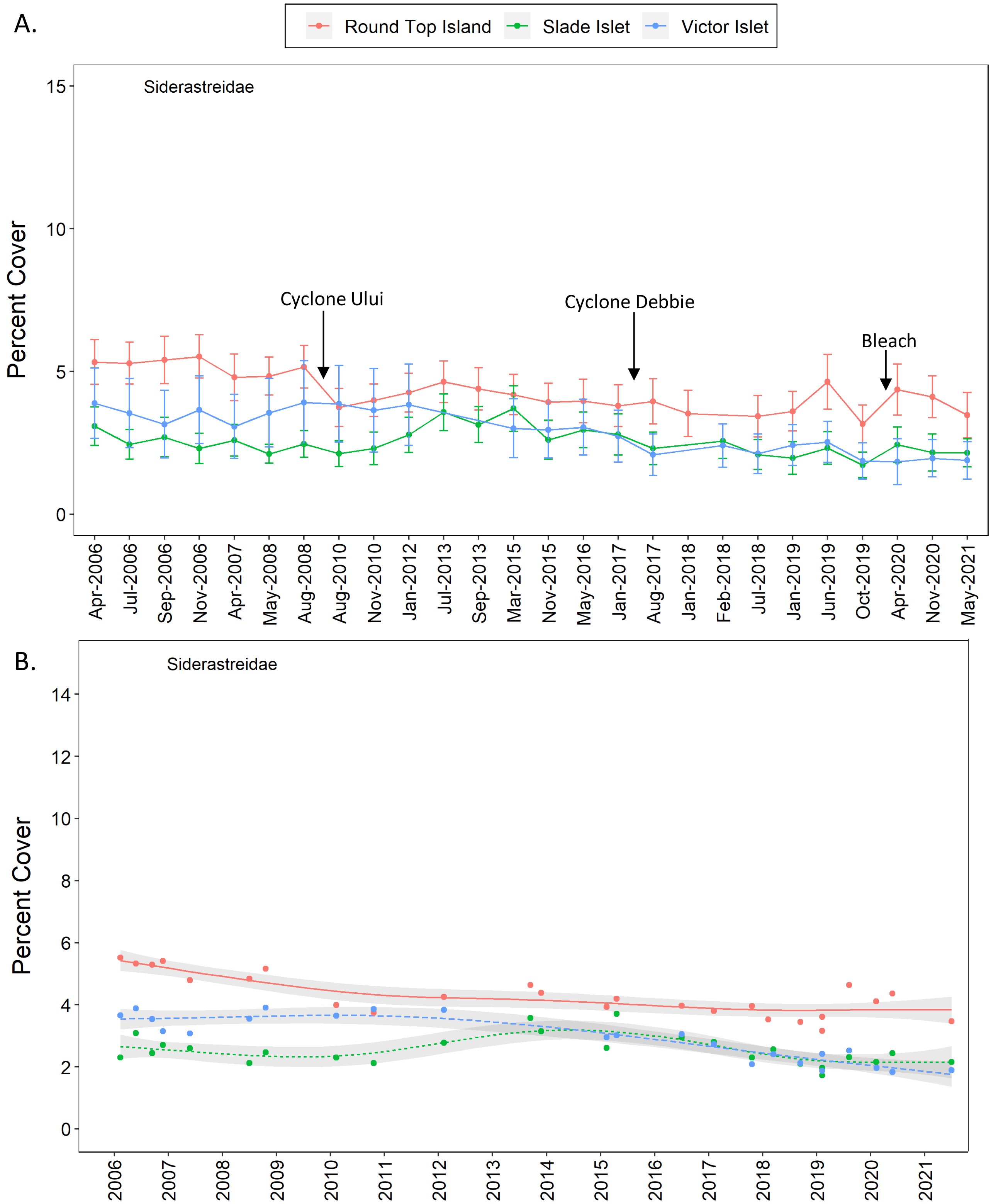

Figure 14. Changes in the cover of Siderastreid corals.
Graphs show A) grand mean percentage benthic cover from the 2020/2010 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

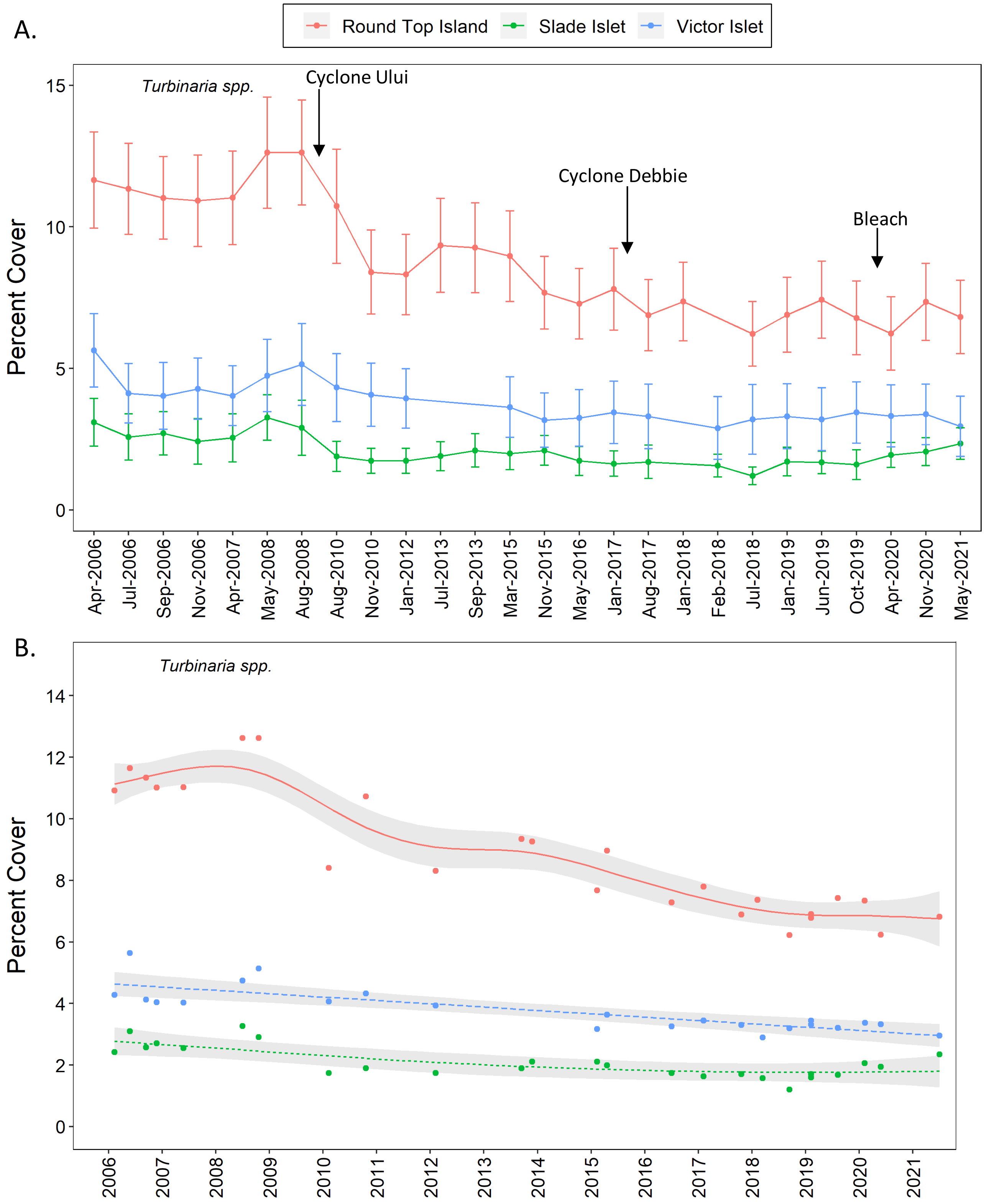

Figure 15. Changes in the cover of *Turbinaria* corals.
Graphs show A) grand mean percentage benthic cover from the 2020/2010 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

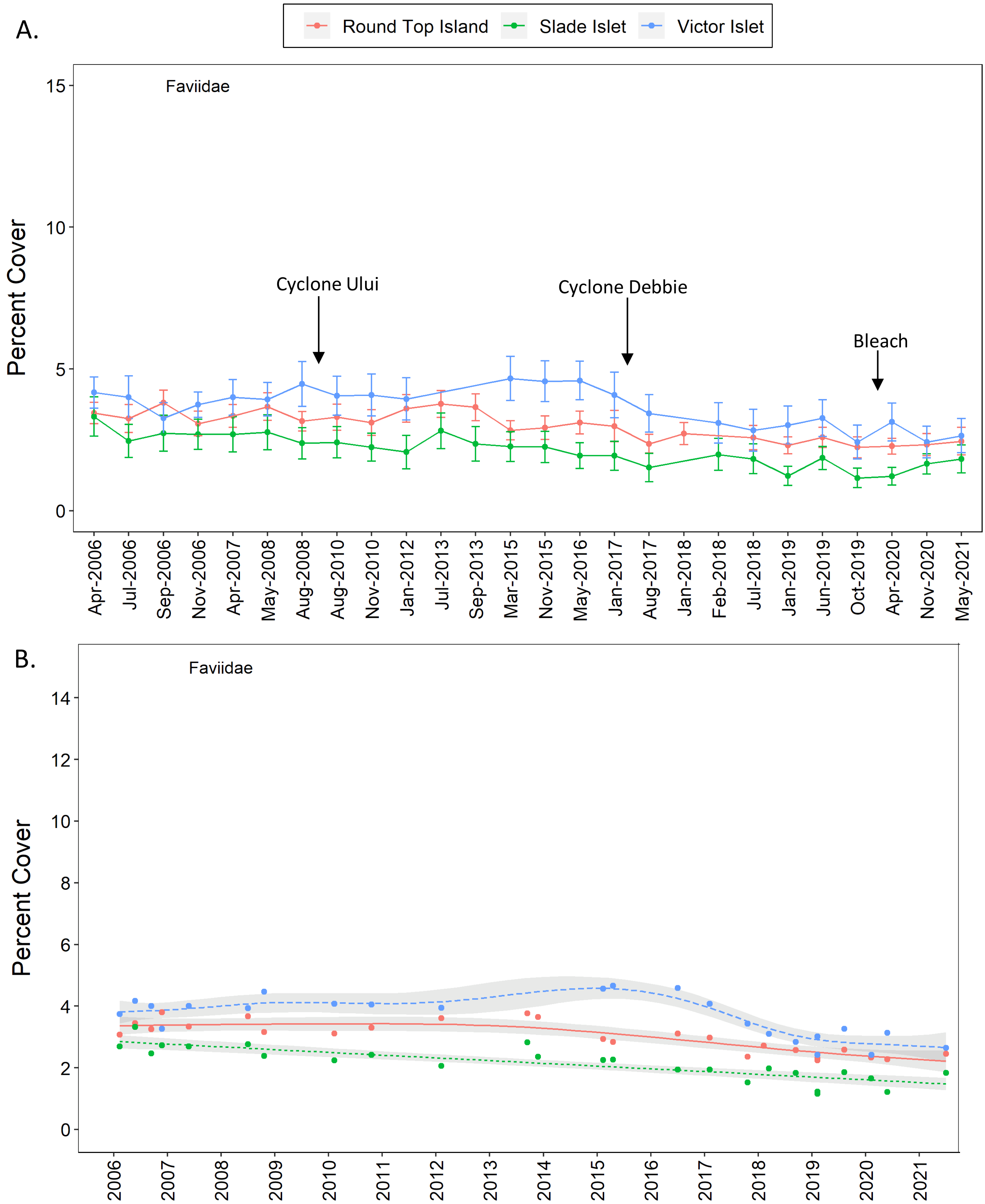

Figure 16. Changes in the cover of Faviid corals.
Graphs show A) grand mean percentage benthic cover from the 2020/2010 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

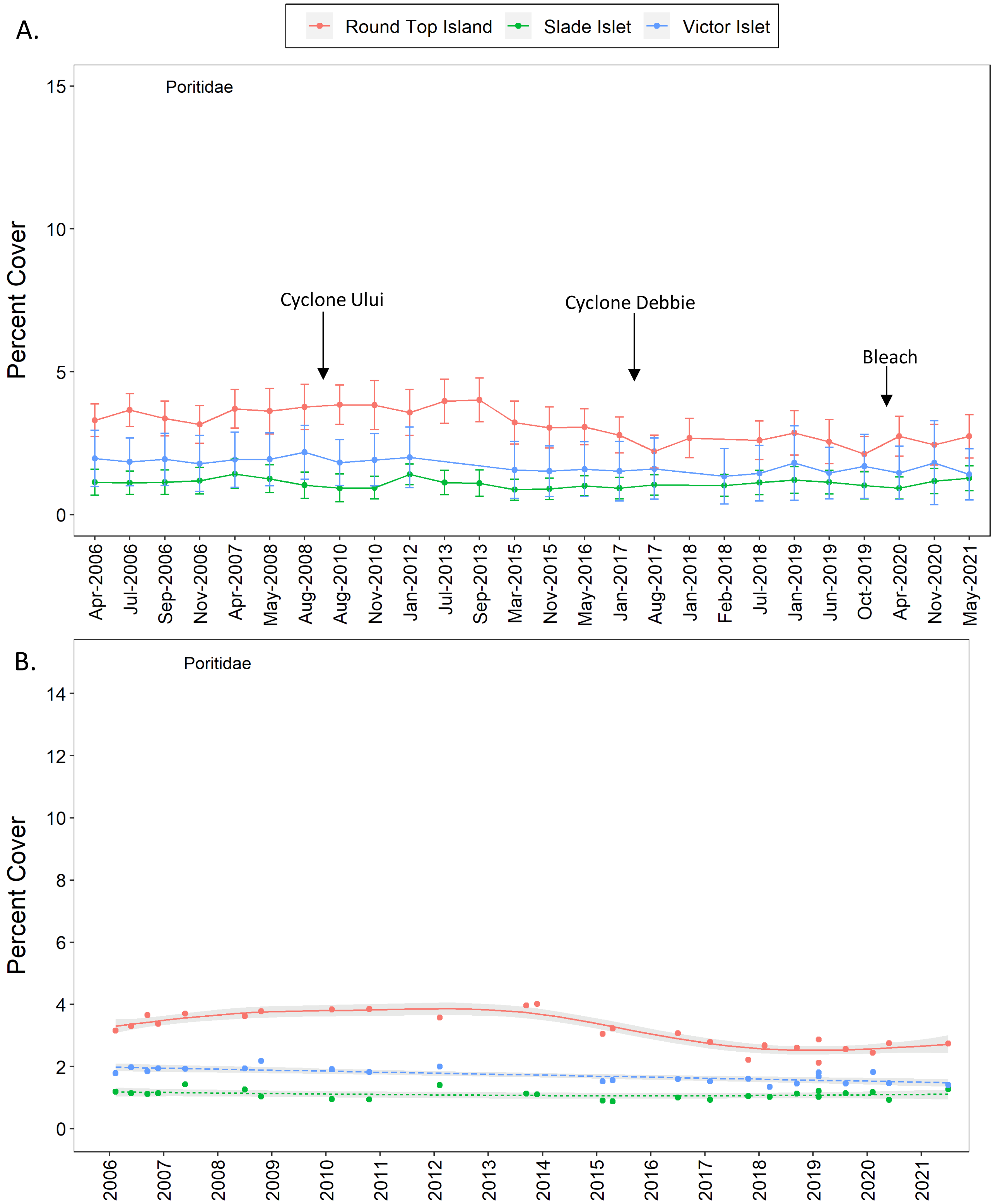

Figure 17. Changes in the cover of Poritid corals.
Graphs show A) grand mean percentage benthic cover from the 2020/2010 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

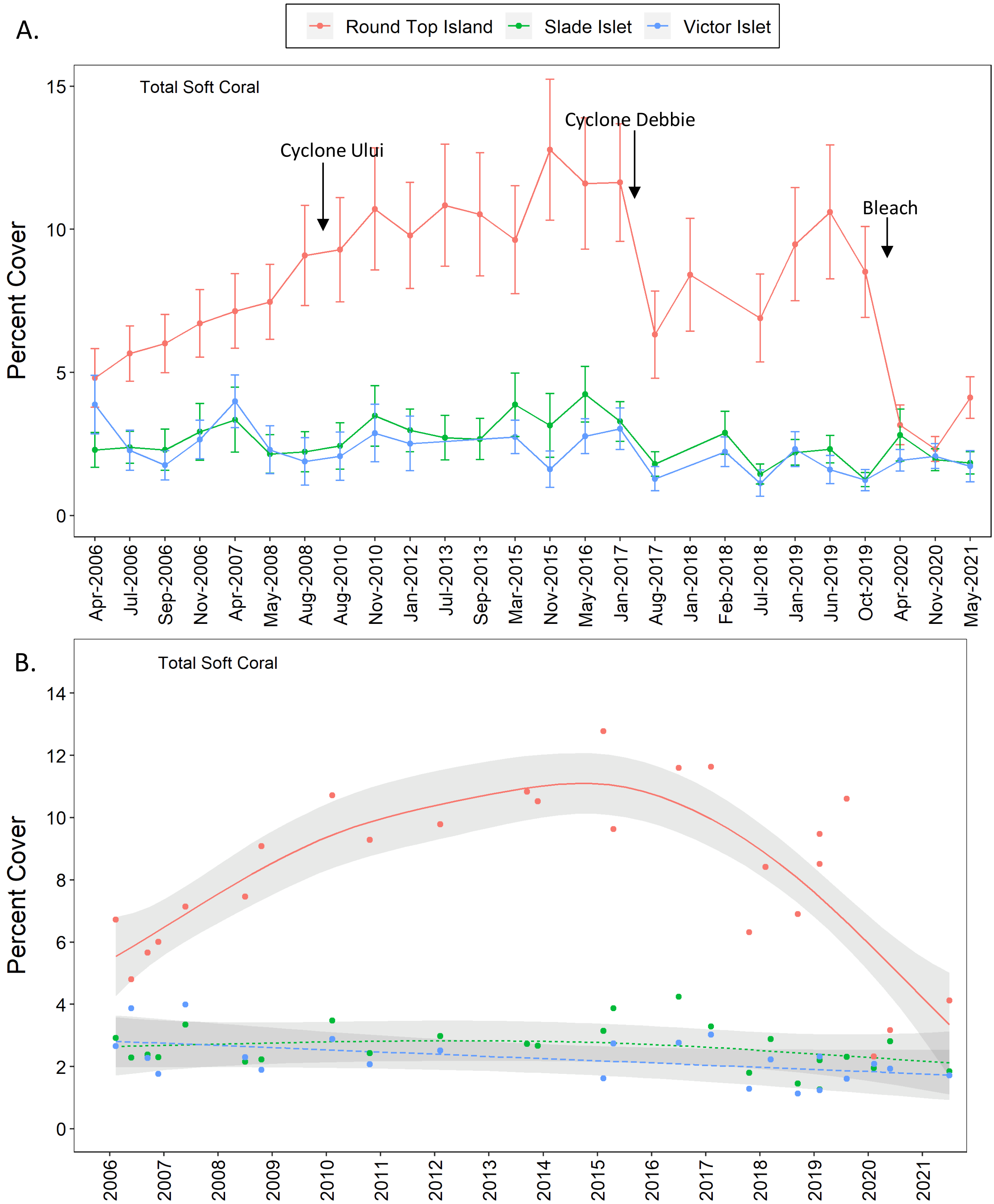

Figure 18. Changes in the cover of total soft coral.
Graphs show a) grand mean percentage benthic cover from the 2020/2021 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

3.3 Photoquadrat vs Line-intercept method

A comparison of photoquadrat versus line intercept for each benthic category was done using the November 2020 and May 2021 benthic cover data. Differences between the two methods were assessed by site at each location for hard coral and macroalgal cover as these two categories are the most likely to be significantly impacted by the change in methodology. Photoquadrats have the potential to underestimate coral cover when there is substantial macroalgae at a transect due to photos not showing any live hard coral underlying the macroalgae canopy which is otherwise recorded using the traditional line intercept method when assessing benthic composition when the canopy is pushed aside by the observer.

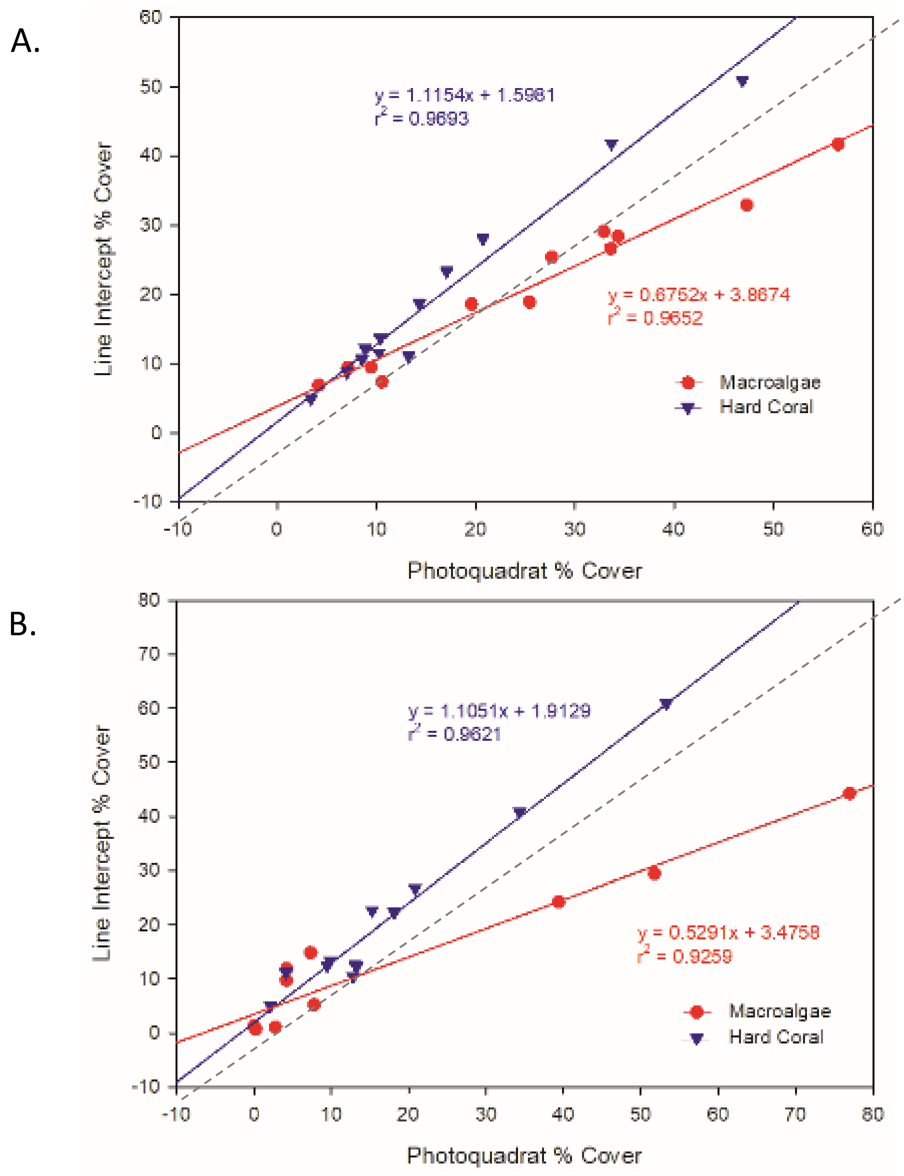

Figure 19. Photoquadrat vs line intercept approximation of macroalgae and hard coral cover. Site data from the three survey locations in A) November 2020 and B) May 2021.

Differences in benthic cover between the techniques were found at all sites and locations (Figure 19). The most notable differences were found at Victor Islet where significant *Sargassum* is still present across the sites despite the impact of the warming event in early 2020 on *Sargassum* coverage. This trend was stronger in May 2021 than November 2020 despite there being greater macroalgae traditionally during the pre-wet survey period. The strongest differences were found at Victor (Table 5). In particular, Victor Site 5 showed a 15% greater estimate of macroalgae from photoquadrats in November 2020 compared to a 33% increase in estimated macroalgae from the photoquadrat technique during May 2021 surveys (Table 5, Figure 19). Round Top, in contrast, showed very little difference in benthic cover estimates between the two techniques (~<2%) irrespective of time of year, which is likely due to the consistently low macroalgae at this location. Results also suggest only minor underestimation of coral cover between the two techniques compared to the stronger differences observed with macroalgae estimates. Irrespective of the magnitude of difference in the linear relationship between techniques, a site- and time-of-year specific adjustment will be considered for historic data when running statistical analyses where historic and new data is compared with disparate techniques. Plotted data will continue to show the historic record with a clear delineation from which the change in methodology takes effect. As discussed in earlier sections, the linear transect data was used in the present report while other significant changes to statistical techniques were applied. The next annual report (2021/22) will have both the new statistical methods and photoquadrat analysis used throughout.

Table 5. Mean macroalgae and hard coral cover estimates from photoquadrat (PQ) versus line intercept estimates from the site level data of the three locations of the ambient monitoring project. RT = Round Top, V = Victor Islet, and SL = Slade Islet.

November 2020						
Site	**PQ Macroalgae**	**Line Intercept Macroalgae**	**PQ Hard Coral**	**Line Intercept Hard Coral**	**Diff. Macroalgae**	**Diff. Hard Coral**
RT1	7.13	9.5	10.24	11.6	-2.37	-1.36
RT3	10.54	7.4	20.73	28.1	3.14	-7.37
RT4	9.43	9.5	33.70	41.8	-0.07	-8.10
RT6	4.17	6.9	13.26	11.1	-2.73	2.16
V2	27.65	25.4	46.86	50.9	2.25	-4.04
V3	47.29	32.9	17.08	23.4	14.39	-6.32
V5	56.56	41.6	3.41	5	14.96	-1.59
V6	34.36	28.4	8.82	12.2	5.96	-3.38
SL1	19.57	18.6	10.38	13.7	0.97	-3.32
SL2	33.61	26.6	14.35	18.7	7.01	-4.35
SL4	25.42	18.9	8.53	10.7	6.52	-2.17
SL5	32.92	29.1	7.03	8.8	3.82	-1.77
May 2021						
Site	**PQ Macroalgae**	**Line Intercept Macroalgae**	**PQ Hard Coral**	**Line Intercept Hard Coral**	**Diff. Macroalgae**	**Diff. Hard Coral**
RT1	0.05	1.4	12.81	10.5	-1.35	2.31
RT3	0.15	0.8	20.86	26.8	-0.65	-5.94
RT4	0.31	0.8	34.32	40.9	-0.49	-6.58
RT6	0.05	1	13.28	12.4	-0.95	0.88
V2	7.81	5.3	53.28	60.9	2.51	-7.62
V3	39.38	24.3	15.30	22.7	15.08	-7.40
V5	76.96	44.3	2.19	5.1	32.66	-2.91
V6	51.77	29.4	4.18	11.2	22.37	-7.02
SL1	2.81	1.1	13.07	12.7	1.71	0.37
SL2	7.37	14.9	18.18	22.4	-7.53	-4.22
SL4	4.29	11.9	9.86	13.4	-7.61	-3.54
SL5	4.25	9.8	9.46	12.5	-5.55	-3.04

The change in methodology does not appear to have an overall impact on index score results (see Section 3.8, Table 11). Future NQBP monitoring will be carried out using the photoquadrat method and coral cover estimates and scores will be adjusted based on this method review.

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

Twenty five surveys spanning more than fifteen years have been made on the three inshore locations since April 2006. Algal cover has been significantly higher on Victor Islet over this period at times than in the other two inshore locations including in May 2021 (Figure 10). Although there were large and significant fluctuations in algal cover on these inshore locations there had been an overall upward trend up until October 2019, especially on Round Top Island and Slade Islet. Between the 2006 baseline and the October 2019 survey algal cover increased from about 8 to 36% overall. However, macroalgal cover decreased dramatically at these three locations during the early 2020 high water temperature event back to 12%. Most of the smaller macroalgal species, such as *Lobophora*, *Padina* and *Hymenea* completely disappeared and many of the larger *Sargassum* plants were damaged and reduced to tattered stipes. Macroalgal cover on Victor Islet in April 2020 was lower than has been recorded during any previous survey but has since rebounded to pre-bleaching levels unlike Round Top and Slade, which have maintained levels similar to baseline surveys in 2006..

There have been significant changes in the cover of hard corals over the fifteen years at all three inshore locations (Figure 10B). 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 10), with 29-35% cover on Victor, 36-41% on Round Top and Slade. Damage from Cyclone Ului reduced coral cover at all three locations but the effect was greatest on Slade and Round Top compared with Victor, for which recovery was observed within the following 18 month period (Figure 10B). 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 10B). Category 4 Cyclone Debbie impacted all three inshore locations in March 2017 causing further coral cover reductions, especially on Slade and Victor Islets. Coral cover did not increase in the first 18 months following Cyclone Debbie in these three locations and was 37% lower than it was during the 2006 baseline. In the 50 months since Cyclone Debbie coral cover has overall remained similar despite some fluctuations between years at these inshore locations with 23.1% in July 2018 to 20.8% in May 2021 and natural variability taken into account among locations (Figure 10B).

There have been significant changes in the cover of all major coral groups over the past fifteen years (Figures 12 - 18). The cover of *Acropora* species was significantly higher on Round Top Island than Victor and Slade until the Cyclone Ului event (Figure 12B). 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 2010 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, the most impacted location for *Acropora* cover, and was nominally lower than the other two inshore locations. *Acropora* cover did not decline on Victor Islet during Cyclone Ului, as it did in the other two locations. *Acropora* cover increased slightly at Victor 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 2.0% , half of the pre-Ului peak (Figure 12B). The cover of these fast-growing corals has not increased significantly in the time since Cyclone Debbie.

The cover of *Montipora* spp. corals has been significantly higher on Slade Islet compared with Victor Islet and Round Top since 2006 (Figure 12B). Cover of this coral group has significantly dropped over the course of the program, from 18-20% in 2006 to <4% in May 2021 following both the Cyclone Ului and Cyclone Debbie events and the high temperature bleaching event of 2020. Following Cyclone Debbie *Montipora* cover on Slade Islet was reduced to a third of pre-Ului levels. The decline in *Montipora* cover on Slade was much higher than in the other inshore locations, giving a strongly significant loss of *Montipora* cover (Figure 12B). This was probably due to the shallow reef on Slade combined with the north-facing aspect of the three *Montipora* dominated sites. The cover of these fast-growing corals had been increasing steadily in the 36 months since Cyclone Debbie up until the bleaching event.

There were fluctuations in the cover of siderasterid corals caused by disease episodes and the two major cyclone events. Overall, Victor populations declined since Cyclone Debbie with overall stability at Round Top and Slade over time. *Turbinaria* corals in the family Dendrophylliidae were the dominant benthic group on Round Top Island where they covered about 6.8% of the substratum during the most recent survey (Figure 15). These corals have been significantly more abundant on Round Top Island than in the other locations (Figure 15B) . There have been significant reductions in *Turbinaria* cover over the fifteen years covered by these surveys, caused by disease and cyclones. These reductions were greatest at Round Top (Figure 15B). Robust corals in the family Faviidae were moderately common at all three locations and declined somewhat in abundance during the fifteen years spanned by these surveys (Figure 16B). Faviid cover decreased more on Slade Islet than on the other locations over time and remain significantly lower in cover at Slade than the other two locations. Poritid corals are also robust but declined somewhat at Round Top from 2015. Besides this slight drop, Round Top and the other locations have had fairly steady poritid cover since monitoring began (Figure 17B).

Soft coral cover doubled on Round Top Island over the ten years till January 2017 (pre- TC Debbie) to a maximum cover of over 12%, but changed very little on Slade Islet and Victor Islet (Figure 18B). There was a marked reduction in soft coral cover in all three inshore locations following Cyclone Debbie but has otherwise been fairly stable at Victor and Slade (Figure 18B). On Round Top soft coral cover initially increased after Cyclone Debbie but decreased significantly during the summer 2020 high water temperature event down to only 2.3% cover in November 2020 with some signs of recovery as of May 2021 but no overall significant improvement.

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 20). 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 20). 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 20).

During the summer months of 2020 high water temperatures caused the first significant coral bleaching event on the Mackay region reefs. A mean of 58% of coral cover was bleached in these four locations, with the percentage of bleached coral cover ranging from 40% on Round Top, to 51% on Victor, and 64% on Slade (Figure 20). Bleaching levels were highest for *Montipora* corals but all coral groups except Siderastreids were affected. These high water temperatures dropped during the late February and early March monsoonal events but corals had not started to recover by the time of the April 2020 ambient survey. Partial mortality of a few bleached colonies was happening during the April survey but coral cover at that time had not been reduced from October 2019 levels (Figure 10).

Other benthic groups were also affected by this bleaching event, including soft corals, some sponges and *Millepora* hydroids. On average, 46 colonies per transect were at least partially bleached compared to <1 colony per transect in October 2019 (Table 6). The greatest frequency of bleaching in Apr 2020 was at Slade where notably the greatest coral mortality was recorded in 2020/2021 (Table 6, Figure 10). At Round Top 54%

of soft corals were bleached, including many *Sinularia* and *Sarcophyton* colonies, with 21% of soft corals bleached on Victor but only around 5% on Slade. The spreading soft coral *Sansibia* had completely disappeared on Round Top Island by the time of the April 2020 survey. It is not known for certain whether this species bleached and died earlier in the bleaching episode but that is the likely explanation for its sudden disappearance.

By November 2020, bleaching frequency had markedly reduced to approximately 2 colonies per transect at all locations; a significantly higher frequency of bleaching for the monitoring program but substantially reduced from the acute stress event earlier in the year. By May 2021, bleaching was completely absent indicating all corals had either regained their pigmentation or had succumbed to the stress event (Table 6, Figure 20).

Table 6. Average coral colony health status during the last four ambient surveys by location.

Location	Oct 2019	Apr 2020	Nov 2020	May 2021
ROUND TOP				
Partially bleached colonies	0.0	44.0	1.62	0.0
Disease damaged colonies	0.56	0.0	0.25	0.56
Sediment damaged colonies	0.31	0.5	0.44	0.12
VICTOR				
Partially bleached colonies	0.0	41.3	0.69	0.0
Disease damaged colonies	0.62	0.06	0.06	0.62
Sediment damaged colonies	0.81	0.12	0.37	0.87
SLADE				
Partially bleached colonies	0.12	53.0	3.62	0.0
Disease damaged colonies	0.94	0.0	0.19	0.06
Sediment damaged colonies	1.56	0.0	0.31	0.50

Corals are recorded as number of colonies per transect.

Table 7. Hay Point fringing reefs: changes in the density of partially bleached, diseased and sediment damaged corals between the four most recent surveys (Oct 2019, Apr 2020, Nov 2020 and May 2021) from the site level data of the three locations of the ambient monitoring project. Results are the anova summary results of a generalised linear mixed effects model output with transect as the random effect.

	ROUND TOP			SLADE			VICTOR		
Factor	**Site**	**Time**	**S x T**	**Site**	**Time**	**S x T**	**Site**	**Time**	**S x T**
Partial bleaching changes	***	***	***	**	***	**	***	***	***
Coral disease changes	**	**	*	NS	***	**	***	**	**
Sediment damage changes	NS	NS	NS	***	***	***	NS	**	**

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

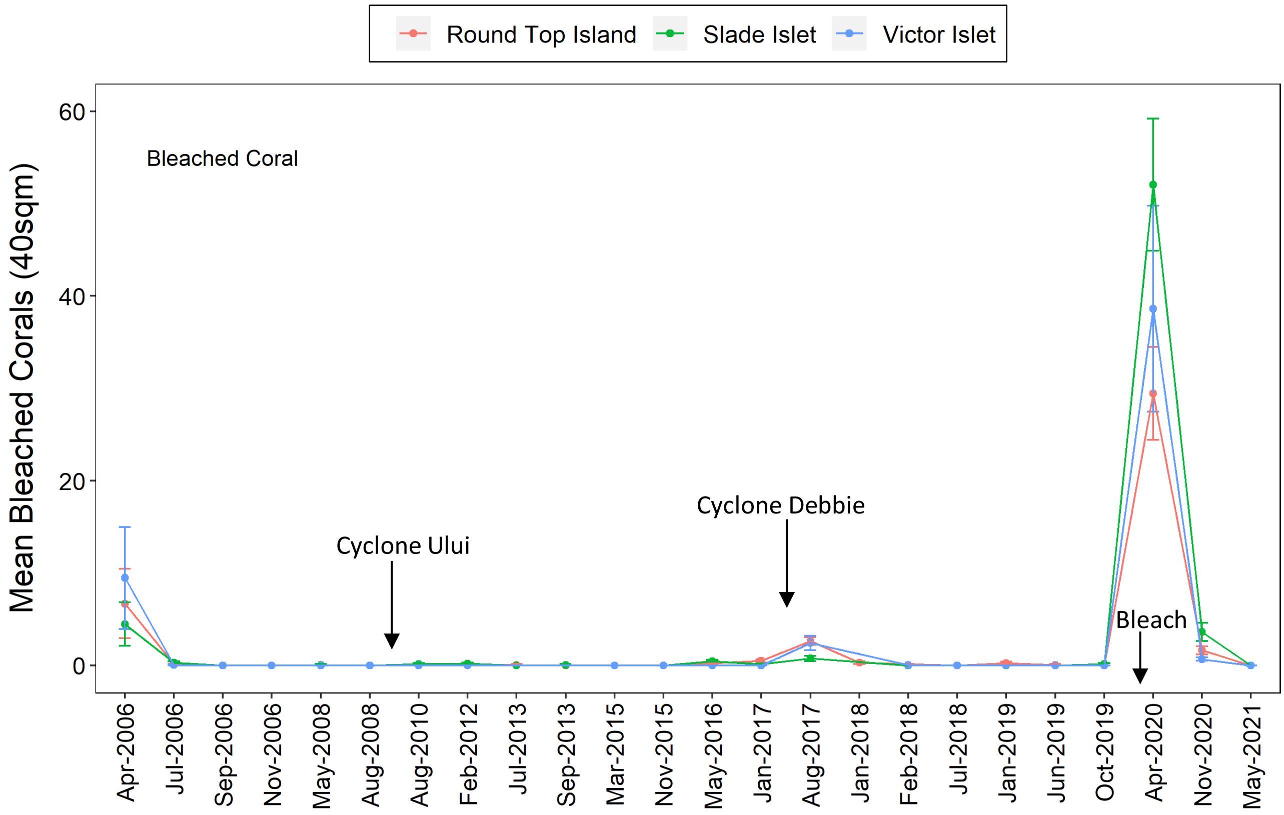

Figure 20. Changes in density of bleached and partially bleached hard coral colonies. Graphs show grand mean density of bleached and partially bleached corals per $40m^2$ from four sites of four 20 x 2m transects in each location from the 2020/2021 ambient surveys and all previous surveys. Error bars are standard errors.

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. In April 2020, the percentage of corals with sediment cover was at an all-time high on Slade Islet (42% of colonies) and also at high levels on Round Top and Victor. Percentage of corals with sediment was similarly high in November 2020, which may be a result of continued stress from the bleaching event hampering efforts by colonies to remove sediment through natural processes of shedding (Figure 21A). Maintenance dredging took place in the Ports of Mackay in December 2020 during the period covered between the latest two ambient surveys. Despite the potential for effects of sediment from dredging, frequency of sediment on colonies was lower in May 2021 or unchanged at all locations and sediment depth was at average levels (Figure 21).

Both the number of corals with sediment load and the depth of sediment on the corals, increased rapidly on Round Top Island and Victor Islet after the commencement of the 2006 capital dredging program, reaching a high of over 1.0mm on Victor Islet (Figure 21). 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 21). 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 21). 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 21). During the 2018 surveys both the number of corals with sediment and sediment depth were at very low levels.

Table 8. 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.	
PERCENT OF TOTAL COLONIES WITH SEDIMENT LOAD						
Apr 2020*	34.2%		37.9%		41.7%	
Nov 2020	25.9%		41.2%		14.1%	
May 2021	11.2%		17.2%		22.2%	
MEAN MAXIMUM SEDIMENT DEPTH (mm)						
Apr 2020	0.23	*0.36*	0.25	*0.41*	0.33	*0.50*
Nov 2020	0.19	*0.37*	0.26	*0.37*	0.10	*0.32*
May 2021	0.07	*0.21*	0.20	*0.80*	0.16	*0.34*

*Figures are grand mean sediment depth in mm with standard deviations in italics where appropriate. Prior to Nov 2020, six sites were monitored making the total number of colonies examined 480.

Table 9. Hay Point Fringing Reefs: Changes in sediment depth on corals between the four most recent surveys (Oct 2019, Apr 2020, Nov 2020 and May 2021) from the site level data of the three locations of the ambient monitoring project. Results are the anova summary results of a generalised linear mixed effects model output with transect as the random effect.

	ROUND TOP			SLADE			VICTOR		
Factor	**Site**	**Time**	**S x T**	**Site**	**Time**	**S x T**	**Site**	**Time**	**S x T**
Coral sediment changes	***	***	**	***	NS	NS	***	NS	NS

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

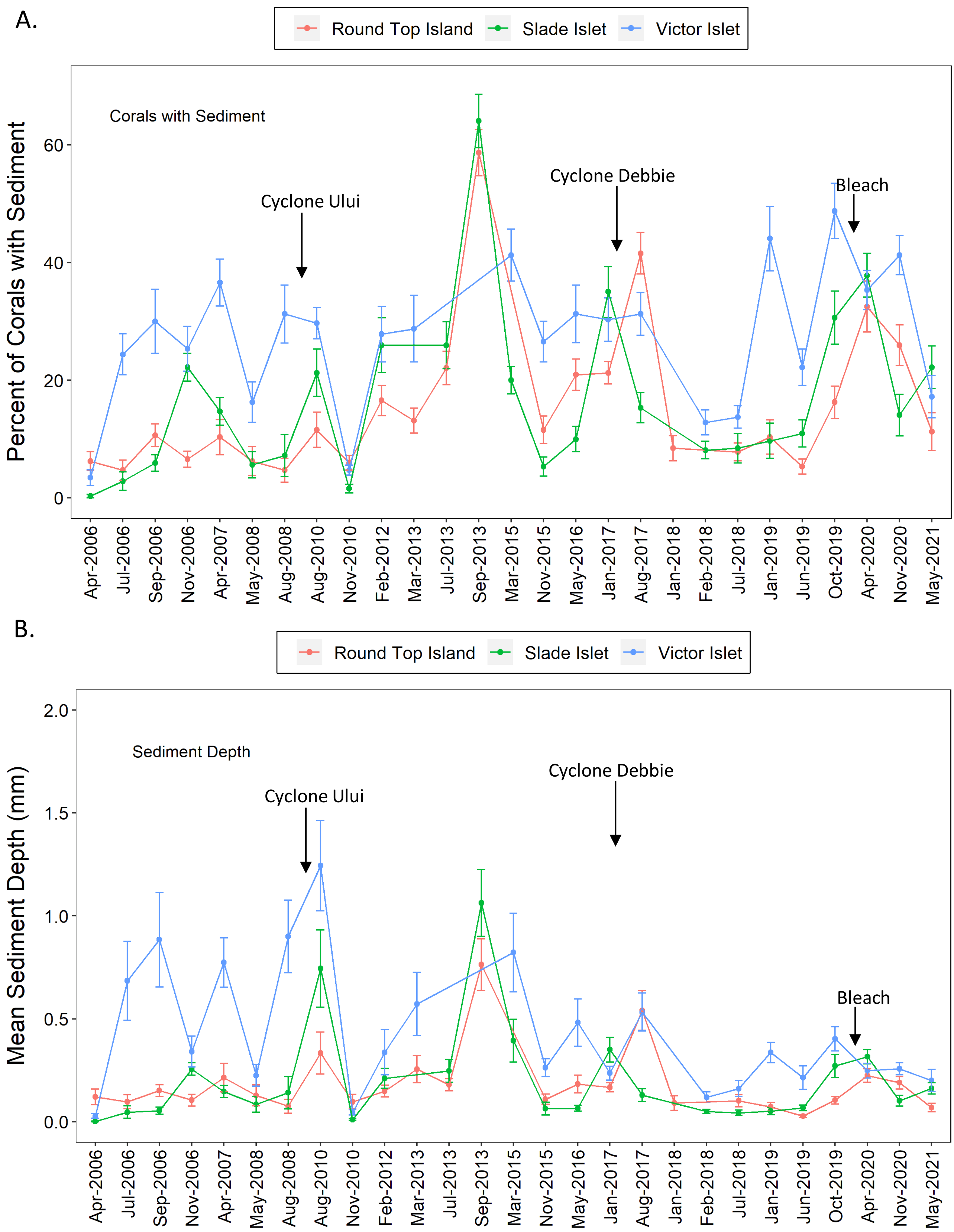

Figure 21. Changes in Number of Corals with sediment load and sediment depth. Graphs show percentage of the 320 coral colonies examined in each location that had measurable sediment on part of the surface during each survey and the mean depth in mm of that sediment for the 2020/2021 ambient surveys and for all previous surveys. Error bars where appropriate are standard errors.

2.6 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 on the inshore locations since the Cyclone Debbie event. The numbers of sediment damaged corals were very low at the time of the November 2020 survey in all locations with no significant increase in May 2021 despite maintenance activity occurring in Mackay Harbour between the 2020/2021 surveys (Figure 22).

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 22A). Damage levels on Slade Islet were low during this event (Figure 22A). There was another much smaller peak in damage levels during the 2008 bed-levelling event on all three locations. Flood and cyclone events during 2011 increased sediment damage at Victor Islet to near capital-dredging levels and caused unprecedented damage on Slade Islet reefs (Figure 22A). 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 fifteen years but this was ended by sediment resuspension during Cyclone Debbie with damage at all locations and unprecedented damage at Round Top Island (Figure 22A).

A small number of diseased corals are present in most coral reef communities. The coral groups most often affected by disease in the Mackay/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 November 2020 ambient survey and similar to April 2020 even after the majority of corals had recovered from the bleaching event evident in April 2020 (Figure 22B). A small increase in disease was found during May 2021 which may be a symptom of reduced resilience following the stress from bleaching the year prior. However, disease was still relatively low in May 2021 which may in part be due to good recovery with relatively benign weather conditions over the 2021 wet season.

There were significant fluctuations in the density of diseased corals over the fifteen years spanned by the surveys reported here, with order of magnitude changes at each inshore location (Figure 22B). Disease impacted corals were present at all four locations and there were no overall trends in abundance at any location (Figure 22). Small colonies sometimes died completely when affected by disease but usually disease only caused partial colony mortality.

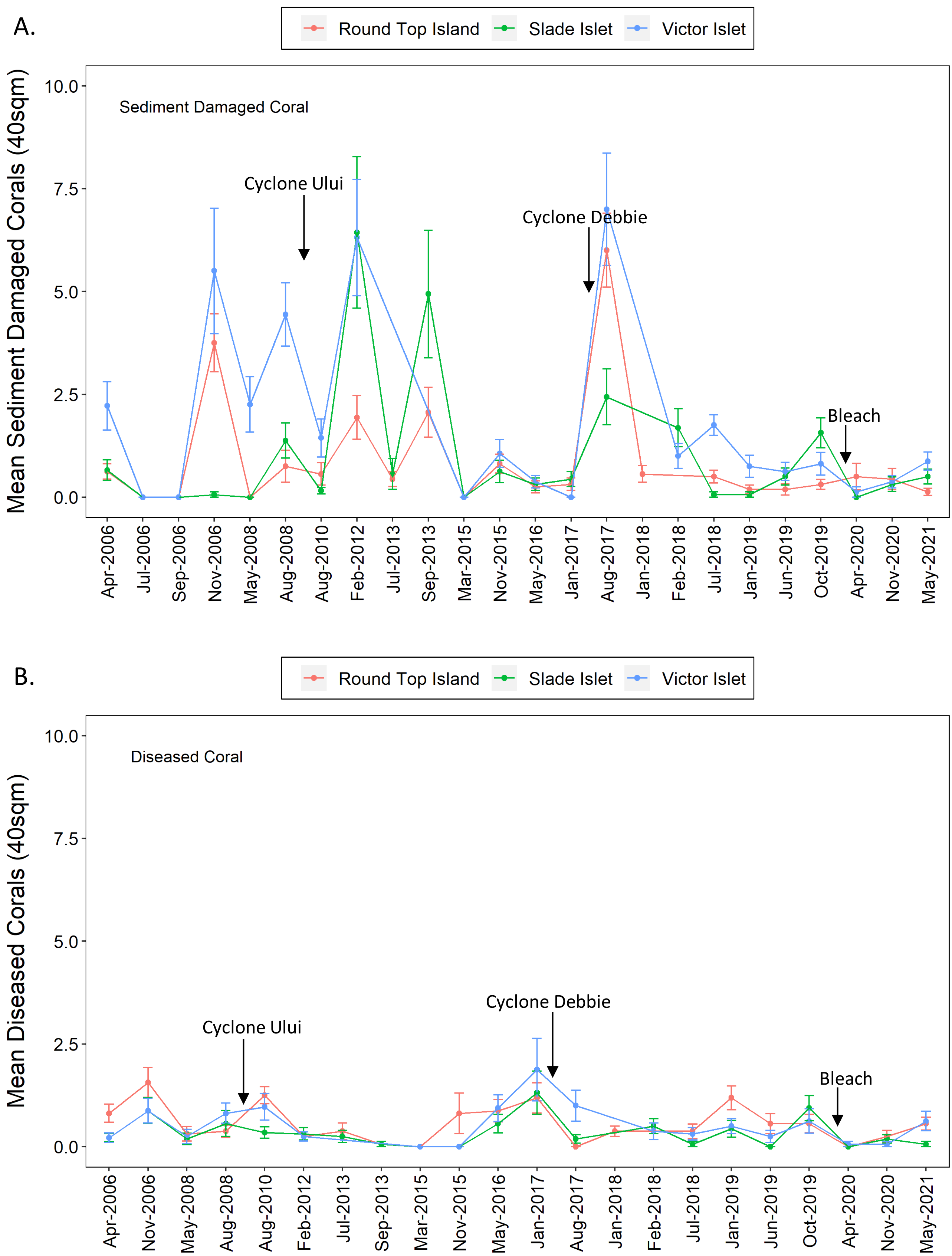

Figure 22. Changes in density of sediment damaged and diseased coral colonies. Graphs show grand mean density of diseased coral colonies and sediment damaged corals per 40 m^2 from four sites of four 20 x 2m transects in each location from the 2020/2021 ambient surveys and all previous surveys. Error bars are standard errors.

2.7 Coral Recruitment Patterns

Numbers of hard coral recruits less than 10 cm in diameter were relatively high on these reefs during the November 2020 ambient surveys, with a grand mean over all locations of about 2.5 recruits m^2 and significantly higher in May 2021 with 3.4 recruits m^2 recorded (Figure 23). Recruit numbers were not significantly different among sites or over time at each location due to the highly variable nature of the dataset (Table 10). Overall, all locations had the highest number of coral recruits for their respective locations since recruit monitoring began in the ambient program in March 2015.

Prior to the recent increase in recruit numbers, there was a significant decrease caused by Cyclone Debbie in 2017 (Figure 23). The decrease in recruit numbers during 2018 and early 2019 was probably due to the marked increase in algal cover over this time. This dense algal cover may have smothered recruits or caused a bias in the counts by making it hard to detect the small corals reliably. In addition, lower reproductive output by corals in the region due to lethal and sublethal stress from the 2017 bleaching events may have reduced recruitment which would have been measurable at these locations in July 2018. Recruit numbers increased again during the first half of 2019 probably due to a reduction in algal cover, decreased in October 2019 when algal cover was again high but were high again during the latest April 2020 survey when algal cover was very low.

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 around 80% of total coral recruits in these locations (Figure 24). The largest number of recruits recorded in this survey was at Round Top Site 1 with 300 recruits in May 2021. Faviids also recruited well on these inshore locations.

Table 10. Mackay/Hay Point Fringing Reefs: Patterns in the density of hard coral recruits between the four most recent surveys (Oct 2019, Apr 2020, Nov 2020 and May 2021) from the site level data of the three locations of the ambient monitoring project. Results are the anova summary results of a generalised linear mixed effects model output with transect as the random effect.

	ROUND TOP			SLADE			VICTOR		
Factor	**Site**	**Time**	**S x T**	**Site**	**Time**	**S x T**	**Site**	**Time**	**S x T**
Hard coral recruits	NS	NS	NS	NS	NS	NS	NS	NS	NS

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

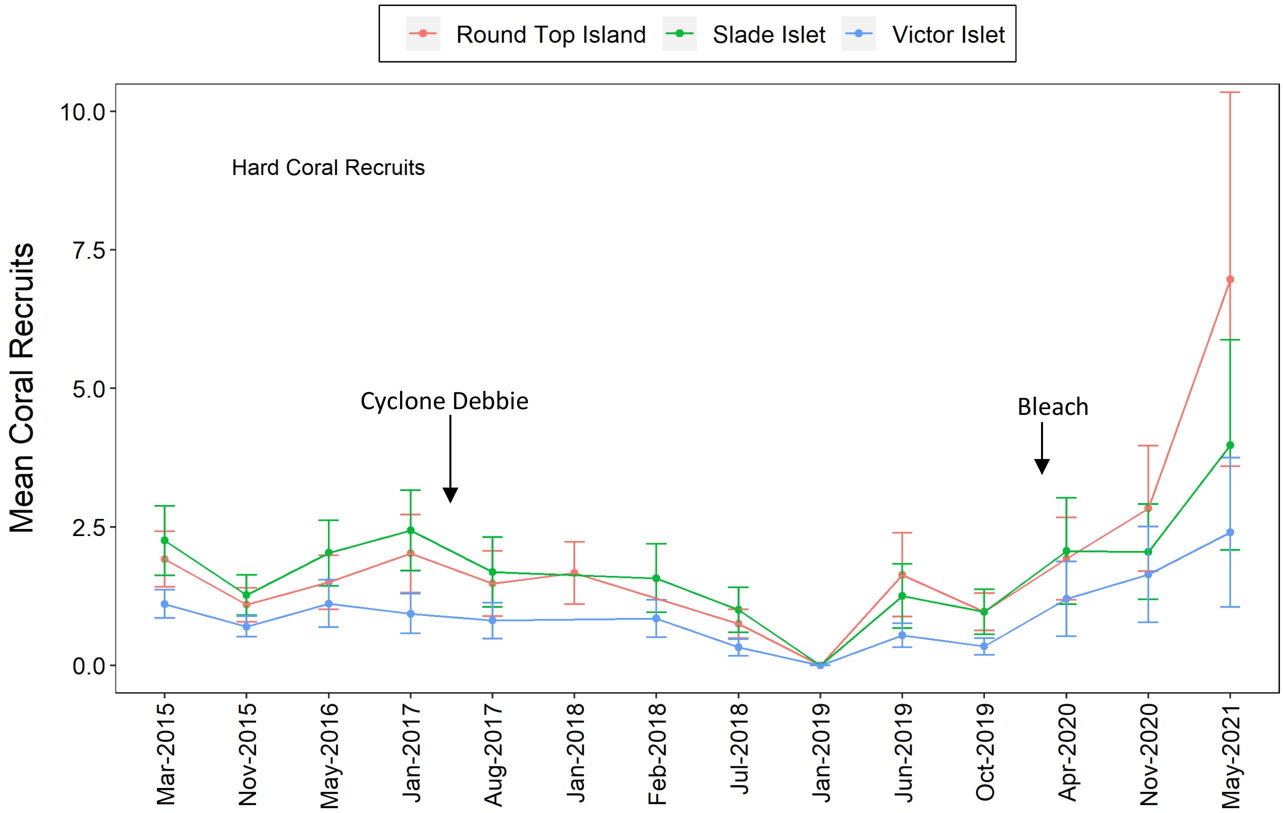

Figure 23. Changes in density of hard coral recruits over the ambient surveys. Graphs show mean density of hard coral recruits per m^{-2} from four sites in each location for the past eleven ambient surveys. Error bars are standard errors.

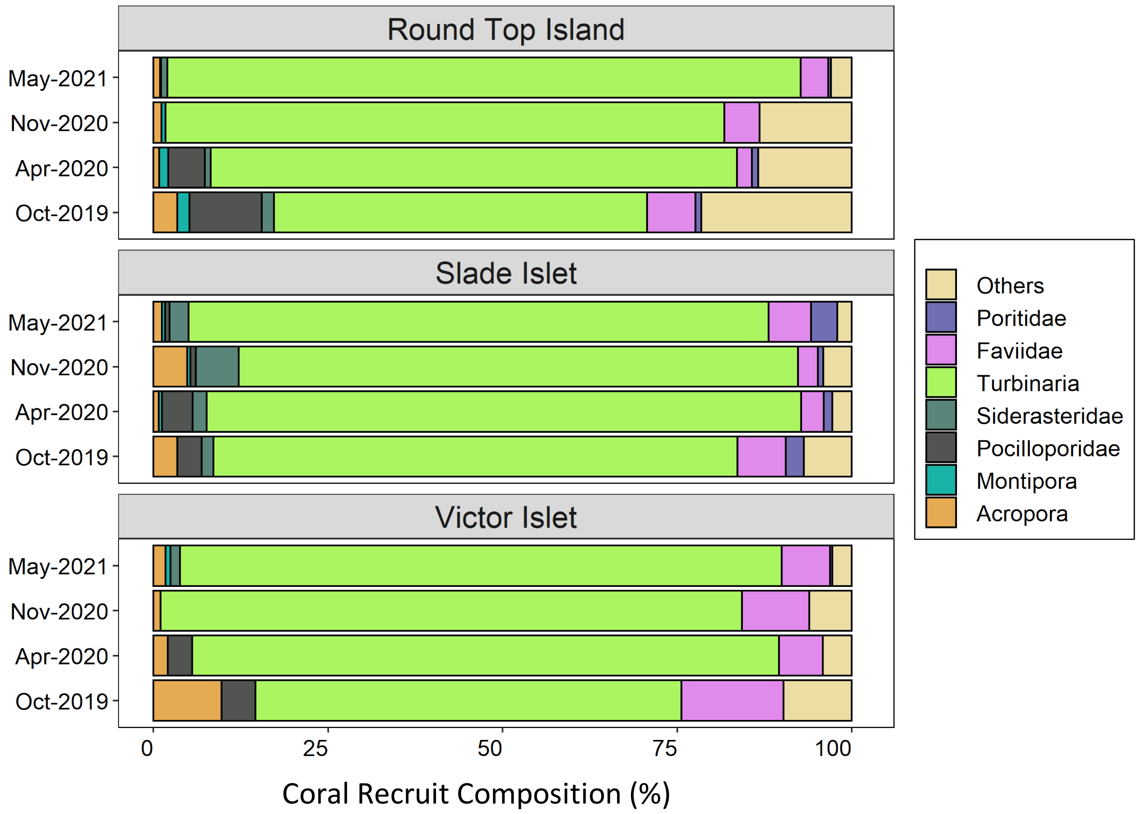

Figure 24. Composition of the hard coral recruit population in the four locations over the last four ambient surveys. Graphs show mean percentage composition of the major groups of coral recruits from the three locations.

2.8 Coral Community Indicators

The Reef Report Card uses a series of indicators to provide an unbiased scale of overall reef condition and resilience. The full reef report card uses five indicators to derive report card scores (Thompson et al. 2016) but two of these require multiple annual observations and other information and are not used here. This follows the precedent set by AIMS in their report on the first four Abbot Point ambient surveys (AIMS 2018). The three indicators used were: Coral Cover; Juvenile Density and Macroalgae Proportion. For details of methods for these indicators see AIMS (2018) and Thompson et al. 2016). Note the coral cover reported here at both locations is based on the line intercept method. A column for line intercept coral cover estimates converted to photoquadrat coral cover estimates using the linear regression established in Section 3.3 is shown in Table 11. Overall, photoquadrat estimates (the AIMS method) do not appear to have a significant effect on the overall index score.

At the time of the November 2020 survey all the Mackay locations had a ‘very poor’ reef index (Table 11). This was driven by the high macroalgae cover recorded at Slade and Victor locations during this survey and the relatively low number of recruits recorded. By the time of the May 2021 survey macroalgae cover had reduced significantly due to the warm early 2020 water temperatures and recruit densities had improved to the point where the overall rating for Mackay improved to ‘poor from ‘very poor’. By location Round Top had the most substantial improvement due to the high *Turbinaria* recruitment driving the overall index score to ‘good’ for this location while Victor was ‘poor’ and Slade ‘very poor’ due to low coral cover (Table 11).

Estimates of reef rating were made for the first three surveys of the original 2006 capital dredge monitoring program that used these same locations and sites. Macroalgal cover was lower and coral cover higher during these 2006 surveys and the overall regional reef rating was ‘poor’ as during the latest May 2021 survey.

Table 11. Reef condition and indicator values during the last two ambient surveys. Note columns ‘PQ’ are indicative only of how scores and cover would be adjusted using adjustments in coverage based on the relationship between line intercept and photoquadrat data. Overall, index scores are not affected by the methodology change.

Location	Survey	Coral cover	PQ† Coral Cover	Macroalgae proportion	Juvenile density	Coral cover score	PQ† Coral score	Juvenile score	Macro-algae score	Index
Round Top Island	Nov 2020	25.4%	21.3	17.6%	3.95	0.34	0.28	0.30	0.32	0.32
	May 2021	26.8%	23.0	2.2%	11.22	0.36	0.31	0.86	1	0.74
Victor Islet	Nov 2020	24.9%	20.9	68.2%	3.85	0.33	0.28	0.30	0	0.21
	May 2021	26.7%	22.9	55.9%	5.48	0.36	0.31	0.42	0	0.26
Slade Islet	Nov 2020	14.9%	11.9	36.5%	3.01	0.20	0.16	0.23	0	0.14
	May 2021	16.5%	12.7	16.6%	5.41	0.22	0.17	0.42	0	0.19
Regional Mean	Nov 2020	21.7%	18.0	40.8%	3.60	0.29	0.24	0.28	0	0.19
	May 2021	23.3%	19.5	24.9%	7.37	0.31	0.26	0.57	0	0.29

Cover score range: ■ Very Poor = 0 to ≤ 0.2| ■ Poor = > 0.2 ≤ 0.4 | ■ Moderate = > 0.4 ≤ 0.6 | ■ Good = > 0.6 ≤ 0.8 | ■ Very Good = > 0.8 | ■ No score/data gap | ■ Not applicable | ■ †scores adjusted with photoquadrat regressions but not used to calculate index scores (indicative only)

2.9 Benthic Community Images

Examples of the benthic community structure at each location and examples of coral health impacts are provided in Figure 25 to Figure 31.

Figure 25. A bleached anemone and red ascidian covering some of Round Top site 1 that has not been seen before at this location.

Figure 26. *Turbinaria* recruits were common at Round Top Island (Site 6) during the November 2020 survey.

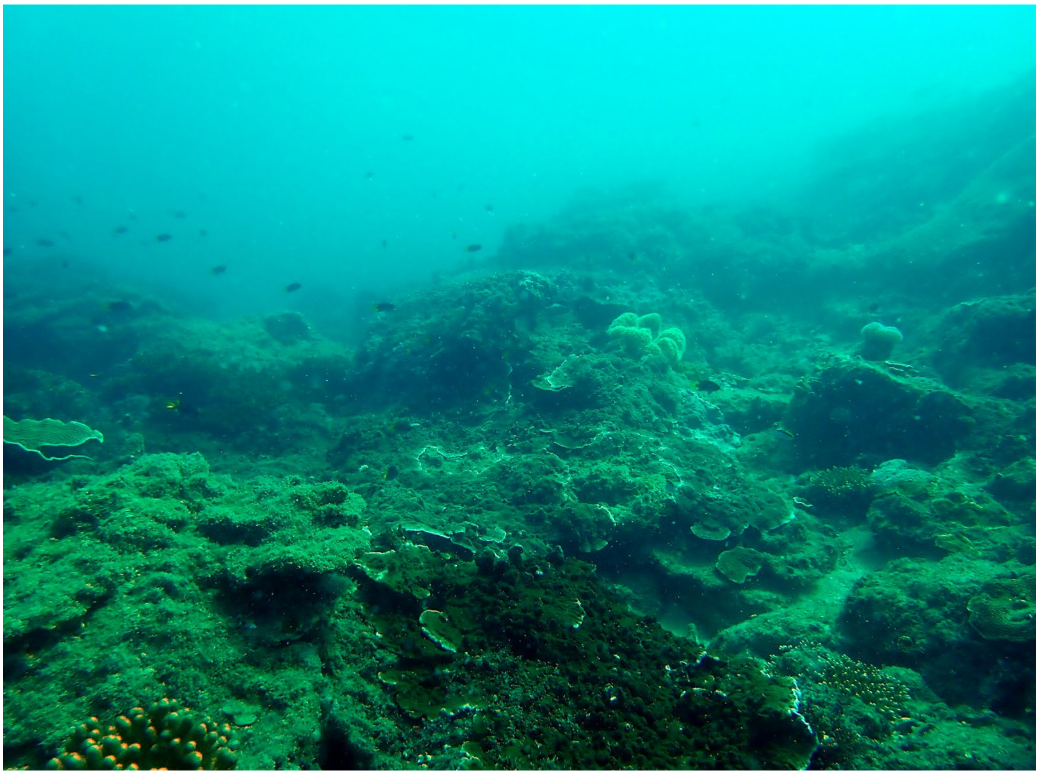

Figure 27. *Montipora* , *Acropora, Turbinaria* and soft corals at Round Top Island in May 2021.

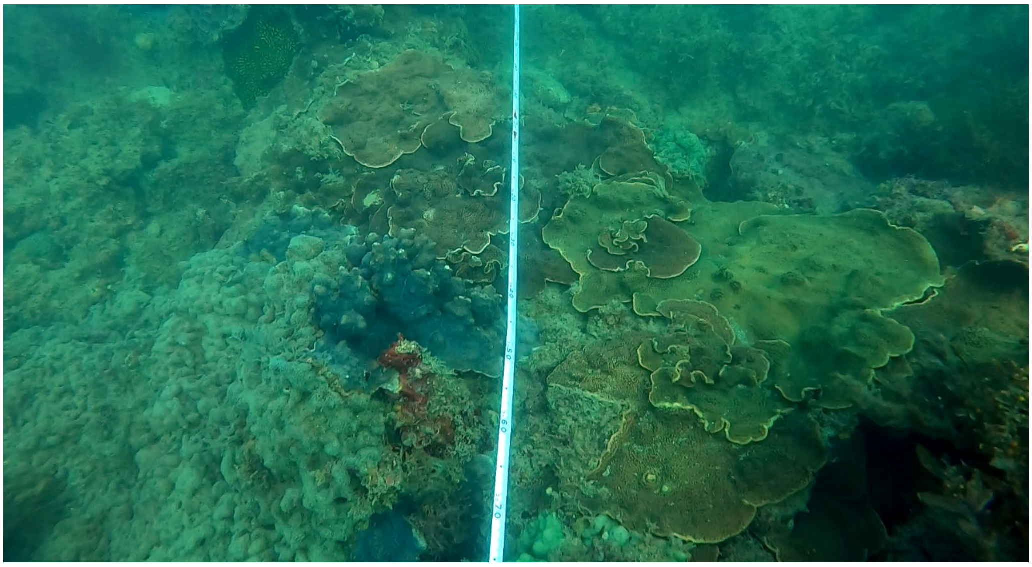

Figure 28. Large colonies of *Montipora* and Porites coral on Victor Islet in May 2021 which were heavily bleached in April 2020.

Figure 29. Healthy *Sargassum* at Victor Islet in November 2020.

Figure 30. Bleached *Montipora* coral colony still recovering its pigmentation on Slade Islet Site 1 in October 2020 following the February/March 2020 bleaching event.

Figure 31. Good visibility in May 2021 but with a noticeable absence of macroalgal cover on Slade Islet following the warming event in February/March 2020.

4 DISCUSSION

4.1 Benthic Cover during the 2020/21 Ambient Surveys

The major change recorded during the 2020/21 ambient surveys covered in this report was twofold: 1) the significant decline in hard coral at Slade Islet and 2) the continued depression in macroalgal cover at Round Top and Slade locations, both likely a result of the 2020 mass bleaching event.

Overall, hard coral for Mackay/Hay Point locations in 2020/2021 was down from 24% in October 2019 to 21% in May 2021, added to the downward trend in the long-term monitoring dataset as a result of the 2020 mass bleaching event. This decline was driven almost entirely by the significant loss of the dominant *Montipora* population at Slade Islet that was detected in November 2020 driving a 50% decline in Slade hard coral cover from April 2020. These further losses in an inshore coral community will slow recovery still further after TC-Debbie -driven declines in the area.

There have been five mass bleaching events caused by high water temperatures that have impacted the GBR. These occurred in 1998, 2002, 2016, 2017 and 2020. The 2020 event was the first to seriously impact reefs in the inshore Mackay region and further south. Up until this event only minor partial bleaching of low numbers of coral colonies had been recorded on three occasions since the 2006 baseline. The 2020 mass bleaching event had affected over 50% of hard coral cover in the three survey locations. Most coral groups had been impacted with the exception of siderastreid corals.

There had been no change in hard coral cover at any of the locations in the first 18 months following Cyclone Debbie (ie to July 2018). Previous fringing reef surveys have suggested that there is rapid recovery of hard coral cover following cyclone events (Sato et al. 2018; Ayling and Ayling 2005), with damaged corals putting on a growth spurt to recover lost space. This has not happened on these fringing reefs, either following Cyclone Ului or Cyclone Debbie. Declines in coral cover caused by extreme events have rather caused a long-lasting change in the community structure. It is worth noting that neither of these events resulted from a direct cyclone hit with the associated very destructive winds but from gale force winds on the outer fringes of the cyclones. Reef damage would have been far more severe and recovery far longer from a direct cyclone impact. Overall, the declines in hard coral at these inshore locations are consistent with documented impacts on inshore reefs from acute storm events (Lam et al. 2018). While cyclones are responsible for driving acute losses, the complexities of chronic and cumulative pressures including poor water quality, wind driven sediment re-suspension, and sublethal bleaching are more difficult to unpack as drivers of supressed recovery despite their well-documented effects on coral reefs worldwide (Lam et al. 2018; Ortiz et al. 2018).

There had been concern that the huge increase in macroalgal cover seen in the July 2018 and October 2019 surveys represented a shift in community structure. However, during the warm summer of 2020 macroalgal cover reduced to levels not seen since the baseline surveys in early 2006 at all three locations. The reason for the strong spike in macroalgal cover in mid-2018 and late 2019 is not clear but is probably related to nutrient peaks in the coastal water mass. It remains to be seen whether the current low macroalgal levels at Round Top and Slade are a temporary dip, caused by the unusually high water temperatures, in a continuing upward trend or whether levels will remain low for some time.

Recruitment, while variable among sites and locations, is stronger than has been recorded over the monitoring program and is a sign of potential recovery for some coral groups. For instance, Round Top has some of the highest *Turbinaria* recruits recorded for an inshore location which may assist recovery if no major disturbances further upset their growth and survivorship. However, recruitment of other important inshore coral groups like *Montipora* that have been reduced by the recent bleaching event, are a very small proportion of juveniles recruiting to these sites. There is further uncertainty about the ability to recover some of these less commonly recorded juveniles and others like *Acropora* that can help with faster reef recovery.

Soft coral cover also reduced dramatically on Round Top Island during the summer of 2020, probably due to bleaching mortality, and was lower during the April 2020 survey than has ever been recorded with only small increases in the November 2020 and May 2021 surveys. The spreading brown soft coral *Sansibia* that previously accounted for about 50% of soft coral cover on Round Top Island had completely disappeared from this location by April 2020 and has not returned in 2020/2021.

4.2 Long-Term Benthic Cover Changes

Macroalgal cover on the inshore survey locations dropped dramatically during the April 2020 survey to be close to baseline levels from early 2006. Apart from this anomaly, that probably resulted from the high water temperatures in early 2020, macroalgal cover has been very high over the past six to seven years and has shown a steady upward trend since early 2006. This is a worrying sign of a possible shift toward more algal dominated reef communities, especially on Round Top and Slade where algal cover was very low during the 2006 baseline survey (1% and 5% cover respectively). It is not known at this stage whether macroalgal cover will recover quickly to previous high levels following this unusual decline. Slow recovery of macroalgal cover may give some respite to coral communities that have been struggling to recover from the impacts of Cyclone Ului and Cyclone Debbie. More rapid recovery of macroalgal cover will continue to slow coral recovery, especially when combined with the ongoing impacts of the early 2020 coral bleaching event. Such suppressed 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 maintenance 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 causing physical breakage or colony removal rather than from sedimentation increases. 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 dropped to almost half of the pre-Ului peak. As would be expected the more fragile coral groups *Acropora*, *Montipora* and *Turbinaria* were most impacted by these events. By the time of the June 2019 survey corals had recovered slightly from the post-Debbie low but the impact of the early 2020 bleaching event had further impacted inshore coral communities as discussed above.

The Mackay/Hay Point locations have not been subjected to a direct cyclone impact over the fifteen years of monitoring. Such a direct hit could cause almost total destruction of shallow fringing reef coral communities on the exposed parts of the islands (A.M. Ayling personal observations from other similar locations). The El Niño–Southern Oscillation (ENSO) outlook shows an established La Niña with current model outlooks that suggest this La Niña will persist until the late southern hemisphere summer or early autumn 2022. La Niña conditions generally result in above average rainfall for the region and potentially above average number of tropical cyclones for the 2021/22 period. Such patterns may further exacerbate recovery if poor water quality or acute cyclone impacts result.

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 was wiped out by Cyclone Debbie and soft coral cover at the other three locations was lower than during the 2006 baseline following this cyclone. Although soft coral cover recovered somewhat in the first 24 months following Cyclone Debbie the 2020 bleaching event caused significant mortality, especially on Round Top Island, driving soft coral cover to the lowest level yet recorded on these reefs.

The major driver of change on these fringing reefs to date appears to be sporadic cyclone events and now some acute coral loss from the 2020 severe bleaching event. 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 in part 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.

4.3 Sedimentation and Coral Damage

The coastal GBR sediment budget has been estimated in a recent study (BMT 2018). Sediments have accumulated in the near-shore region over thousands of years and it is estimated that there is presently about 2 billion tonnes of sediment in the vicinity of the Ports of Mackay and Hay Point. There is less than 200,000 tonnes of new sediment input from river catchments into these port areas each year or about 0.01% of existing material. The major contributor to sediment levels in inshore waters is resuspension of existing seafloor sediments by wave action and tidal currents. It is estimated that there is about 9.7 million tonnes of sediment resuspended every year within the combined Mackay/Hay Point Port areas. Most resuspension occurs during strong wind events (ie when the wind is 18 knots or higher) with an average of around 25 such events a year. Cyclone events resuspend an order of magnitude more sediment than these regular strong wind events with an estimated 7.5 million tonnes of sediment moved within the combined ports region by an average cyclone. For comparison maintenance dredging for the combined ports is about 350,000 tonnes every three years equating to about 83,000 tonnes per year. In contrast, the major 2006 capital dredging project moved about 9 million tonnes of sediment, substantially more than a typical cyclone and about equivalent to the total annual resuspension budget but over a much shorter time period.

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

Cyclone events have caused partial, sediment-driven damage of up to 5% of coral colonies in this region on several occasions over the past decade but the actual decrease in coral cover due to such sediment damage has been much less than 1%. The 2006 capital dredging program caused similar levels of sediment damage to corals and also resulted in a coral cover reduction of much less than 1%. The maintenance dredging for Port of Mackay in 2013 coincided with a strong wind event and sedimentation from these combined events caused significant damage to encrusting *Montipora* corals on the NE face of Slade Islet. During the post-dredging survey following this maintenance dredging over 60% of coral colonies had surface sediment around Slade Islet with mean sediment depth of about 1mm. This event only resulted in a reduction of *Montipora* cover from 18.1% to 16.6% and is the only significant sediment damage to corals we have ever recorded (Ports and Coastal Environmental 2013), including no measurable effect on corals from the latest 2020 maintenance dredging campaign.

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

4.4 Mortality and Coral Disease

Levels of coral disease during the 2020/2021 ambient surveys were in line with levels recorded over the fifteen years spanned by the long-term surveys. Less than 2% of hard corals were affected by disease on these locations at any one time and trends have been down or flat over this fifteen year period. Diseased corals are often present on fringing reefs especially during the warmer summer months and rarely cause significant coral mortality (Ayling and Ayling 2005). Disease affects all major coral groups but rarely causes complete colony mortality.

Studies in the GBR region indicate disease can be more prevalent following warmer than normal sea temperatures (Bruno et al. 2007). However, there is no evidence that stress caused by past dredging operations has increased the susceptibility of corals in this region to disease outbreaks and disease levels have been stable with no measurable effect on disease levels from the 2020 mass bleaching event during 2020/2021 surveys.

4.5 Coral Recruitment

Recruit numbers have been lowest when algal cover has been very high, suggesting that it is partly the ability to detect the recruits that is changing rather than the actual recruit numbers fluctuating. When there is a dense, multi-layer algal community even a careful search may miss small recruits. The significant drop in recruit numbers caused by Cyclone Debbie is, though, a real change and the major impact recorded during these surveys. Macroalgae can deter settlement due to chemical signatures so also may affect recruitment rates. The bleaching event of early 2020 had not appeared to reduce recruit densities recorded during the April 2020 survey. However, the very low macroalgal cover during that survey may have improved detection rates for new recruits. The marked increase in recruitment from the May 2021 survey also is a positive increase, likely influenced by the macroalgae decrease as available substrate for recruitment increased.

Turbinaria corals were by far the dominant component of the recruit population on the inshore locations. This group of corals are inshore, turbid water specialists and are relatively tough and slow growing. Larval input would probably be from adult corals either in the local area or from nearby similar habitats rather than from distant or offshore reefs. Recruitment to these inshore locations is probably not affected by distant, large-scale events such as the 2016 and 2017 coral bleaching episodes but may be impacted as a result of stress to the surviving corals caused by the 2020 bleaching event. Longer term recruitment patterns are needed to assess broader impacts on local area reef recovery.

4.6 Conclusion

Over the last decade, cyclonic impacts have reduced coral cover significantly on all three inshore island reefs and now further impacted by a mass bleaching event. Coral cover has changed least at Victor Islet as a result of cyclonic events in spite of this location being the most affected by sediment during dredging operations over the past fifteen years. This suggests that although many coral colonies on the protected back sites at

Victor Islet are still recovering from previous sediment damage the coral communities are still resilient enough to deal with continued natural impacts. Coral cover impacts have been greatest on Slade Islet where potential dredge impacts were limited to the small Port of Mackay maintenance program in 2020. Slade Islet was the most impacted of the inshore locations by both major cyclone events because it is the furthest north, hence closer to both major cyclones paths, and has the shallowest, most vulnerable reefs that were also affected by mass bleaching. Victor Islet is furthest south of the inshore locations and has been further from the path of the major cyclones, with the lowest level of cyclone impact on coral communities. The slow rate of recovery of hard coral communities on these fringing reefs in the period since Cyclone Debbie together with added declines and stressors from the 2020 bleaching is a cause for concern.

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