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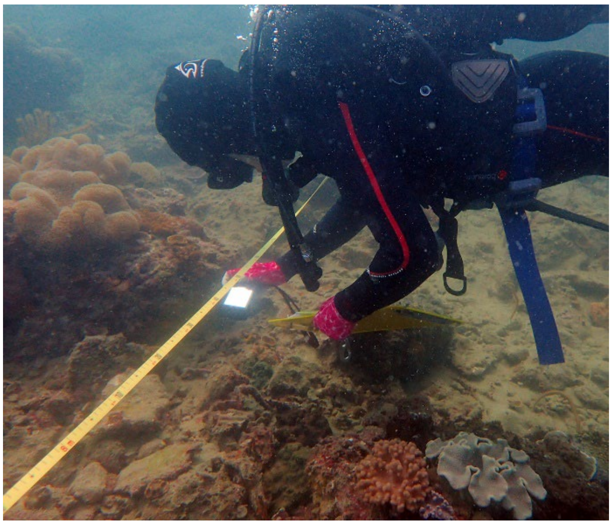

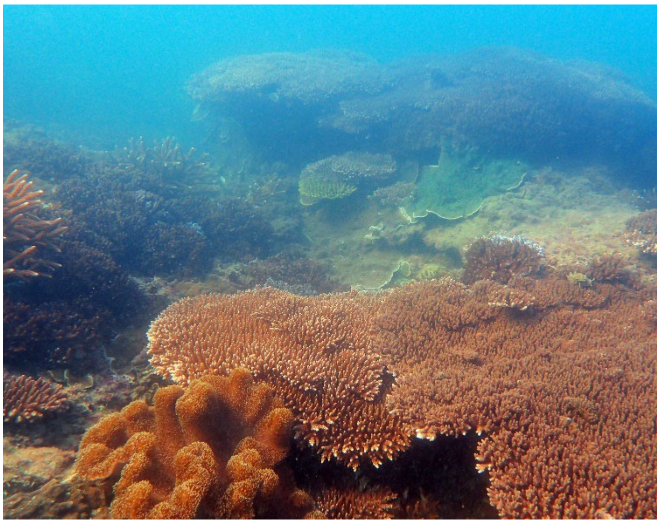

Ports of Mackay and Hay Point Ambient Coral Monitoring Surveys: 2021-2022

Chartrand KM, Hoffmann LR, Ayling A, and Ayling T

Report No. 23/07

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A Report for North Queensland Bulk Ports

Report No. 23/07

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Information should be cited as:
Chartrand KM, Hoffmann LR, Ayling A, and Ayling T. 2022. Ports of Mackay and Hay Point Ambient Coral Monitoring Surveys: 2021-2022. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 23/07, James Cook University, Cairns.

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This publication has been compiled by the Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University.

Acknowledgments:
This project was funded by the North Queensland Bulk Ports Corporation Ltd. We wish to thank the TropWATER field team and research staff who assisted with image processing and statistical analysis including Abbi Scott and Jules Wilkinson. We also wish to thank Tony and Avril Ayling of Sea Research staff for their valuable assistance in the field and data processing. We acknowledge and pay our respects to the Yuwibara People as the traditional custodians of the lands and waters of the Mackay and Hay Point region. We offer our respect to elders past, present and emerging as we work towards a just, equitable and reconciled Australia, and one where we recognise and build our shared knowledge and experiences.

KEY FINDINGS

1. Mackay reefs went through a region-wide mass bleaching event in early 2020. Hard coral mortality led to Slade Islet sites dropping >50% in *Montipora* within 12 months and broader declines at Round Top and Slade in *Acropora*, *Montipora* and *Turbinaria* populations as well as significant soft coral losses at Round Top.

2. Macroalgal cover remains dramatically lower at Round Top Island and Slade Islet with a mean of 3% during the latest June 2022 surveys at these locations. Macroalgal cover had followed a gradual increasing trend at all locations and reached an overall peak of 47% in July 2018 before the 2020 bleaching event knocked back these gains. Victor Islet macroalgae has unfortunately rebounded back to 33% cover in June 2022.

3. Some coral recovery over the 2021/2022 survey period is the first increasing trends in hard corals at these locations since pre-Cyclone Debbie in 2017. Hard coral cover declined 58% on the three inshore locations between the 2006 baseline and post-2020 bleaching surveys. Cover dropped from 38% to 16% due to 2020 bleaching before a small increase to 22% during the latest June 2022 survey. Over the longer term, significant coral loss has been driven primarily by cyclonic impacts with further declines from the 2020 mass bleaching.

4. Soft corals have increased relatively quickly over the last 12 months to regain losses following signs of recovery that began last year. Recovery of soft corals at Round Top, however, did not include the previously dominant *Sansibia*.

5. There was a significant number of coral recruits, particularly at Round Top, for a second year in a row in 2021/2022. Coral recruits were dominated by *Turbinaria* across all three locations.

6. 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 loss of *Montipora* at Slade Islet from the 2020 bleaching event.

7. During the 2021/2022 surveys, both the number of corals with sediment and sediment depth were significantly elevated. Despite these findings, preliminary results from November 2022 site visits found sediment had reduced and no damage or major disease concerns. 2021/2022 surveys were done following localised rainfall which may have temporarily elevated sediment levels at all locations.

8. Overall, lower macroalgae and some increases in coral cover at the majority of sites are positive signs following the 2020 mass bleaching event. 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. Uncertainty remains whether recovery can be significant enough before additional disturbances such as bleaching or cyclones impacts the Mackay/Hay Point reef communities.

IN BRIEF

Coral monitoring in the vicinity of the Ports of Mackay and Hay Point has been ongoing since before the 2006 Hay Point capital dredging program and included four locations; Round Top Island, Victor Islet, Slade Islet and Keswick Island. A 2020 review of the program led to the removal of Keswick Island from the program as it is considered a more mid-shelf reef rather than an appropriate indicator of inshore coral communities. Additional methodology changes were also completed at this time to align better with the inshore coral monitoring at Abbot Point. 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.

Monitoring surveys related to dredging activities and port developments began in April 2006 and continued 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.

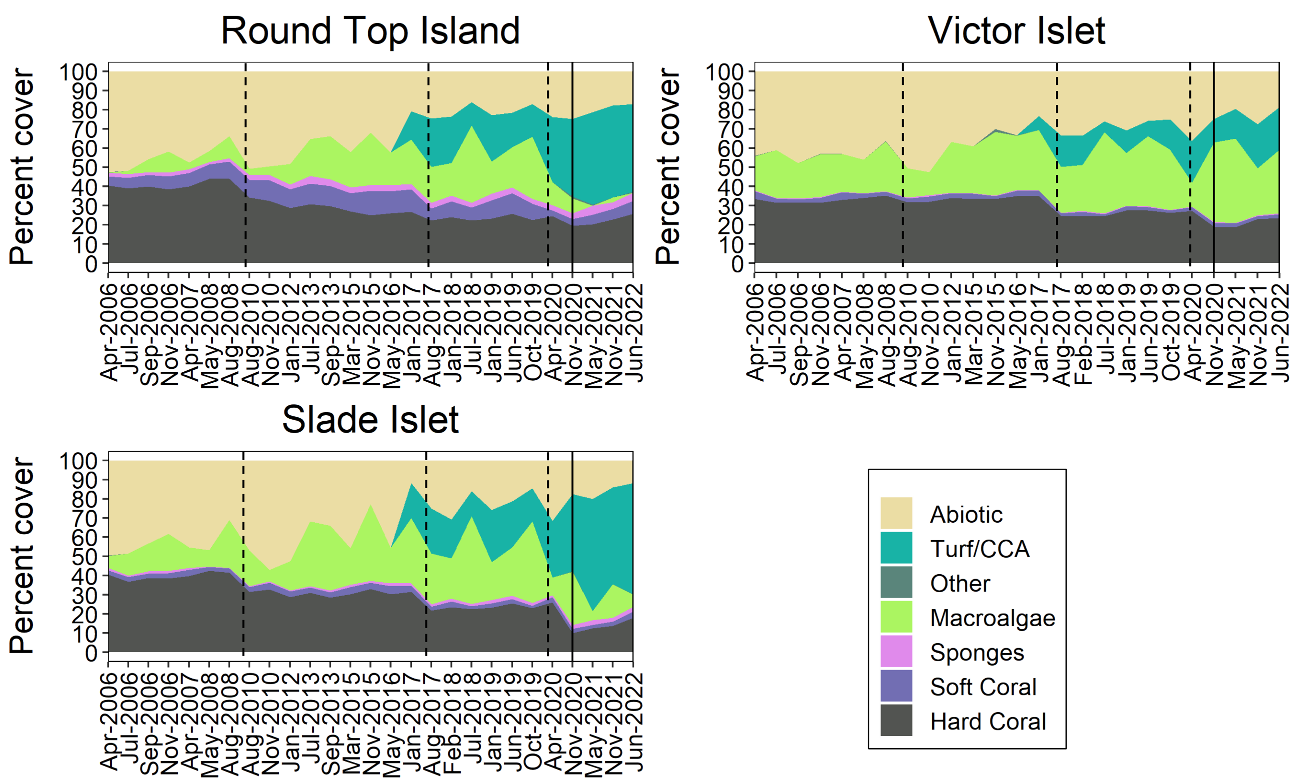

Figure i Summary of changes in the major benthic categories at the three Mackay - Hay Point locations. Graphs show cumulative percent cover from all ambient surveys. Broken vertical lines indicate the times of Cyclone Ului (Mar 2010) and Cyclone Debbie (Mar 2017) and the 2020 warm water event (March 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'. Solid vertical lines indicate the change in methodology from line intercept to photoquadrat analysis to estimate benthic cover composition.

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 from <1% to approximately 30% of the benthic community at all locations.

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 22.4% in June 2022. Since the 2020 marine heatwave, macroalgal cover at Round Top Island and Slade Islet dropped off to levels not recorded in a decade while Victor Islet has seen a rebound in cover.

Over 49% of living hard corals across all locations had some sediment present and with average sediment depth on colonies above average during 2021/2022 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 40-60% of corals affected and mean sediment depths of around 1 mm. Sediment deposition can cause patches of mortality but rarely are significant. Sediment damage from the elevated sediment loads in 2021/2022 appear was very low. 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 due to the marine heatwave. 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 evident by November 2020, particularly in the *Montipora* community at Slade Islet. Soft corals were also bleached during the 2020 event which led to a 50% reduction in soft coral cover at Round Top Island between October 2019 and April 2020 with the mortality of *Sansibia* soft corals. The soft coral cover has returned to pre-2020 levels 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 2021 and June 2022 at Round Top Island and Slade Islet. The macroalgal loss is likely due to the high summer water temperatures in early 2020. The macroalgae declines at Round Top and Slade have provided a reprieve for coral to 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 but it is unclear if these positive effects will lead to long term 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 Round Top and Slade in 2021/2022 surveys with low levels at Victor Islet.

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 at Slade Islet and depressing trends at the other two locations as well as soft coral at Round Top. 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 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 2021-2022 financial year was almost 3.6 million tonnes and nearly 44 million tonnes through Hay Point. The current export capacity through both existing coal terminals 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.

1.2 Objectives of Survey

Survey design is structured to relate to 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-2021 and mid-2022 that have not been included in previous reports, but makes comparisons with the results from previous surveys.

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

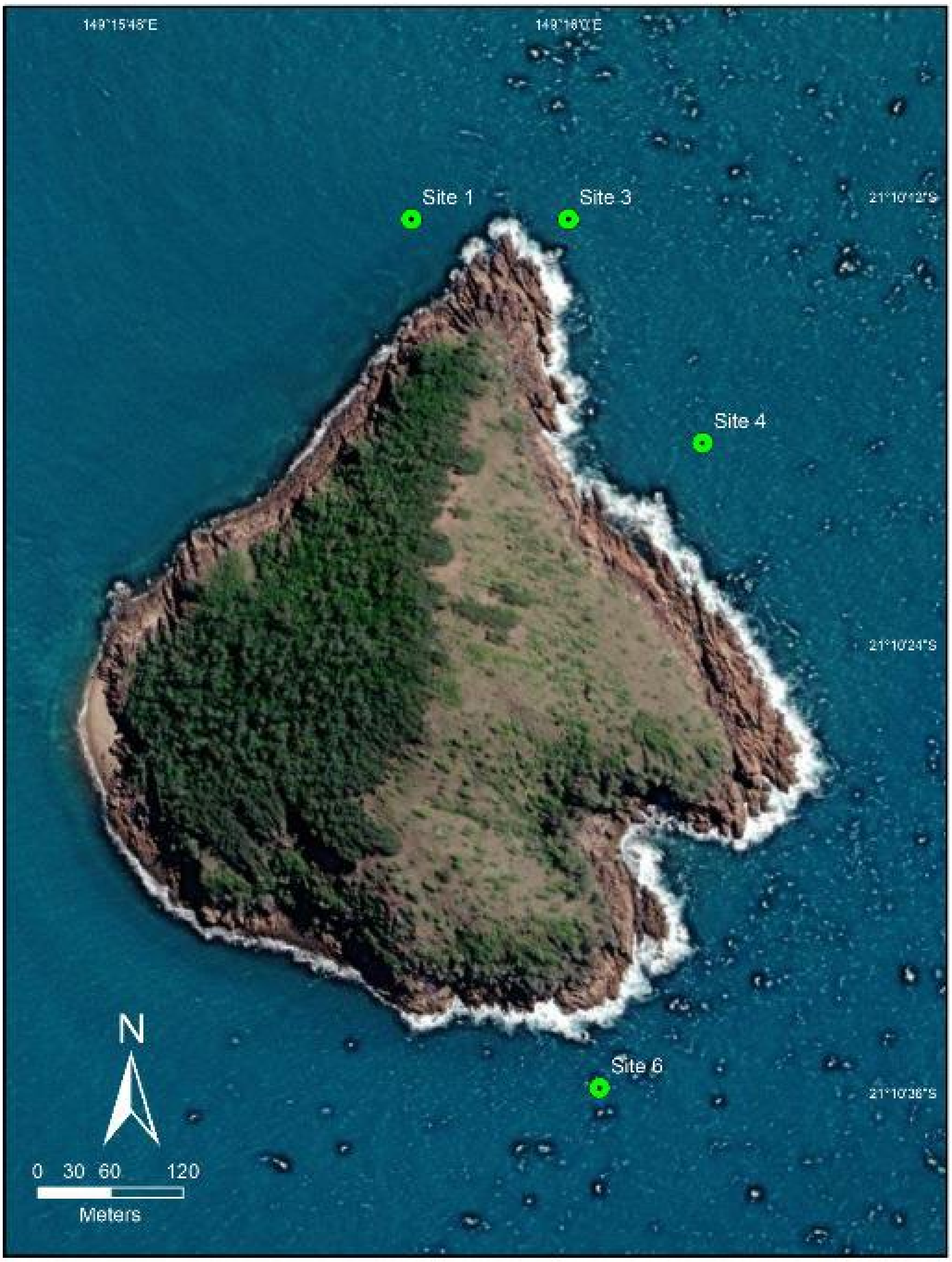

Figure 2. Round Top Island location showing position of the four coral monitoring sites

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

* Two sites per location dropped from the program in November 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). This same review saw Keswick Island removed as a monitoring location. Previous site locations and timing can be found in historic monitoring reports.

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
Nov 2021	X	X	X
Jun 2022	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 November 2021 to June 2022. The two survey periods were pre-wet, from 24-26 November 2021 and post-wet from 3-5 June 2022.

During rough weather, underwater visibility in the study areas can be zero due to high levels of turbidity. In general, visibility is best during the post-wet surveys with lower macroalgae cover making it easier to locate stakes and observe the benthic composition compared to pre-wet surveys later in the year. Round Top typically has the best visibility followed by Slade Islet and Victor Islet which are prone to higher turbidity from regular tidal movement and shear stress at these shallower sites.

2.3 Benthic Transect 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. 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 for benthic composition, sediment deposition, coral health including disease and bleaching and coral recruitment to be assessed.

2.4 Benthic composition from photoquadrats

From November 2020 (pre-wet) surveys, methods were modified to use photoquadrats in place of line intercept techniques to estimate reef benthic composition. The line intercept method was used since the inception of the Mackay ambient coral monitoring program and has 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). However, a desire to align with the Australian Institute of Marine Science (AIMS) methodology for calculating benthic cover (Jonker et al. 2020) led to a review and shift to the current photoquadrat technique. The 2020-2021 coral report (Chartrand et al. 2022) contains a review of local benthic cover based on photoquadrat analysis compares to historical line intercept categories. Overall, trends were not significantly affected except at some sites with high seasonal macroalgae cover which is taken into account during analysis of data.

The photoquadrat method captures 40 images along each transect taken at approximately 0.5m intervals and analysed using coral point count open source software CoralNet to annotate images and estimate data at the transect, site and location level. This type of analysis is used widely to estimate percent cover data generated as the proportion of points assigned to a given label relative to the total number of points. Twelve points were analysed per photo providing a total of 480 points categorised per transect.

The following labels were assigned under each point analysed:

- 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.

Substantial updates were also made to the statistical analyses in the ambient coral monitoring program's annual report in the 2020-2021 period (see Section 2.8). Historical line intercept data is still used in all plots but modified to represent the reduction in sites in order to compare ongoing trends at each location. A clear delineation is provided in all benthic composition plots to indicate the shift in methodology from November 2020 onwards.

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

In order to assess relatively rare events such as coral disease or sediment damage, a wider area surrounding fixed transects lines was evaluated using the following parameters:

- 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 2021 to July 2022 and compares these conditions to data collected since coral monitoring began in early 2006. The Pioneer River which discharges into the nearshore environment inshore from Round Top Island is used here as an indicator of local river inputs.

3.1.1 Rainfall and River Flows

The rainfall measured by the Bureau of Meteorology (BOM) at the Mackay Airport (BOM 2017) is provided graphically in Figure 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 2016) 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 2017). Additional rainfall in the catchment areas inland from Mackay contributed to the elevated river discharges. Since then, river discharges have been lower than average apart from slightly elevated rainfall and river flow in 2016/2017 (Sea Research 2017; Advisian 2016). The 2021/2022 wet season was near or slightly above average in total rainfall but only one rainfall event with over 200mm in a 24hr period was recorded in late November 2021 (Figure 5A, see inset). While not a substantial single event, rainfall was above average in May 2022 just prior to post-wet sampling in early June.

Water discharge events from the Pioneer River were well below average for the 2021/2022 period (Figure 5B) with an overall annual river flow of 248,326 ML, the third consecutive year well below the 10 year average level (see inset). The only substantial peaks of over 10,000 ML/day was recorded in late April and May 2022 which were 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.

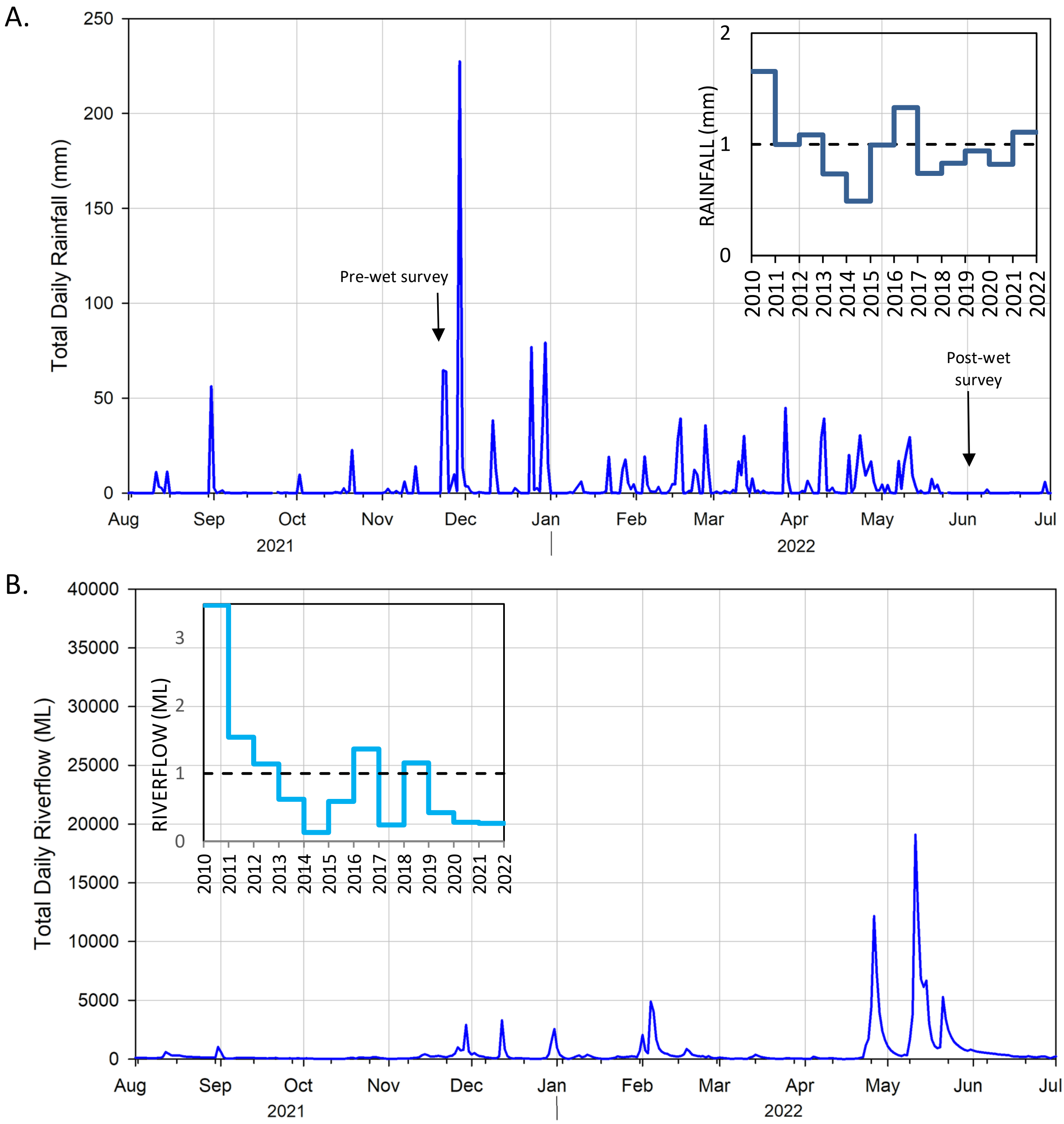

Figure 5. A. Daily rainfall measured at the Mackay Airport with inset of change in rainfall as a proportion of the long-term average, B. the Pioneer River discharge at Dumbleton Weir. Insets represent data as a proportion of long-term average.

3.1.2 Cyclones

During the 2021/2022 ambient monitoring period no cyclones or significant monsoonal event impacted the region with no major rainfall event of the wet season. The only cyclone recorded in the Great Barrier Reef region was Cyclone Tiffany which had minor impacts as a category 2 system when it crossed the coast near Princess Charlotte Bay in the Far North.

Strong winds impacted the Mackay region on 20th of October 2021 when a severe thunderstorm recording hail and a maximum wind gust of 120 km/h was recorded at the Mackay airport despite little rainfall accumulation during this event.

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

Sea temperature measurements are collected by TropWATER at a number of sites in the nearshore environment offshore from Mackay (Waltham et al. 2021). Water temperatures in the Mackay region were elevated for a brief time during the 2021/2022 summer period (Figure 6). The highest temperatures recorded in the summer of 2021/22 were in early March when all three locations reached >30°C for 11 consecutive days before beginning to decline (Figure 6). At that time, the NOAA Coral Reef Watch (CRW) Southern GBR Virtual Station recorded an Alert Level 1 which indicates the potential for bleaching but did not reach Alert Level 2 which indicates a significantly higher risk of bleaching stress to corals (NOAA Coral Reef Watch). In comparison, sustained elevated water temperatures recorded by TropWater loggers and by the CRW Virtual Station in March 2020 leading to an Alert Level 2 and mass coral bleaching in the region. Overall, sea surface temperatures continue to remain above the long term average† in the Great Barrier Reef Marine Park (Figure 7).

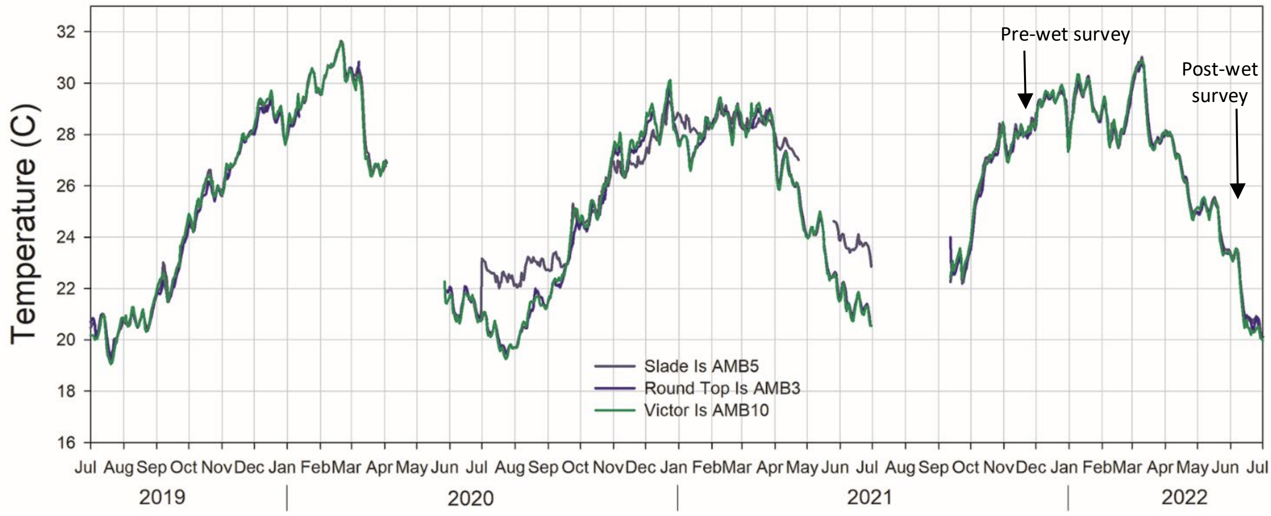

Figure 6. Maximum daily temperature recorded from 2019-2022 by the NQBP water quality monitoring team at nearby logger sites (Waltham et al. 2022).

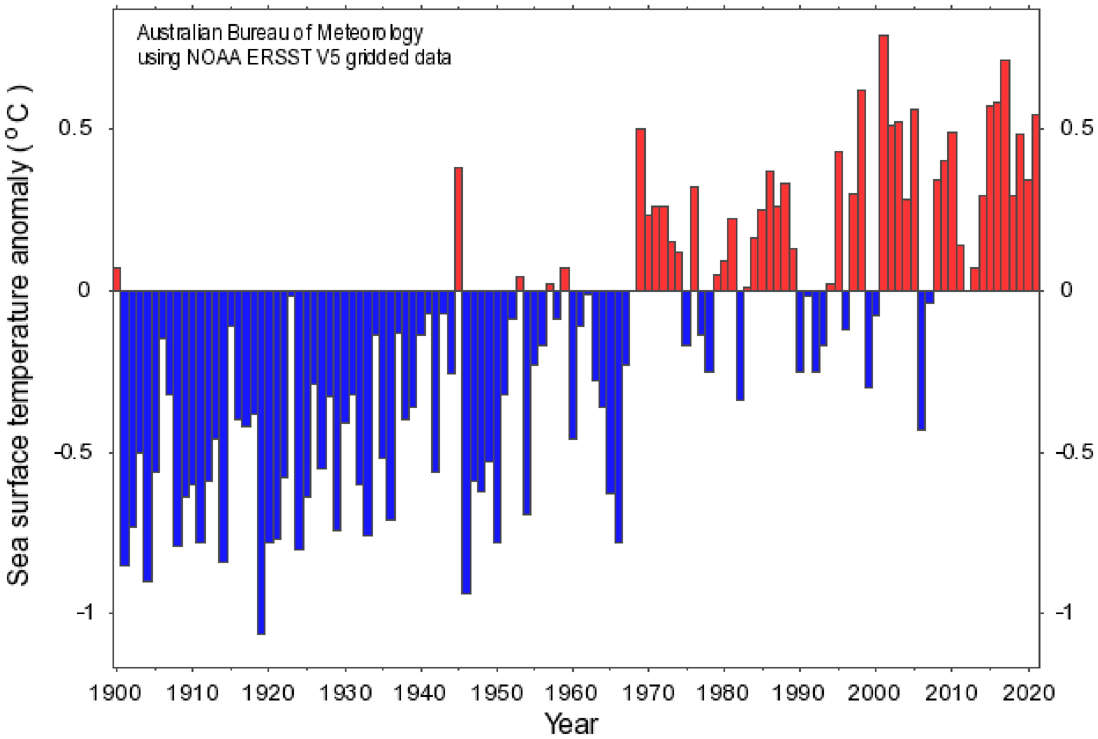

Figure 7. Wet season (Oct – Apr; 1900-2022) sea surface temperature anomaly (deviation from normal) compared to the 1961–1990 average for the Great Barrier Reef†; adapted from Bureau of Meteorology

† 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 2021/2022 benthic cover and short term community changes

Macroalgae were common on these fringing reefs. During the November 2021 survey macroalgal cover ranged from 2.5% to 24% at the three locations, dropping at each from levels recorded a year prior during the November 2020 surveys (Figure 9). There was a further significant decrease in macroalgal cover between the pre-wet and post-wet surveys at Round Top and Slade but not at Victor (Figure 9, Table 4). Victor Islet macroalgae remains significantly higher than the other two locations with 24% and 33% during November 2021 and June 2022 surveys respectively (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. At the site level, Victor has significant variability with consistently higher macroalgae at site 5 affecting location level trends (Table 4; Appendix Figure A1).

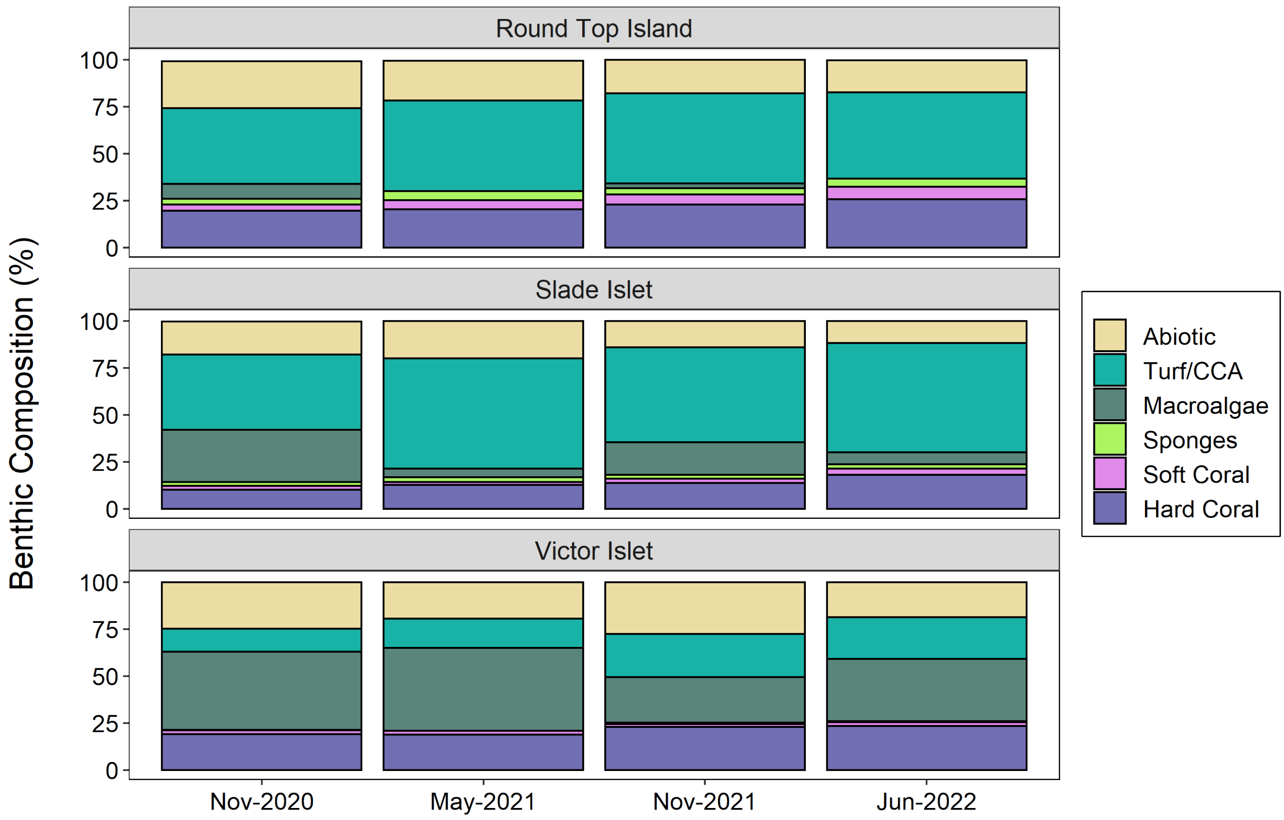

Figure 8. Changes in benthic composition in the four locations between October 2020 and June 2022. Plots show mean percentage benthic composition from the last four ambient surveys at each location. Benthic category 'Abiotic = sand + rubble + bare reef.

Sponges have remained uncommon at all locations (Figure 8) with the most proportion found at Round Top Island over the monitoring program. Sponge cover, while relatively low, has remained at 3-4% in the last two surveys at Round Top. The most abundant sponge has consistently been brown *Turpios* sp. that takes over living coral (Figure 26). Many of the brown *Turpios* colonies partially bleached at the time of the April 2020 survey but did not dieback following the warming event.

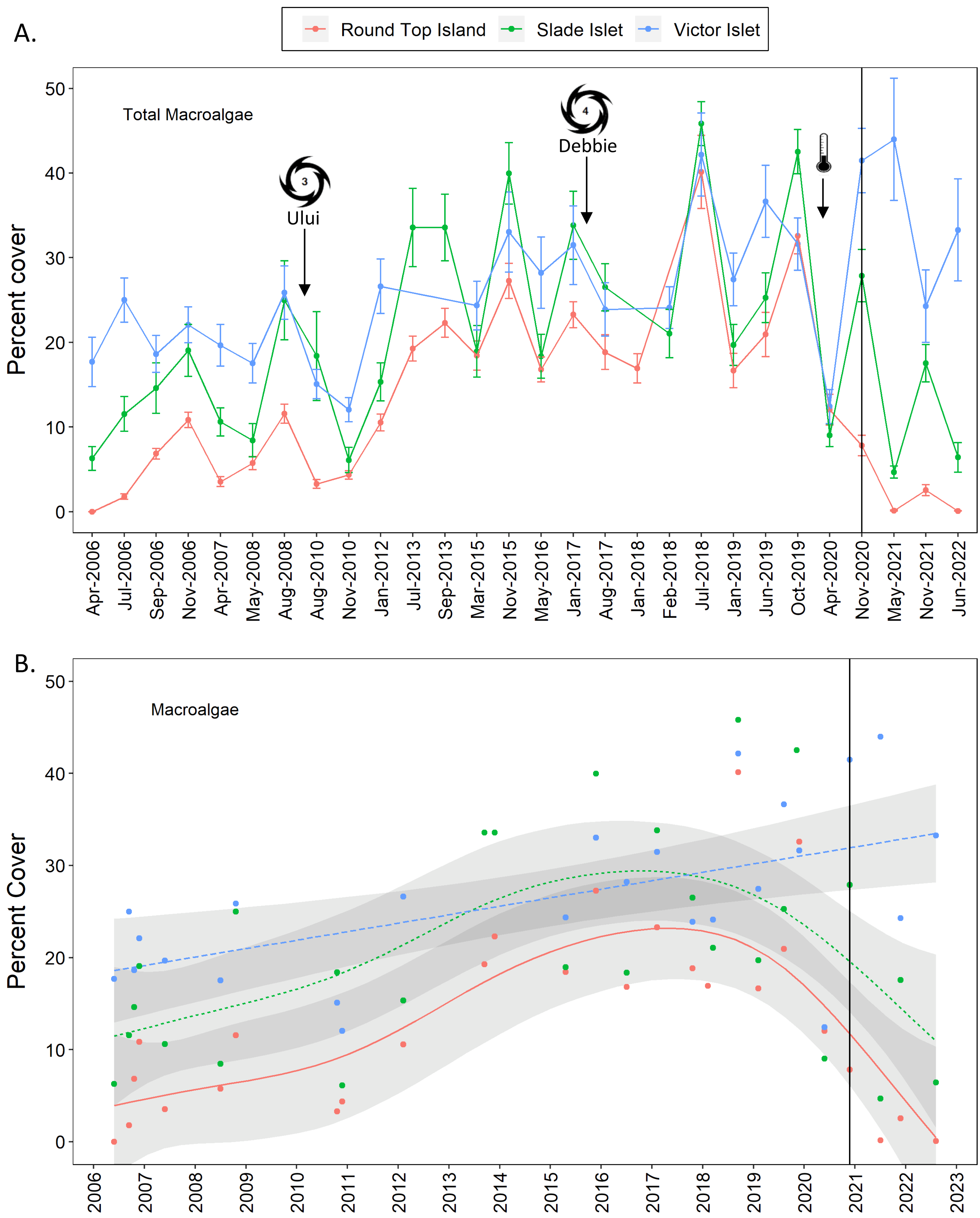

Figure 9. Changes in percentage cover of macroalgae.

Graphs show A) grand mean percentage macroalgal cover from the 2021/2022 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 and the black line indicates the change to photoquadrat methodology in Nov 2020. 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 (Nov 2020, May 2021, Nov 2021 and Jun 2022) 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	***	NS	***	***	**
Total hard corals	***	NS	NS	*	**	NS	***	*	NS
Acropora spp.	**	NS	NS	***	*	NS	***	NS	NS
Montipora spp.	***	NS	NS	***	NS	***	***	NS	NS
Pocilloporidae	NS	NS	NS	NS	NS	*	NS	*	NS
Siderasteridae	***	NS	NS	**	NS	NS	***	NS	NS
Turbinaria spp.	***	*	NS	***	**	NS	***	NS	NS
Faviidae	**	NS	NS	***	NS	NS	***	NS	NS
Poritidae	NS	NS	NS	***	NS	NS	**	NS	NS
Total soft corals	***	***	NS	**	*	***	***	NS	*

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

Mean hard coral cover during the 2021/2022 surveys was between 23-26% on Round Top and Victor while Slade was slightly lower at ~16%. Over the past 12 months average hard coral cover has been unchanged at Round Top and Victor despite an increasing trend since the dieback recorded in November 2020 (Figure 10, Table 4) while Slade significantly increased from November 2020 to June 2022 (Figure 10, Table 4). At the site level, Victor Site 2 and Round Top Site 4 have had significantly greater hard coral cover over the life of the monitoring program which magnifies location variability (Appendix Figure A2) .

In 2021/2022, Slade Islet had significantly lower hard coral cover than Round Top or Victor as a result of large losses at this location from the 2020 bleaching event.

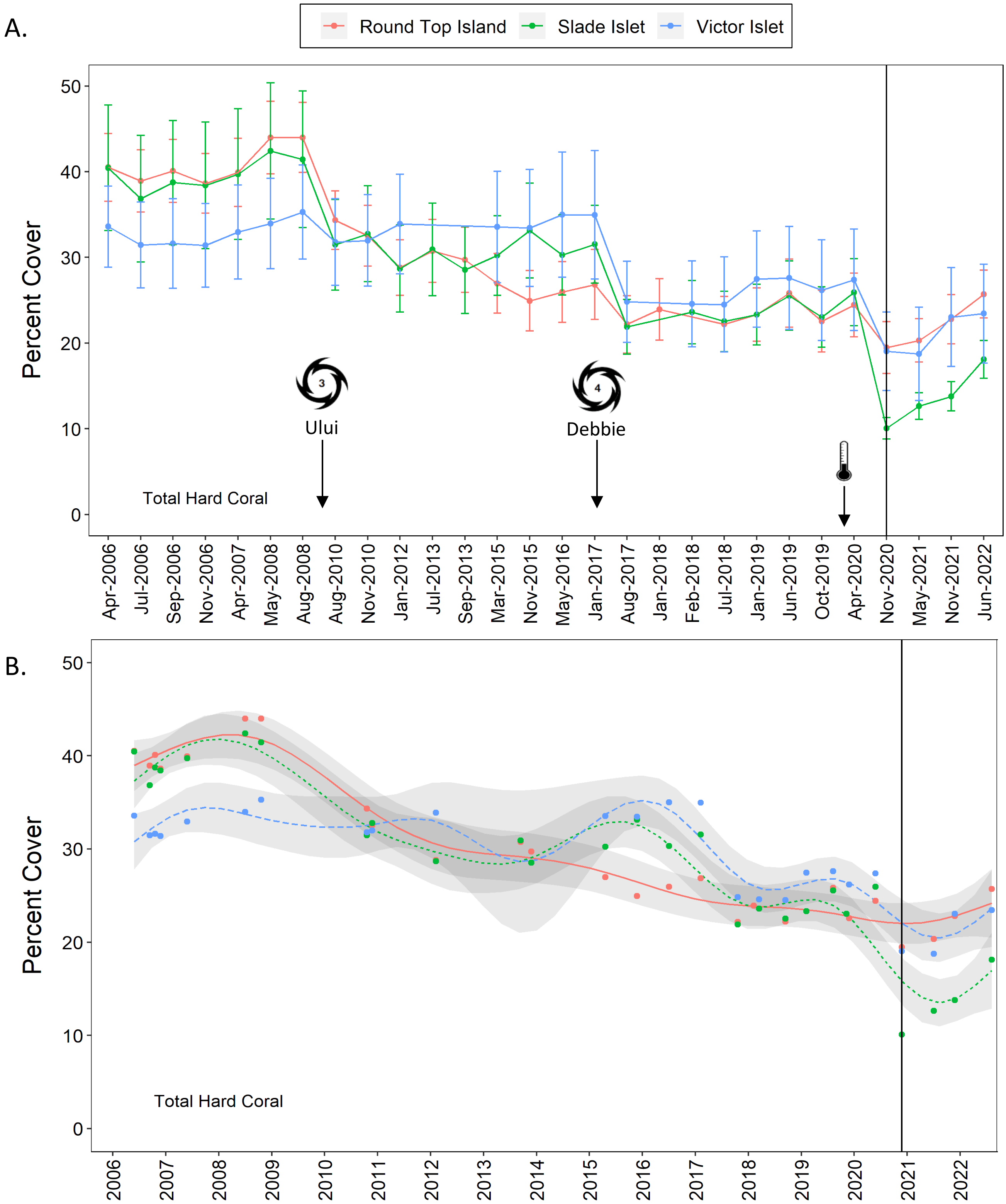

Figure 10. Changes in the cover of total hard coral.
Graphs show A) grand mean percentage benthic cover from the 2021/2022 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors and the black line indicates the change to photoquadrat methodology in Nov 2020. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

Relative hard coral community composition was different in each location (Figure 11). During the latest June 2022 surveys coral communities at Round Top Island were dominated by *Turbinaria* spp. (30% of total coral cover) followed by *Montipora* spp. (26%) with siderasterids, faviids and poritids also common. On Slade Islet *Montipora* spp. corals accounted for 25% of all hard coral cover, a steep decline from the >50% of the hard coral community prior to the 2020 heat stress event. *Acropora* spp. also went from approximately 5% to 20% of the hard coral composition as did other Slade Islet coral families when hard coral declined from the 2020 bleaching event. Victor Islet reefs were dominated by *Montipora* spp. with 33% of the hard coral cover with *Turbinaria* spp. (23%) and faviids (18%) also prevalent. Faviids have historically been the greatest proportion of the hard coral community at the Victor Islet location. In general, coral composition patterns had remained similar since Cyclone Debbie until the bleaching event affected *Montipora* at Slade Islet.

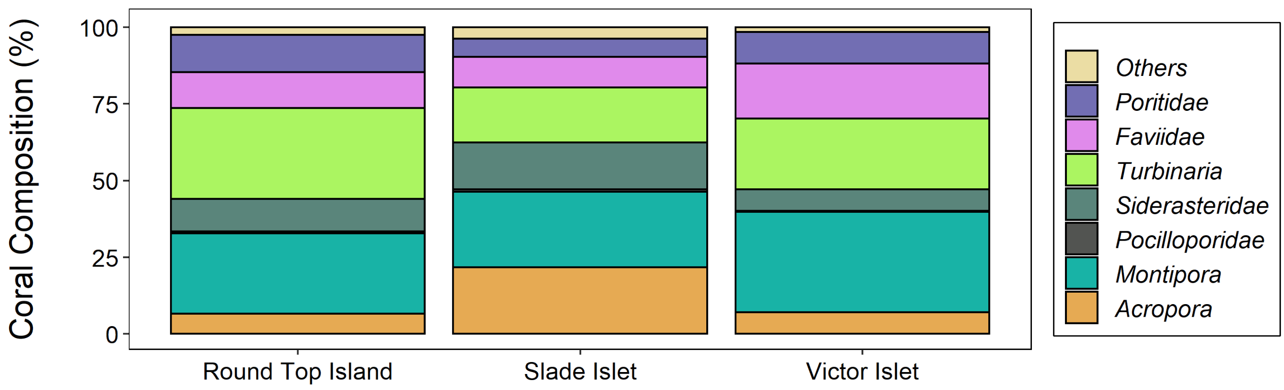

Figure 11. Coral community composition at the four locations for the latest June 2022 ambient survey. Graphs show mean percentage composition of the major coral groups from the four locations.

Coral groups dominated the overall reef community at each location differently except for faviids which were not significantly different among the three inshore locations (Figure 12-18). At the site level, coral communities varied within each location during the latest surveys and over the last two years (Table 4). *Acropora* spp. cover was relatively low at all locations following cyclone impacts in previous years and remains at <5% as of June 2022. *Acropora* spp. cover was not further impacted at any location from the bleaching event in 2020 nor has it significantly increased at Round Top or Victor (Figure 12; Table 4). Significant increases in *Acropora* spp. at Slade make up the greatest increase in total hard coral at this location since November 2020 surveys when the lowest coral cover was recorded in the monitoring program (Figure 12; Table 4).

Montipora spp. has not significantly increased over the last four surveys at any location (Table 4; Figure 13). This coral group historically was highest on Slade but dieback was the greatest at this location following bleaching in early 2020 with the loss an average of 70% of the *Montipora* spp. *Montipora* at Victor Islet did have some declines following bleaching but overall has remained fairly stable over the same period with the highest average *Montipora* spp. location at 13 ± 5% in June 2022 (Figure 13). Round Top *Montipora* spp. was not affected and has remained fairly stable albeit low in cover (~7%) since monitoring began (Figure 13).

Turbinaria spp. cover significantly increased at Round Top and Slade as of June 2022 from November 2020 levels indicating the potential to recover quickly (Figure 14; Table 4). Victor was unchanged over the same period. Significantly higher cover at Round Top (7.8 ± 1.3%) persists compared to Slade (2.5 ± 0.5%) and Victor (2.8 ± 0.9%); a persistent pattern since 2006.

Lesser, slower growing hard corals found at all locations are siderastreid, faviids, and poritid corals cover approximately 2% of the benthic community (Figures 15-17). Siderastreid corals have declined somewhat at Round Top and Victor whereas Slade increased over the 2021/2022 survey period (Figure 15). The end result is significantly lower Siderastreidae corals at Victor compared to other two locations by June 2022. Faviid corals have also steadily declined in all locations over the monitoring program (Figure 16) while poritid corals have remained fairly stable albeit low in cover since 2006 (Figure 17). Poritids remain highest at Round Top Island.

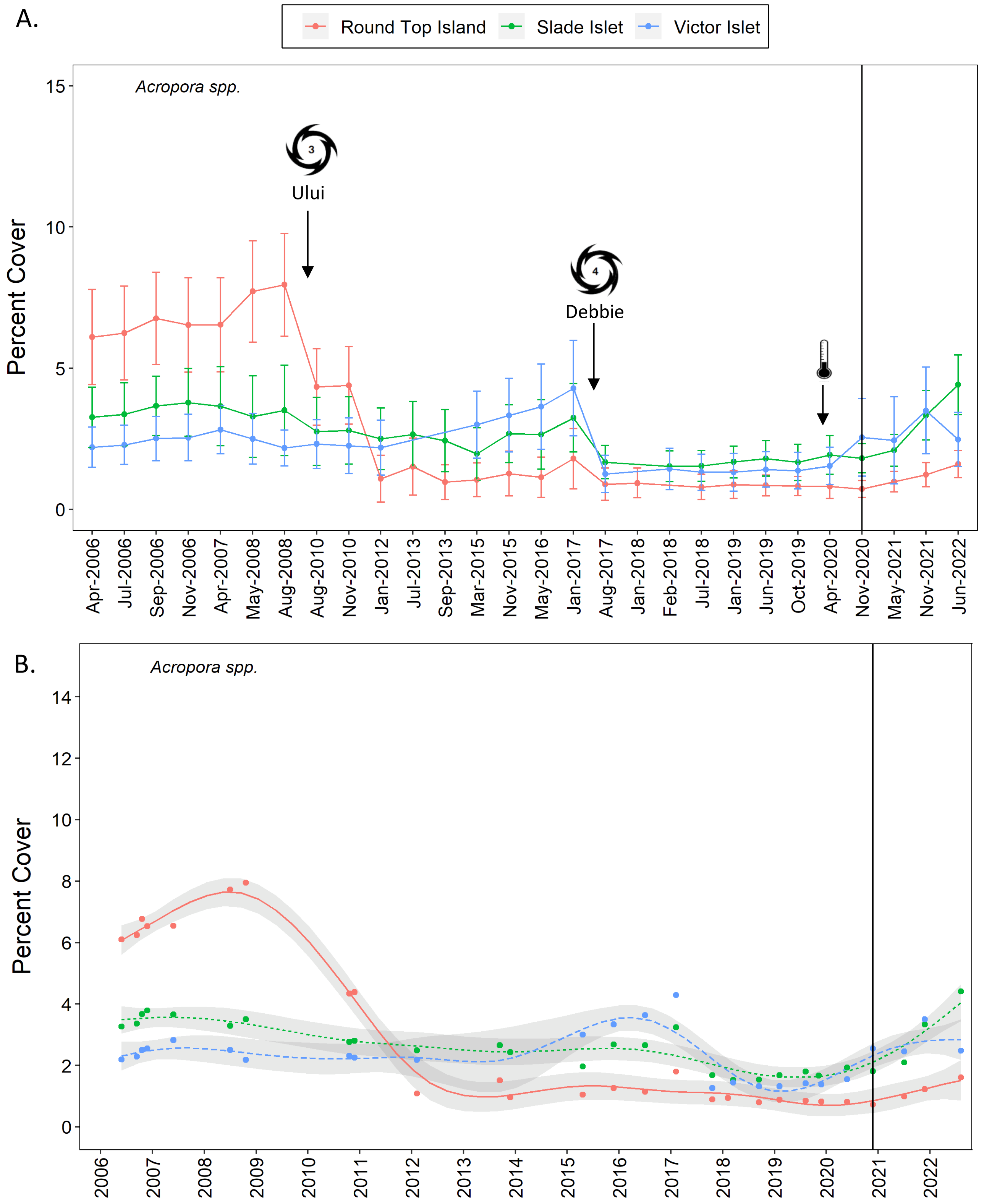

Figure 12. Changes in the cover of *Acropora* corals.
Graphs show A) grand mean percentage benthic cover from the 2021/2022 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors and the black line indicates the change to photoquadrat methodology in Nov 2020. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

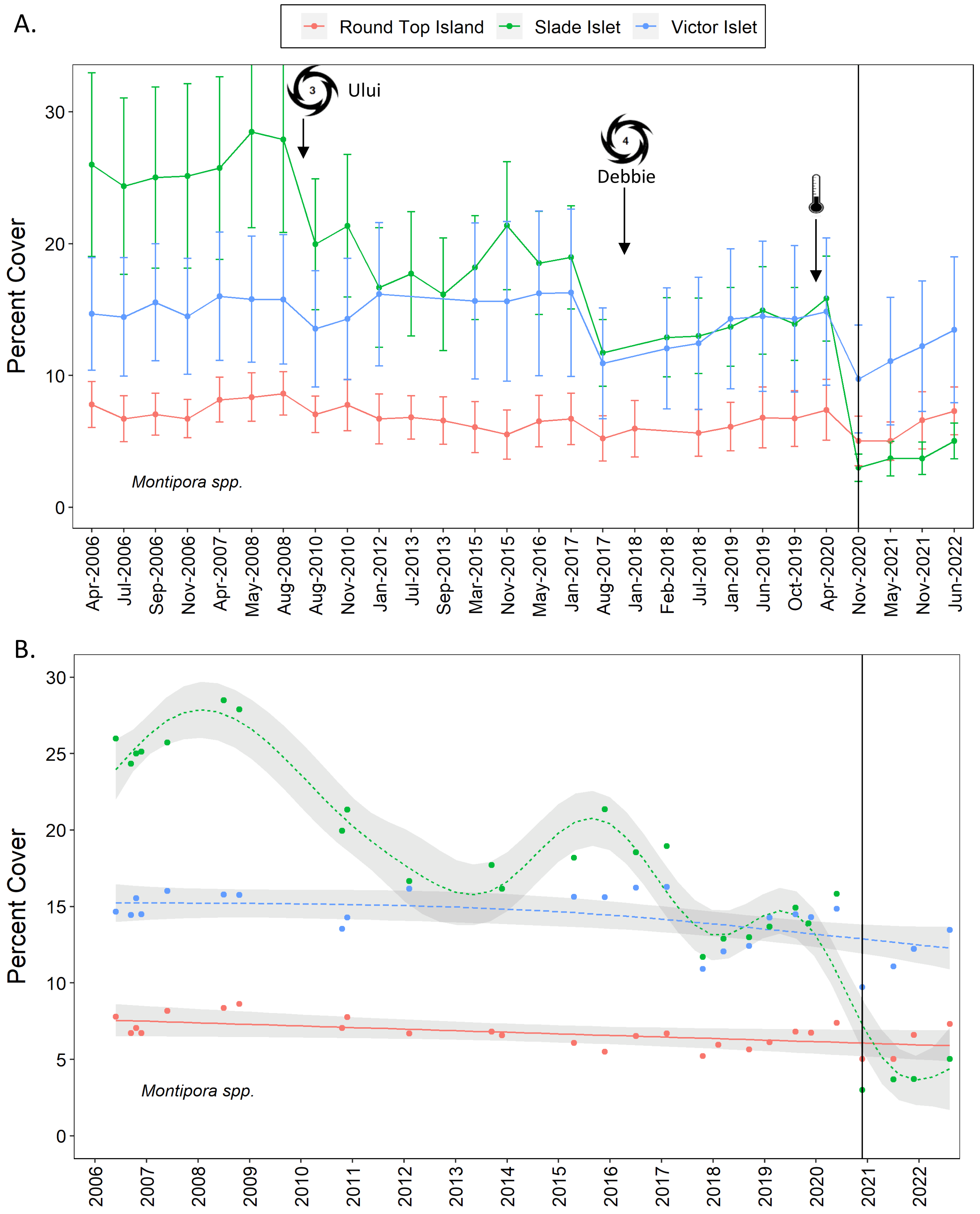

Figure 13. Changes in the cover of *Montipora* corals.
Graphs show A) grand mean percentage benthic cover from the 2021/2022 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors and the black line indicates the change to photoquadrat methodology in Nov 2020. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

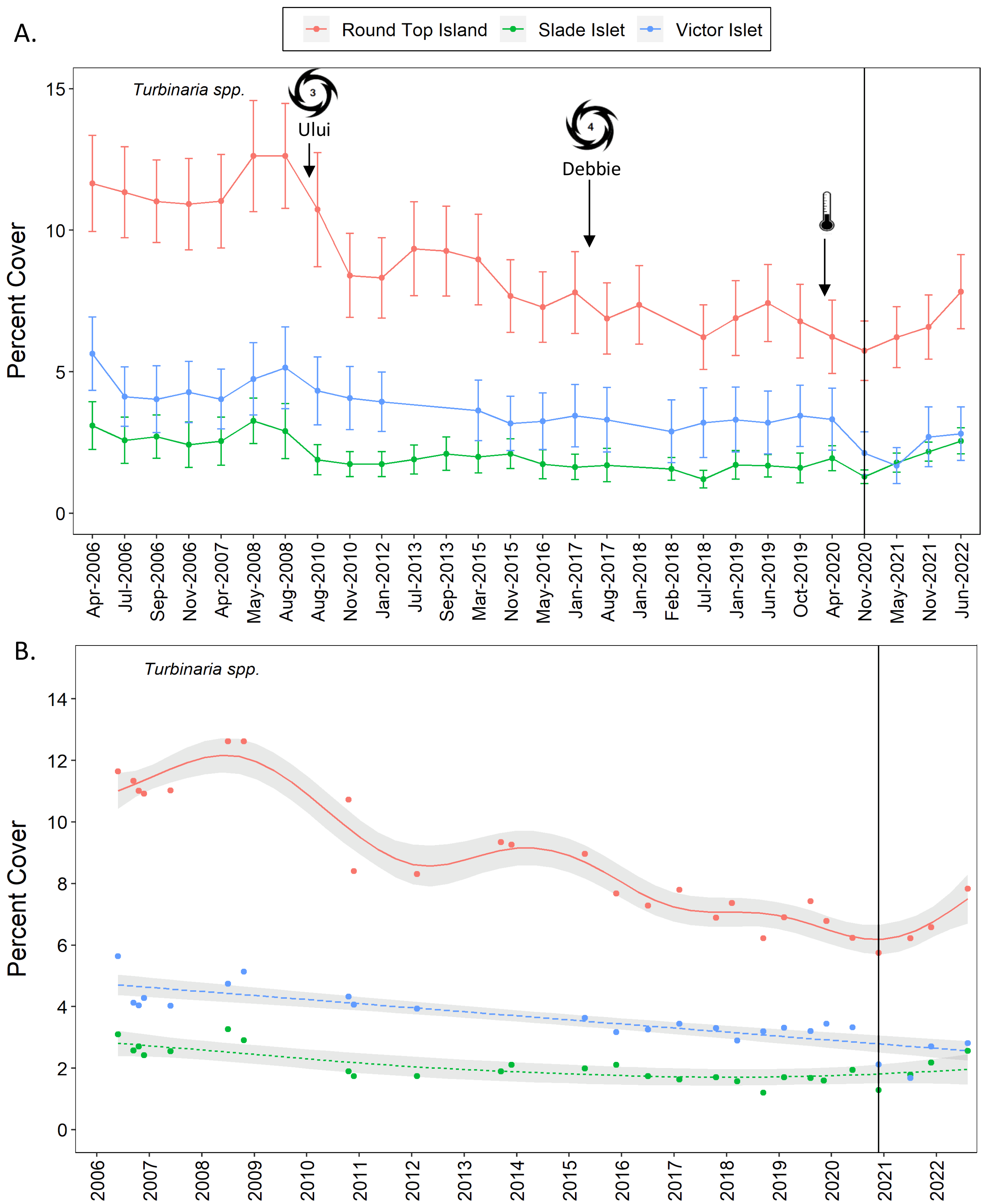

Figure 14. Changes in the cover of *Turbinaria* corals.
Graphs show A) grand mean percentage benthic cover from the 2021/2022 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors and the black line indicates the change to photoquadrat methodology in Nov 2020. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

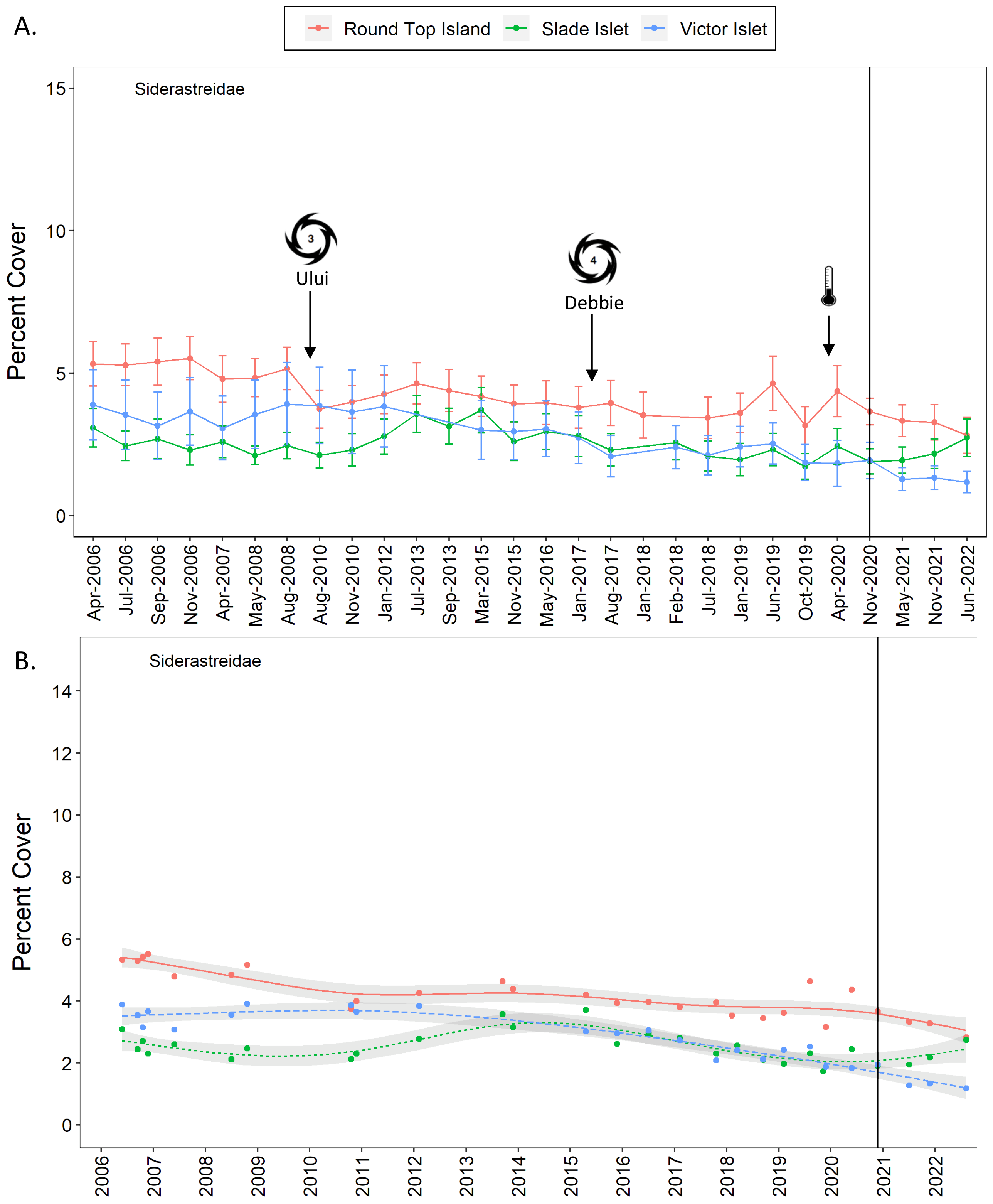

Figure 15. Changes in the cover of Siderastreid corals.
Graphs show A) grand mean percentage benthic cover from the 2021/2022 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors and the black line indicates the change to photoquadrat methodology in Nov 2020. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

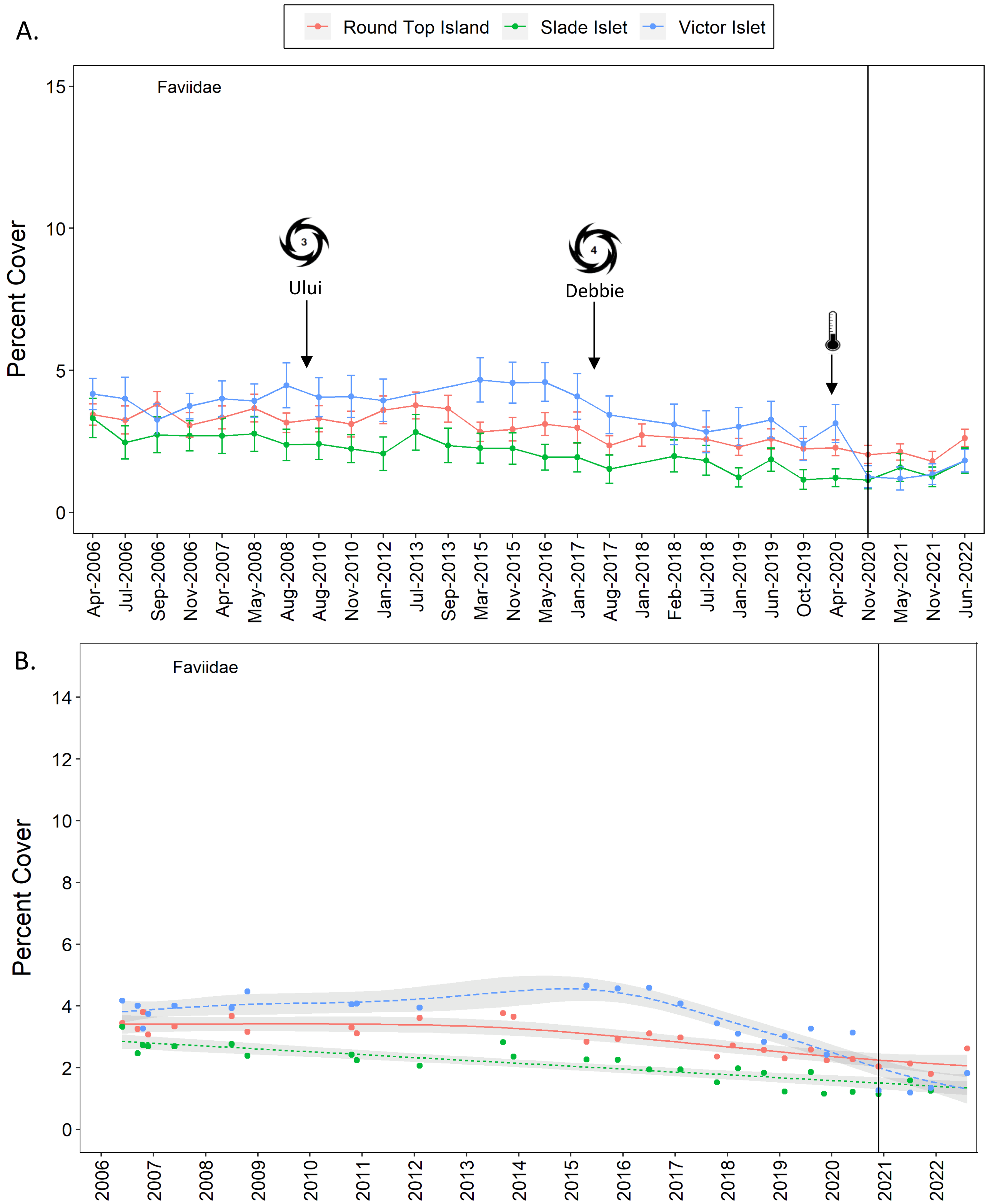

Figure 16. Changes in the cover of Faviid corals.

Graphs show A) grand mean percentage benthic cover from the 2021/2022 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 and the black line indicates the change to photoquadrat methodology in Nov 2020. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

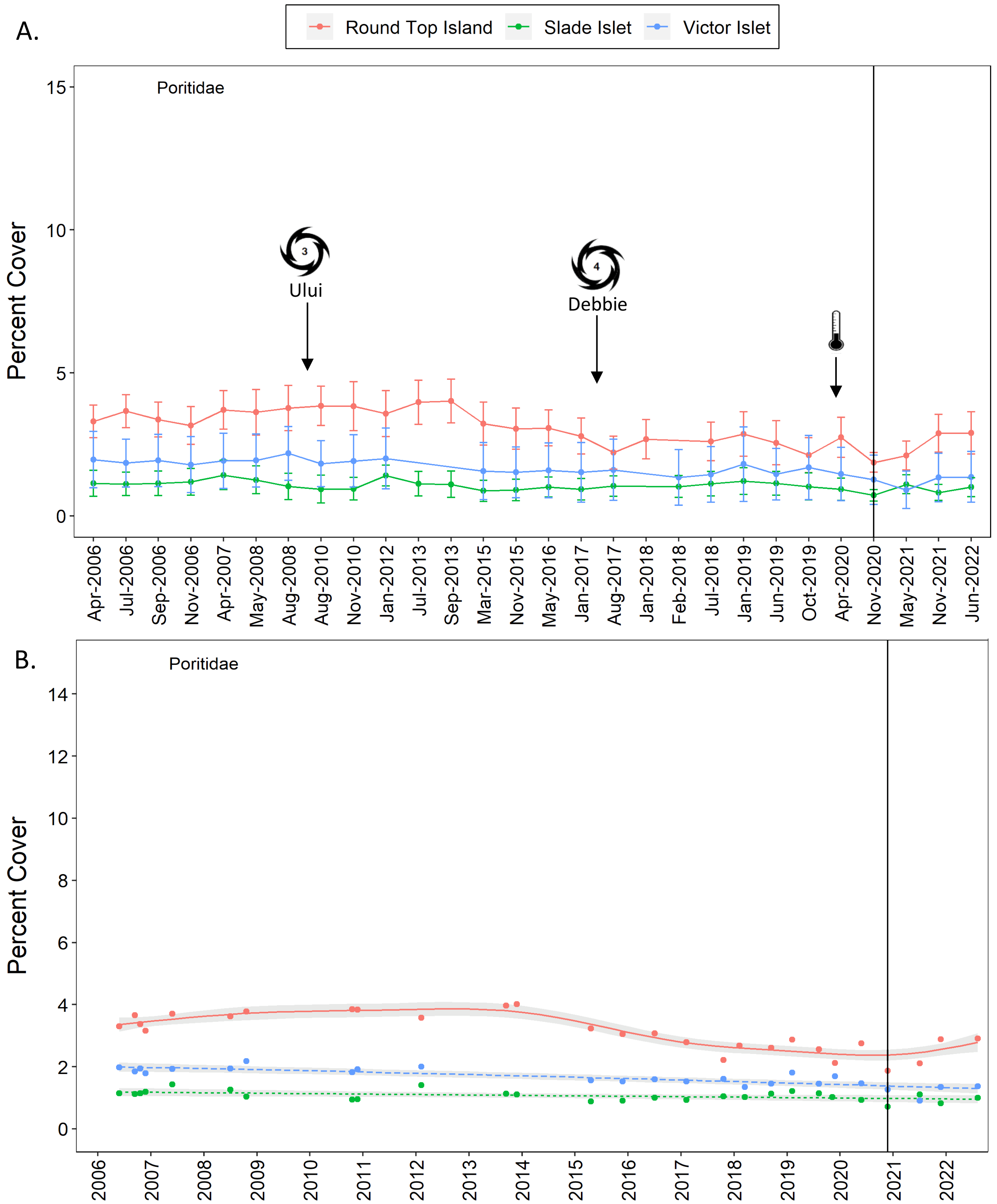

Figure 17. Changes in the cover of Poritid corals.
Graphs show A) grand mean percentage benthic cover from the 2021/2022 ambient surveys and from all previous surveys at each island location (four 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors and the black line indicates the change to photoquadrat methodology in Nov 2020. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

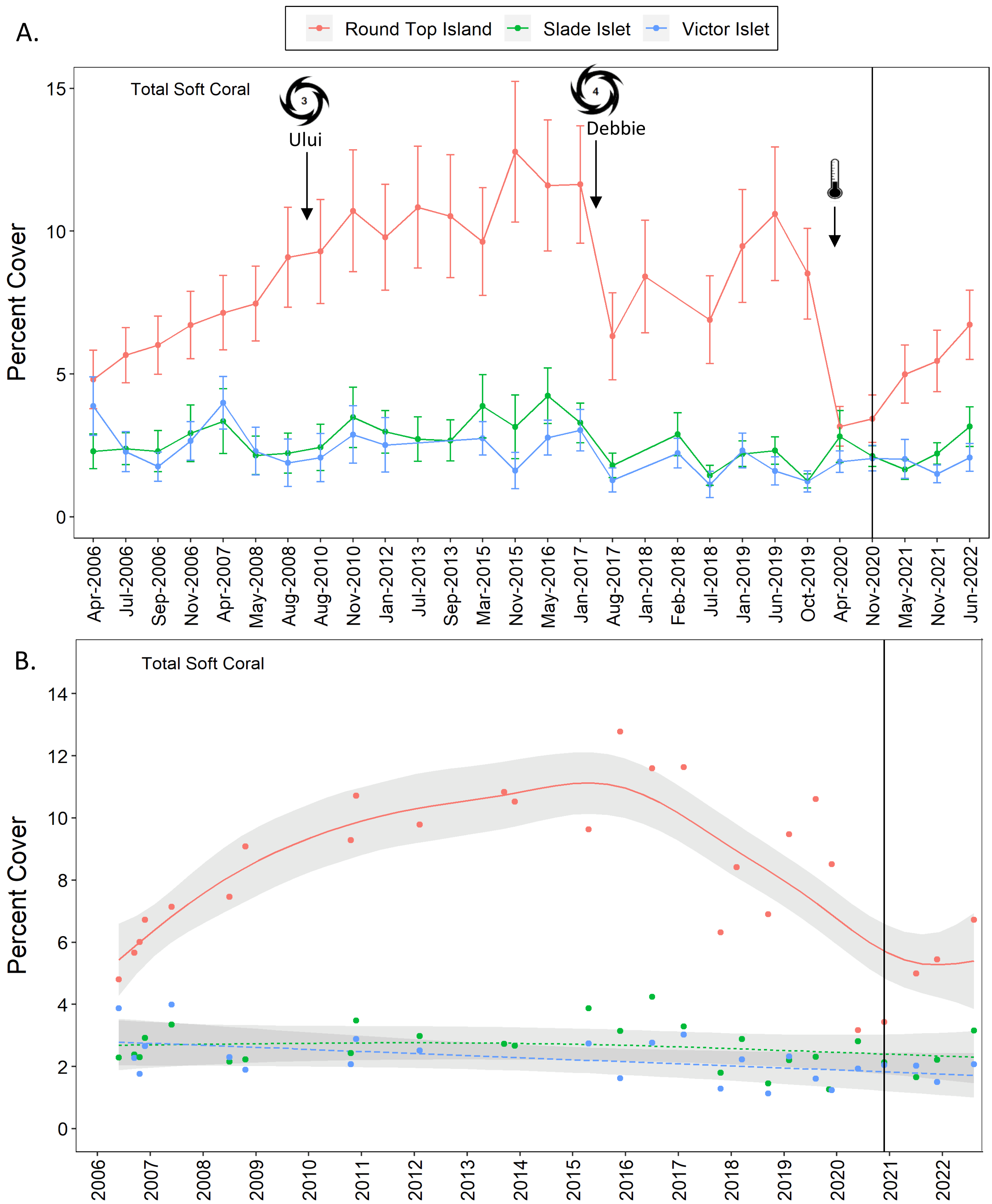

Figure 18. Changes in the cover of total soft coral.

Graphs show a) grand mean percentage benthic cover from the 2021/2022 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 and the black line indicates the change to photoquadrat methodology in Nov 2020. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

Soft corals were significantly impacted by the warming event in early 2020 at Round Top Island but have rebounded relatively quickly with 6.7 ± 1.2% — on par with 2006 estimates and up from 3.4 ± 0.8% in November 2020 (Figure 18). Soft corals at Victor and Slade did not have major changes following the warming event in 2020 that impacted Round Top soft corals, however levels have always been low (~2%) since monitoring began. While ANOVA shows statistically significant time variance, the additive model provides a clearer picture of the trend for soft corals being negligible at these two locations. The soft coral cover decline in 2020 at Round Top was in large part due to the complete disappearance of the dominant *Sansibia* species. *Sansibia* has not returned to the sites as of June 2022 despite increases in the broader coral group.

3.3 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. Macroalgae increased at all locations from 2006 following various local impacts, most notably severe cyclones, until the extreme warming event in early 2020. Between the 2006 baseline and the October 2019 survey, algal cover increased from about 8 to 36% overall. However, macroalgal cover decreased dramatically at all three locations during the early 2020 high water temperature event to a grand mean of 12%. This lower algal cover has remained at Round Top and Slade while elevated macroalgae returned to pre-heatwave levels at Victor in November 2020 (Figure 9B). Over the monitoring program, algal cover has been significantly higher on Victor Islet at times than at the other two inshore locations (Figure 9). During the warming event, 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.

There have been significant changes in the cover of hard corals over the fifteen years at all three inshore locations (Figure 10B). All locations have trended downward in hard coral cover since the inception of monitoring with a 45% decline in hard coral cover since 2006 levels (Figure 10B). Between the original capital dredging baseline in April 2006 and the impact of Cyclone Ului in March 2010, coral cover at all locations only fluctuated slightly (Figure 10), with 29-35% cover on Victor, 36-41% on Round Top and 31-35% on Slade. Damage from Cyclone Ului reduced coral cover at the three locations but the effect was greatest on Slade and Round Top compared with Victor, with recovery recorded 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 despite concurrent increases in macroalgae (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 and the effect of the mass bleaching in 2020. Coral cover was 23.1% in July 2018 compared to 22.4% in June 2022 on average for all locations (Figure 10B). Steady increases in hard coral from a number of coral groups has assisted some recovery since 2020. Early in the program, Round Top and Slade had greater hard coral cover than Victor before declines dampened any location-specific differences. The most recent survey period showed Slade had the lowest hard coral cover of the three 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. Grand mean *Acropora* cover in these three locations was only 2% , half of the pre-Ului peak (Figure 12B). Since the 2020 warming event, the cover of these fast-growing corals has significantly increased for the first time at Slade with positive trends at Round Top and Victor for the first time since Cyclone Debbie (Figure 11B).

The cover of *Montipora* spp. during the monitoring program has been relatively stable at Round Top and Victor compared to the repeated declines and significant at Slade Islet following two major cyclones and the 2020 bleaching event (Figure 13B). Cover at Slade peaked at 42% in 2008 and was <4% in May 2021. The cover of these fast-growing corals had been increasing steadily in the 36 months since Cyclone Debbie up until the bleaching event. The shallow reef on Slade combined with the north-facing aspect of the three *Montipora* dominated sites are contributing factors at this location. *Montipora* spp. at Round Top and Victor has not changed from 2006 to 2022 with approximately 7% and 14% cover respectively from 2006 to the latest June 2002 surveys.

There were fluctuations in the cover of siderasterid corals caused by disease episodes and the two major cyclone events. Overall, Round Top and Victor populations declined since 2006 with Slade populations fluctuating somewhat over the life of the program but overall remaining fairly stable. *Turbinaria* corals have been significantly more abundant on Round Top Island than the other two locations (Figure 14B). *Turbinaria* corals, in the family Dendrophylliidae, were the dominant benthic group on Round Top Island at the beginning of the program when they covered ~11% of the substratum. Cover steadily declined for over 10 years caused by disease and cyclones since Cyclone Ului until 2021 when cover began to increase (Figure 14B). Smaller losses of *Turbinaria* have occurred over the more than 15 years of surveys at Victor whereas the <3% of cover at Slade has remained unchanged (Figure 15B). Corals in the family Faviidae were less common at all three locations and declined or stayed relatively unchanged since 2006 with cover at all locations of ~2% (Figure 16B). Poritid corals, like faviids, are more resilient to impacts and have had fairly steady cover since monitoring began (Figure 17B).

Soft coral cover doubled on Round Top Island over the ten years until 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 been fairly stable at Victor and Slade throughout monitoring while Round Top had further losses due to the 2020 heat stress event (Figure 18B). On Round Top, soft coral cover has been more strongly impacted at times but with rapid recovery compared to the hard coral community. For example, soft corals dropped to 2.3% cover in November 2020 but recovered to 6.7% by June 2022.

3.4 Coral Bleaching

There was no significant bleaching observed at Mackay locations over the 2021/2022 period (Figure 20) despite elevated water temperatures at NQBP water quality monitoring stations and the Alert Level 1 reported by the NOAA CRW program in early March (see Section 3.1.3). The short duration of elevated temperatures were not sustained long enough to cause significant bleaching stress during early June 2022 surveys.

During the summer months of 2020 high water temperatures caused the first significant coral bleaching event on the Mackay region reefs. In April 2020, 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. Other benthic groups affected by this bleaching event included soft corals, some sponges and *Millepora* hydroids.

Bleaching at Round Top and Slade was significantly variable among sites during November 2020 with greater bleaching at Round Top sites 4 and 6 as well as Slade site 2 (Table 6).

By November 2020, bleaching frequency had markedly reduced to approximately 2 colonies per transect at all locations; a significantly higher frequency of bleaching since the monitoring program began 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 5. Average number of coral colonies affected by bleaching, disease or sediment damage during the last four ambient surveys by location.

Location	Nov 2020	May 2021	Nov 2021	Jun 2022
ROUND TOP				
Partially bleached colonies	1.6	0.0	0.1	0.1
Disease damaged colonies	0.2	0.6	0.2	0.0
Sediment damaged colonies	0.4	0.1	0.1	0.0
VICTOR				
Partially bleached colonies	0.7	0.0	0.1	0.0
Disease damaged colonies	0.1	0.6	0.1	0.3
Sediment damaged colonies	0.4	0.9	0.4	0.1
SLADE				
Partially bleached colonies	3.6	0.0	0.0	0.0
Disease damaged colonies	0.2	0.1	0.1	0.0
Sediment damaged colonies	0.3	0.5	0.1	0.1

Corals are recorded as number of colonies per transect.

Table 6. Changes in the density of partially bleached, diseased and sediment damaged corals between the four most recent surveys (Nov 2020, May 2021, Nov 2021 and June 2022). Anova summary results of a generalised linear mixed effects model output with transect as the random effect shown for the site level data at the three monitoring locations.

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

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

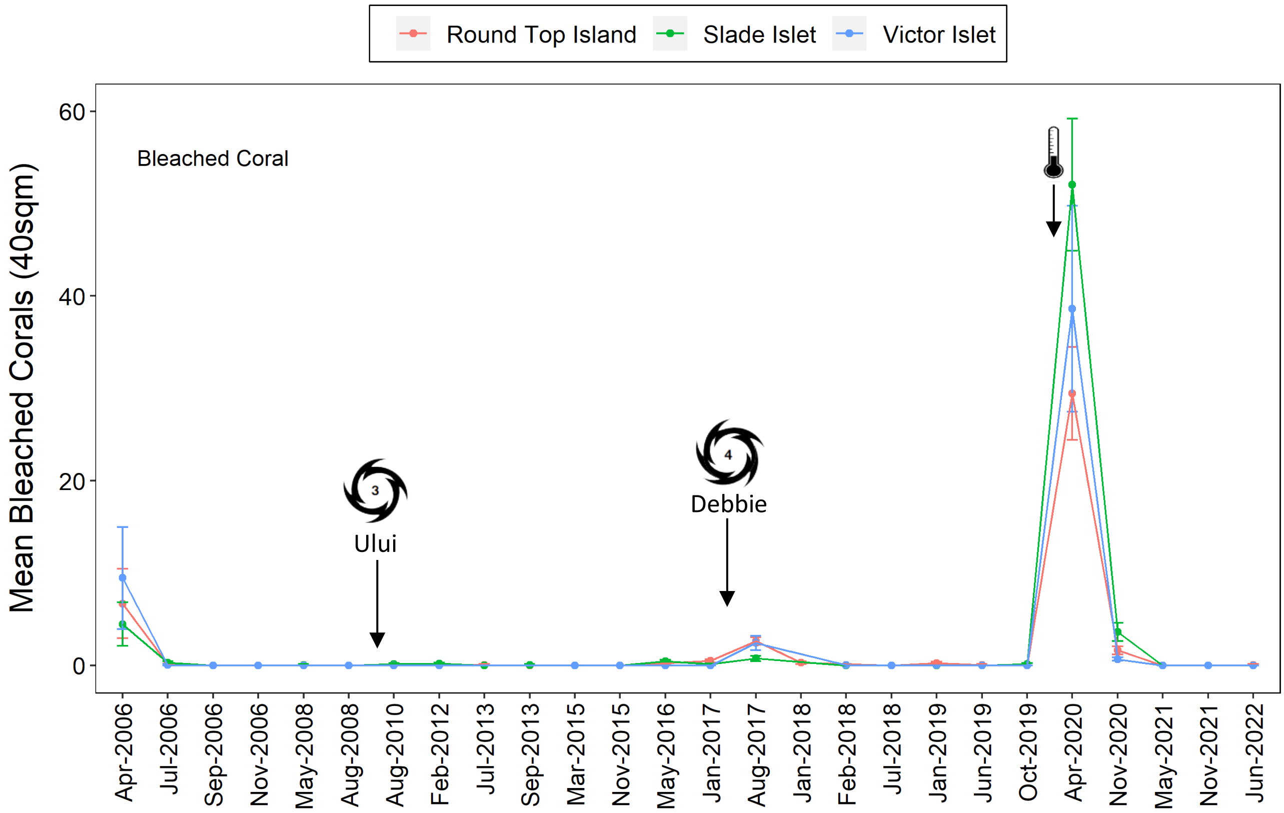

Figure 19. Changes in density of bleached and partially bleached hard coral colonies. Graphs show grand mean density of bleached and partially bleached corals per 40m^2 from four sites of four 20 x 2m transects in each location from the 2021/2022 ambient surveys and all previous surveys. Error bars are 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 June 2022, the percentage of corals with sediment cover was at an all-time high at all three locations with >55% colonies with sediment and with significant sediment depth (Figure 21, Table 8). Sampling took place soon after wet season rain events eased which may have contributed to localised sediment loads from the local catchment. Percentage of corals with sediment was similarly high in November 2021 at Slade Islet which was surveyed soon after a rainfall event of 60mm. Site visits subsequent to June 2022 has confirmed the sediment loads have not led to substantial sediment damage or loads at any locations.

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 20). 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 20). 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 20). 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 20). During the 2018 surveys both the number of corals with sediment and sediment depth were at very low levels.

Table 7. Changes in frequency and depth of sediment load on corals over the four most recent survey events.

Location:	Round Top Is.		Victor Is.		Slade Is.	
PERCENT OF TOTAL COLONIES WITH SEDIMENT LOAD						
Nov 2020	25.9%		41.2%		14.1%	
May 2021	11.2%		17.2%		22.2%	
Nov 2021	19.7%		26.9%		51.6%	
June 2022	60.3%		77.2%		57.8%	
MEAN MAXIMUM SEDIMENT DEPTH* (mm)						
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*
Nov 2021	0.11	*0.01*	0.17	*0.03*	0.42	*0.06*
June 2022	0.54	*0.04*	0.77	*0.07*	0.47	*0.06*

*Grand mean sediment depth in mm with standard deviations in italics.

Table 8. Changes in sediment depth on corals between the four most recent surveys (Nov 2020, May 2021, Nov 2021 and June 2022). Anova summary results of a generalised linear mixed effects model output with transect as the random effect shown for the site level data at the three monitoring locations.

	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 = not significant; * = 0.05>p>0.01, ** = 0.01>p>0.001; *** = p<0.001ites 1, 4 and 6 much higher deposition

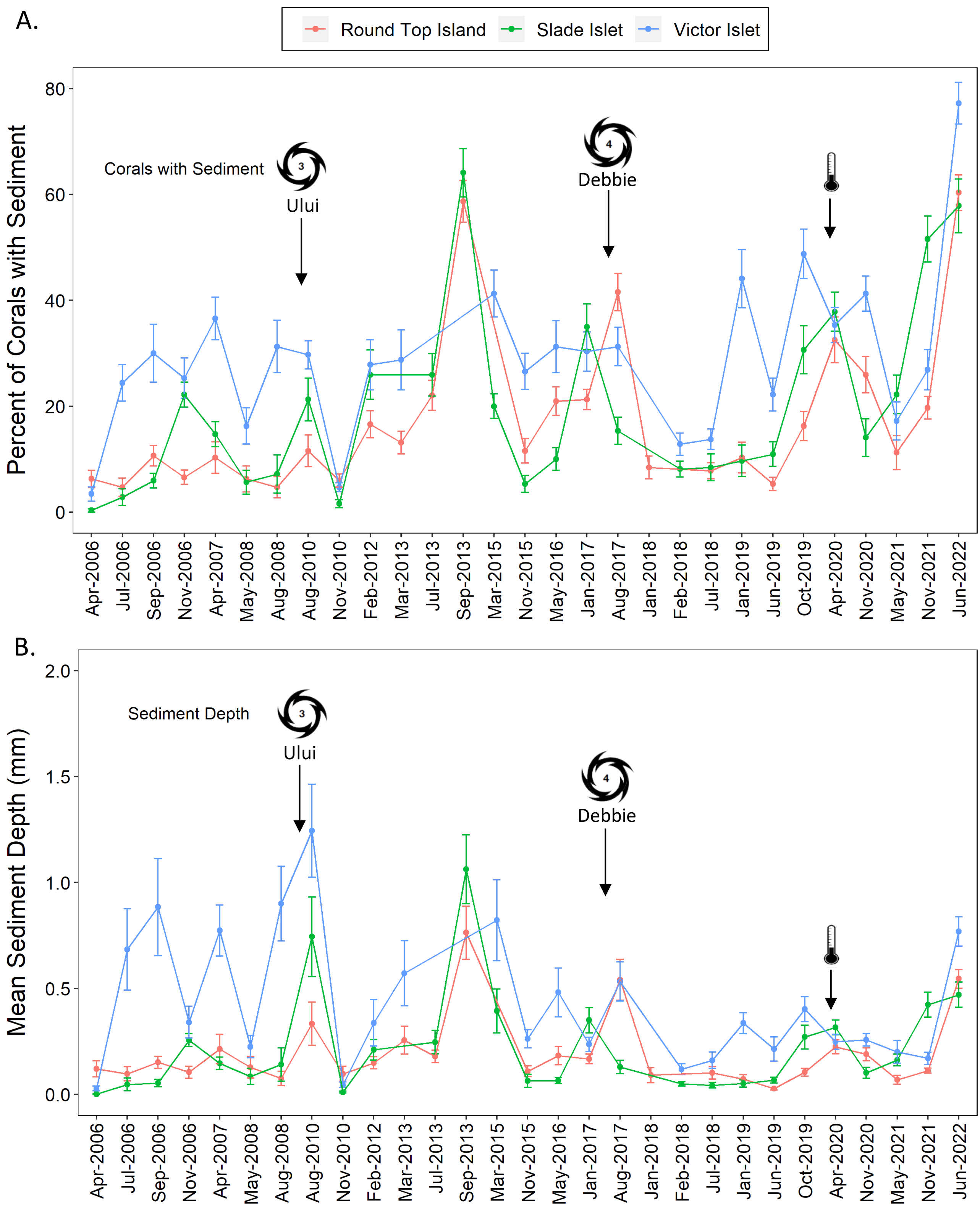

Figure 20. Changes in Number of Corals with sediment load and sediment depth.
Graphs show percentage of the 320 coral colonies examined in each location that had measurable sediment on part of the surface during each survey and the mean depth in mm of that sediment for the 2021/2022 ambient surveys and for all previous surveys. Error bars where appropriate are standard errors.

3.6 Sediment Damage and Disease in Coral Colonies

Heavy sediment deposition on living coral can cause patches of mortality on the coral surface. Despite the high sediment depth and prevalence of sediment on colonies at all locations in June 2022, there was no substantial sediment damage observed (Figure 22). Overall, numbers of sediment damaged corals have reduced significantly on the inshore locations since the Cyclone Debbie event.

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 21A). 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 21A). 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 21A).

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 2021 and June 2022 surveys (Figure 22B). Disease has been relatively low since the 2020 bleaching event apart from a small increase in May 2021. Overall low disease post bleaching is a sign of good recovery with relatively benign weather conditions over the 2021 and 2022 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 21B). Disease impacted corals were present at all four locations and there were no overall trends in abundance at any location (Figure 21). Small colonies sometimes died completely when affected by disease but usually disease only caused partial colony mortality.

There continues to be no evidence of predation from crown of thorn starfish or Drupella snails at any of the sites across all three locations.

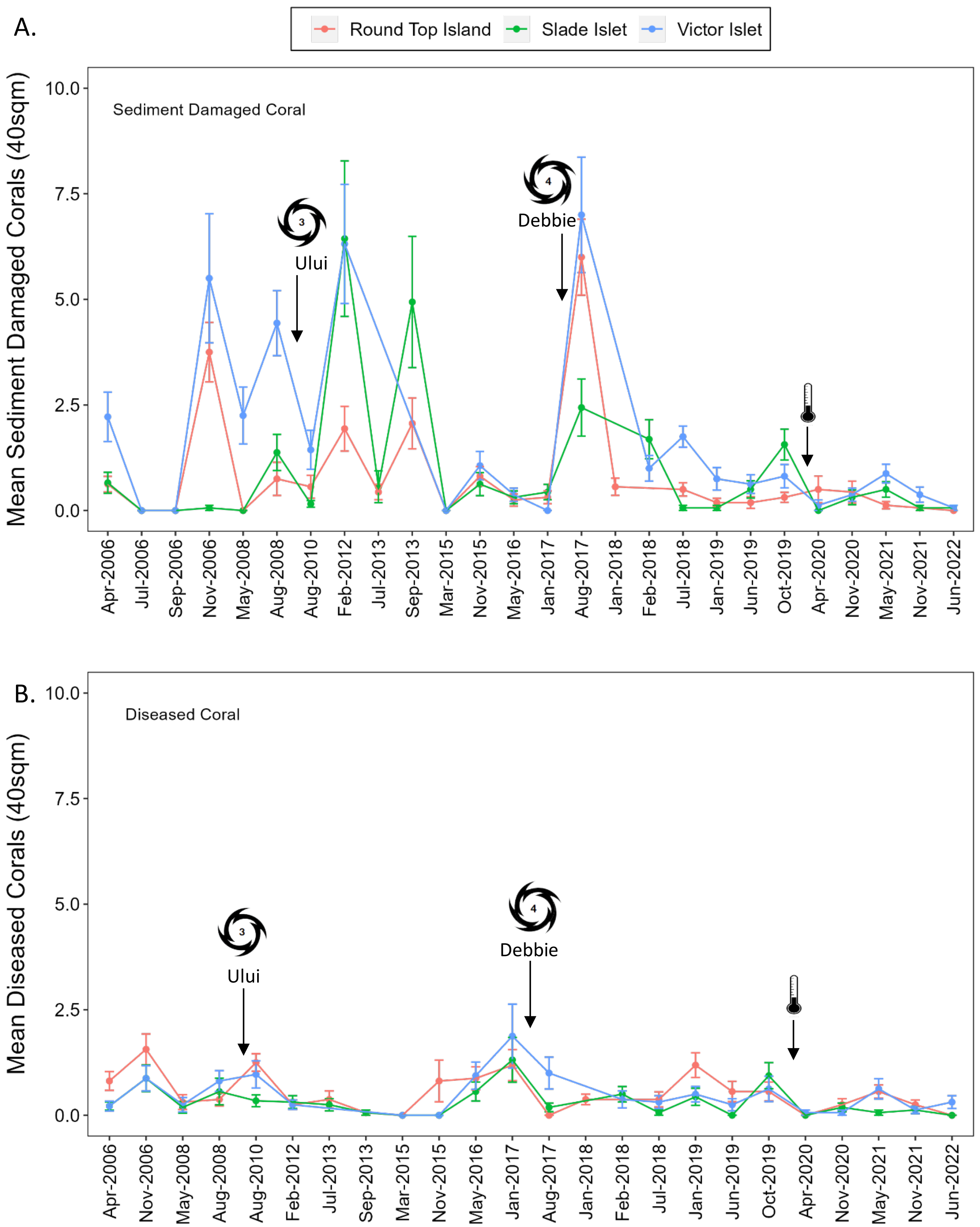

Figure 21. Changes in density of sediment damaged and diseased coral colonies.
Graphs show grand mean density of diseased coral colonies and sediment damaged corals per 40 m^2 from four sites of four 20 x 2m transects in each location from the 2021/2022 ambient surveys and all previous surveys. Error bars are standard errors.

3.7 Coral Recruitment Patterns

Numbers of hard coral recruits were relatively high on Mackay inshore reefs during the last four ambient surveys for the three locations since recruit monitoring began in the ambient program in March 2015 (Figure 22). Over the last three surveys, recruit densities have been highly variable at Round Top and Slade compared to Victor. The highest number of recruits was recorded at Round Top in June 2022 with 9.1 ± 3.5 recruits m^2 compared to Slade with 4.8 ± 2.1 recruits m^2 and Victor at 2.2 ± 1.0 recruits m^2. Overall, there was no significant change in recruits over the last four surveys nor among sites at any location (Table 10).

Prior to the recent increase in recruit numbers, there was a significant decrease caused by Cyclone Debbie in 2017 (Figure 22). 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. Macroalgae can also release inhibitory chemical cues (Evensen et al. 2019), thereby reducing potential coral recruits which may contribute to low numbers. Recruit numbers increased again during the first half of 2019 probably due to a reduction in algal cover but decreased in October 2019 when algal cover was again high. The decline in macroalgae at Round Top and Slade over the last three surveys may have helped with available substrate for new recruit settlement as well as with observer detection of juvenile corals.

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 70% of total coral recruits in these locations (Figure 23). The largest number of *Turbinaria* recruits recorded is consistently at Round Top Site 1 with >200 recruits during each of the last three surveys. This substantial supply of *Turbinaria* recruits may in part contribute to the significant increase in *Turbinaria* cover at Round Top in addition to asexual growth of persistent colonies (Figure 14). Faviids also recruited well on these inshore locations.

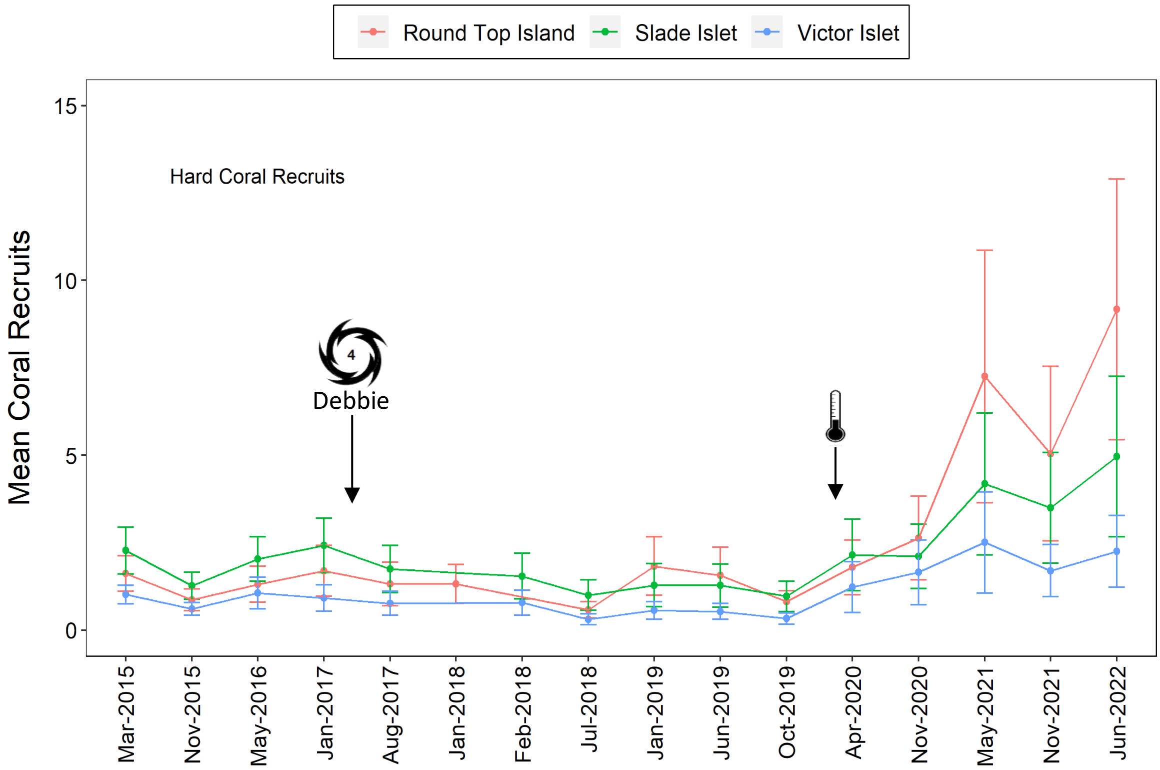

Figure 22. Changes in density of hard coral recruits over the ambient surveys.
Graphs show mean density of hard coral recruits per m^{-2} from four sites in each location for the past seven years of ambient surveys. Error bars are standard errors.

Table 9. Mackay/Hay Point Fringing Reefs: Patterns in the density of hard coral recruits between the four most recent surveys (Nov 2020, May 2021, Nov 2021 and June 2022) 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

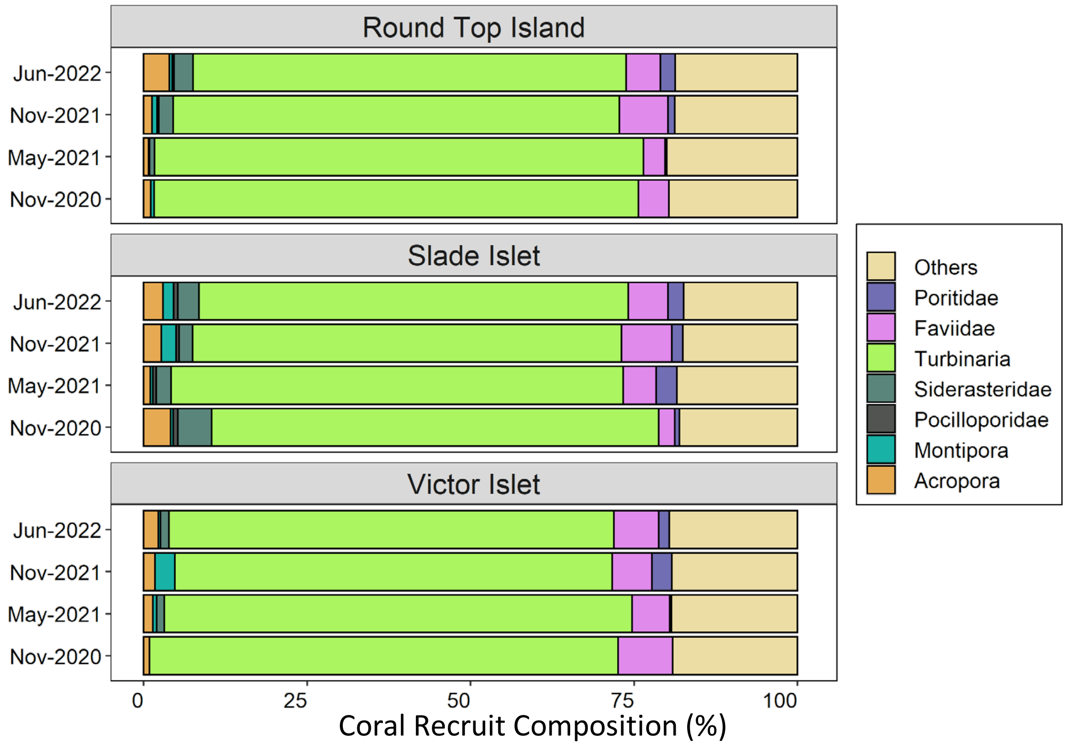

Figure 23. Composition of the hard coral recruit population in the four locations over the last four ambient surveys. Graphs show mean percentage composition of the major groups of coral recruits from the three locations.

3.8 Coral Community Indicators

The Reef Report Card uses a series of scores from post-wet season surveys to provide an unbiased scale of overall reef condition and resilience. The full reef report card uses five metrics to derive report card scores (Thompson et al. 2023) but one of these, community composition requires observations and other information not available in this program. This follows the precedent set by AIMS in their report on the first four Abbot Point ambient surveys (AIMS 2018). The four metrics used here—coral cover, juvenile density, macroalgae proportion, and coral change—are based off of June 2022 data only to align as much as possible with the inshore monitoring program and report card methods. For details of methods for these indicators see AIMS (2018) and Thompson et al. (2023).

The overall index score for the Mackay locations in June 2022 was 'moderate' and unchanged from May 2021 for these Mackay reef locations (Table 11). The only other significant change at all locations was the juvenile score which decreased at Victor from 0.38 to 0.28 over the 12 month period with somewhat lower recruit density at this location. Strong recruitment at Round Top continued with the maximum possible score of 1.0 in 2022 due to the ongoing high *Turbinaria* recruitment (Table 11).

Table 10. Reef condition and indicator values during the post-wet ambient surveys. Arrows indicate if a change in category from 2021 scores.

Location	Survey	Coral cover	Macroalgae proportion	Juvenile density	Coral cover score	Juvenile score	Macro-algae score	Coral change score	Index
Round Top Island	Jun 2022	25.7%	0.09%	16.41	0.34	1.00	1.00	0.43	0.69
Victor Islet	Jun 2022	23.4%	33.3%	3.25	0.31	0.28	0	0.34	0.23
Slade Islet	Jun 2022	18.1%	6.4%	5.46	0.24	0.46	0.71	0.29	0.43
Regional Mean	Jun 2022	22.4%	39.8%	5.37	0.30	0.58	0.57	0.35	0.45

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

3.9 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.

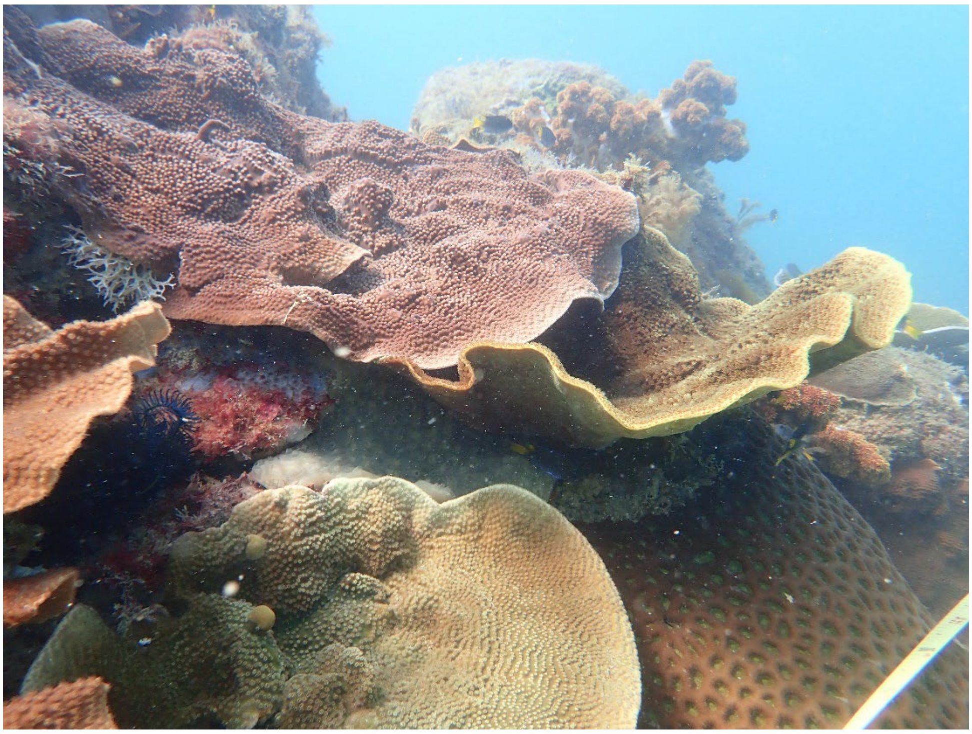

Figure 24. Healthy *Montipora*, *Turbinaria* and *Favites* at Round Top site 3.

Figure 25. Round Top Island sites typically have good visibility and a high proportion of *Montipora* and *Turbinaria*. Macroalgae has been the lowest observed in over a decade during the last three surveys following the warming event in early 2020.

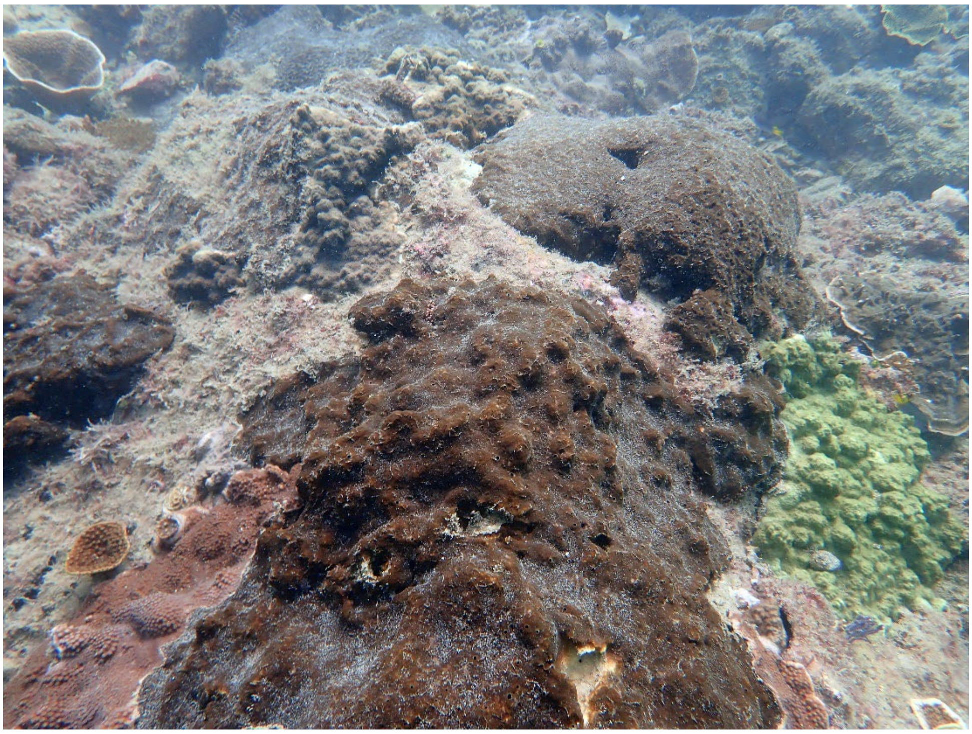

Figure 26. *Turpios* sponge overgrowth was prevalent at Round Top Island site 3 in June 2022.

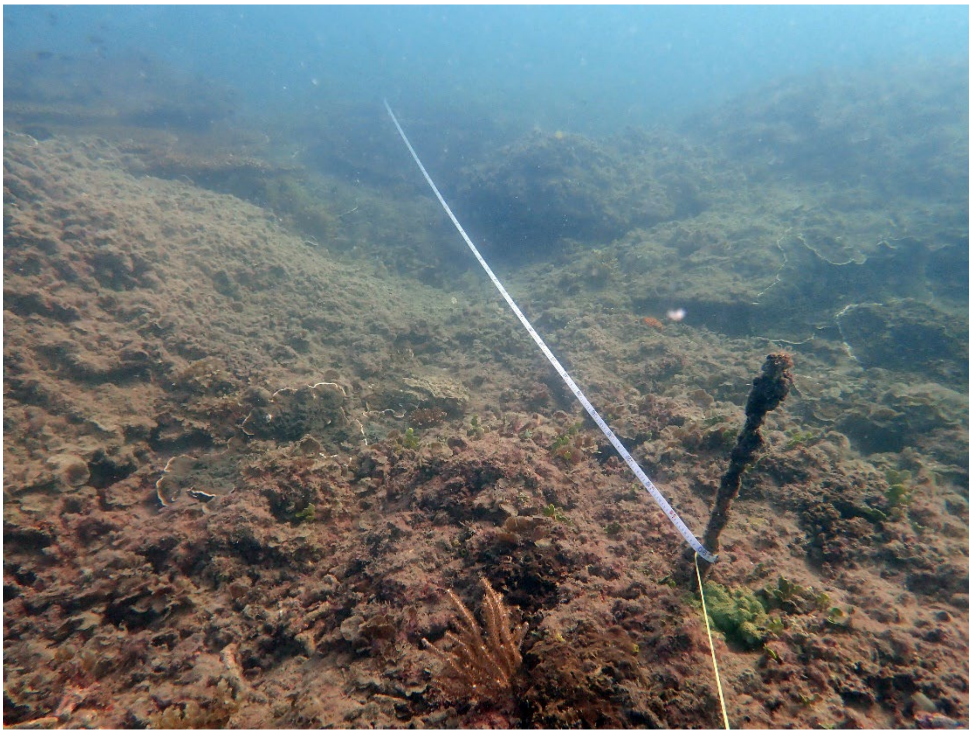

Figure 27. Turf algae at Slade Islet site 4 in June 2022; the dominant benthic structure at this location.

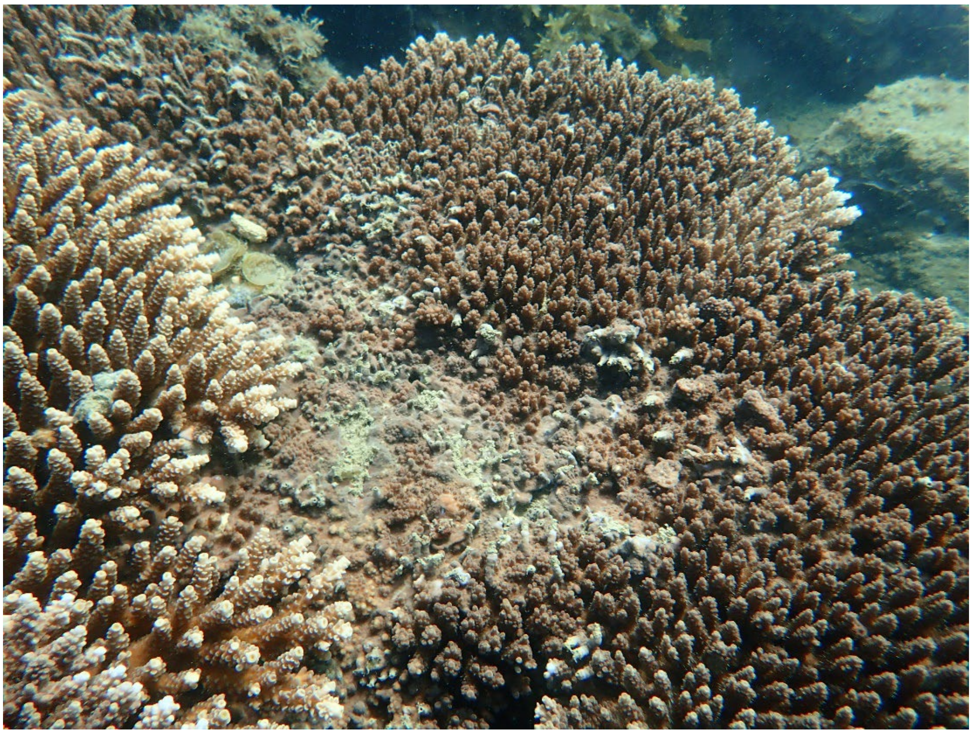

Figure 28. *Acropora* colony with previous sediment damage that has been rapidly repaired and overgrown by surrounding coral tissue at Slade Islet site 5.

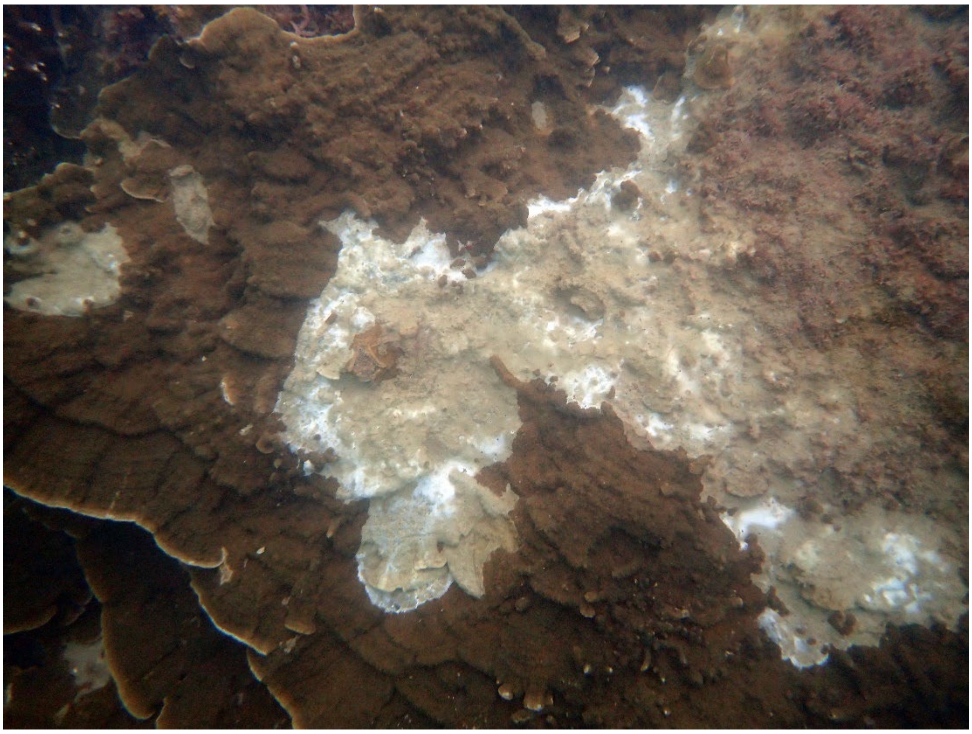

Figure 29. Sediment damage on a *Montipora* coral colony at Victor Islet Site 2 in November 2021.

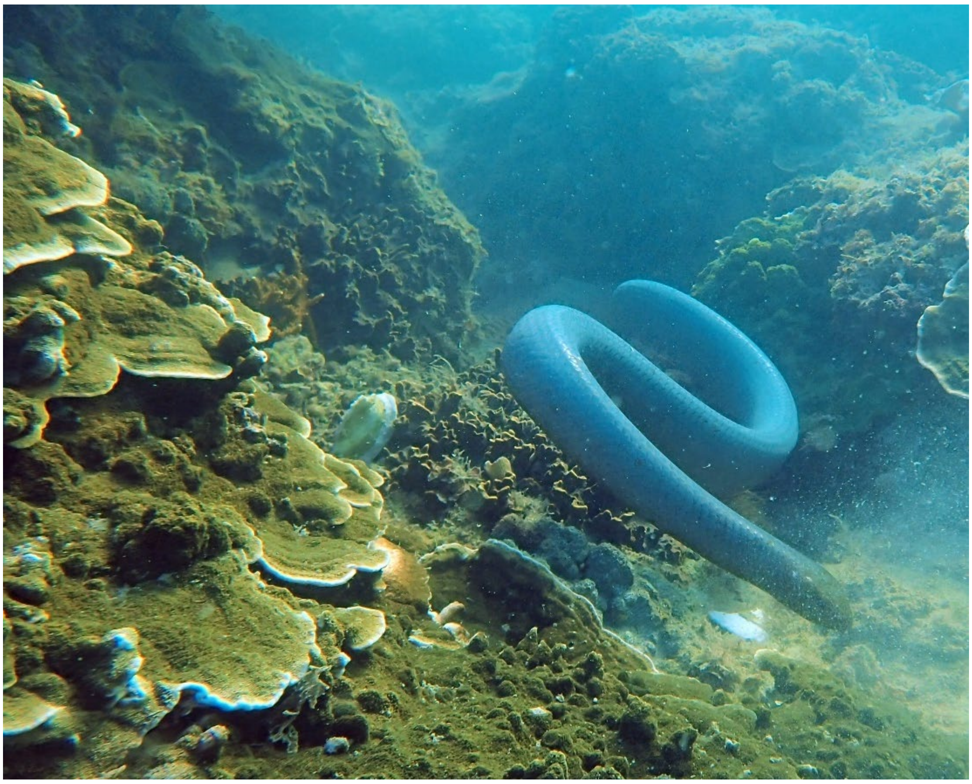

Figure 30. Olive sea snakes are common at all locations such as this visitor during surveys at Victor Islet in June 2022.

Figure 31. Good visibility in June 2022 with significant *Sargassum* at Victor Islet site 5.

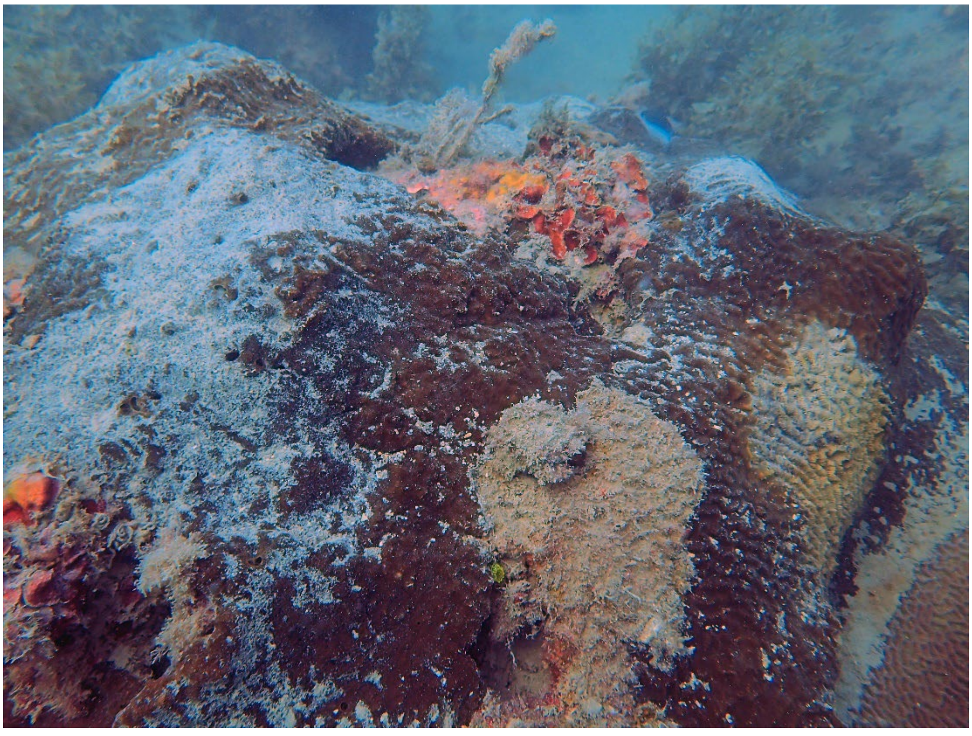

Figure 32. *Platygyra* overgrown by *Turpios* at Victor Islet site 5 in June 2022.

4 DISCUSSION

4.1 Benthic Cover during the 2020/21 Ambient Surveys

The 2021/2022 ambient surveys found some positive signs of recovery following the 2020 mass bleaching event albeit small. Hard coral cover at all three locations is on an increasing trend since November 2020 lows following the significant mortality, most strongly recorded at Slade Islet. The relatively faster growing *Acropora*, *Montipora* and to a lesser extent *Turbinaria* are driving this overall positive trend. Macroalgae has also remained low compared to previous levels at Slade and Round Top providing further recovery potential.

Overall, hard coral for Mackay/Hay Point locations in 2021/2022 went from 17% in May 2021 to 22% in June 2022 providing a small but positive trend since the 2020 mass bleaching event. Hard coral cover in June 2019 was 26% overall for the Mackay/Hay Point reefs indicating further improvements are needed to at least reach coral cover pre-2020 bleaching event. These coral communities were heavily impacted by TC Debbie and still require substantial improvements in coral cover and reductions in macroalgae at some sites to return to their previous condition.

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 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 were no major cyclones or storm events during 2021/2022 that affected Mackay reefs. Previous significant damage by Cyclone Debbie in 2017 was followed by no change in hard coral cover at any of the locations in the first 18 months post-impact. 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. The low macroalgal levels at Round Top and Slade have remained since the warming event which has provided potential space for coral growth and recruitment to boost recovery.

Recruitment, while variable among sites and locations, continues to be strong with a third year of high recruits and is a positive sign for potential recovery of 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 (Thompson et al. 2023). However, for a second year the most frequent size class of *Turbinaria* recruits is<2cm which suggests they might not be surviving beyond the initial settlement phase. Recruitment of other important inshore coral groups like *Montipora* that have been reduced by the recent bleaching event, are still 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 in 2020, likely due to bleaching mortality, but has increased significantly as of June 2022. The spreading brown soft coral *Sansibia* that previously accounted for about 50% of soft coral cover on Round Top Island is still absent.

4.2 Long-Term Benthic Cover Changes

Macroalgal cover on the inshore survey locations dropped dramatically during the April 2020 survey and has remained supressed at Round Top Island and Slade Islet. The high water temperatures in early 2020 are likley responsible for this shift, helping to reduce macroalgal cover that has been very high over with a steady upward trend since early 2006. The continuing high macroalgae at Victor Islet is a worrying sign of a possible shift toward more algal dominated reef communities. While macroalgae at Slade is reduced, it has not returned to the very low levels recorded during the 2006 baseline survey of 5% cover. It is not known at this stage whether macroalgal cover will return 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) and evidenced in local water quality reporting (Waltham et al. 2021).

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.

Despite established La Niña conditions in the southern hemisphere over the 2021/2022 period, no significant cyclones or significant rainfall affected the Mackay/Hay Point locations despite above average total rainfall. La Niña conditions generally result in above average rainfall for the region and potentially above average number of tropical cyclones. Such patterns can further exacerbate recovery if poor water quality or acute cyclone impacts result. These reefs 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 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. Cyclone Debbie wiped out much of this increase with some recovery before the 2020 bleaching event caused significant mortality, especially on Round Top Island, driving soft coral cover to the lowest level recorded on these reefs. Rapid growth at Round Top Island over the 24 months since the bleaching event has led to some recovery in a relatively short period.

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. The upward trend in macroalgal cover, particularly at Victor Islet, has led to marked changes over a relatively short period of time. Lower macroalgae at Round Top and Slade Islet is promising and provides a window for possible recruitment of hard corals to help boost recovery. However, ongoing pressures from nutrient increases and global warming that are human related put these coral communities at risk of shifting towards a phase-shifted system. 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

Sediment loads and damage on the Mackay/Hay Point reefs was elevated during the 2021/2022 period, however damage and disease were minimal. Both pre- and post-wet season surveys occurred around rainfall events which may have led to increased catchment loads and sediment deposition for a short period on local reefs. Additional visits to survey sites since June 2022 found sediment had not persisted at the frequency or depth with no marked impact on coral health.

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 (BMT 2018). 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 2021/2022 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 2021/2022 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 did not appear 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 over the last three surveys also is a positive increase, likely influenced by the macroalgae decrease as available substrate for recruitment increased. Notably, the lowest recruitment densities were recorded at Victor Islet where macroalgae cover has remained high.

Turbinaria corals are 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. The most prominent size class of Turbinaria was the <2cm recruits and it is unclear what proportion of these will survive to contribute to ongoing site recovery of the adult coral population. Young recruits are more susceptible to smothering from sediments and competition with other benthic invertebrates for space.

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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6 APPENDIX

Figure A1. Changes in the cover of macroalgae by site for each location.
Graphs show grand mean percentage benthic cover from the 2021/2022 ambient surveys for each location in bold with simple lines indicating mean cover at the site level. Black line indicate the change to photoquadrat methodology in Nov 2020.

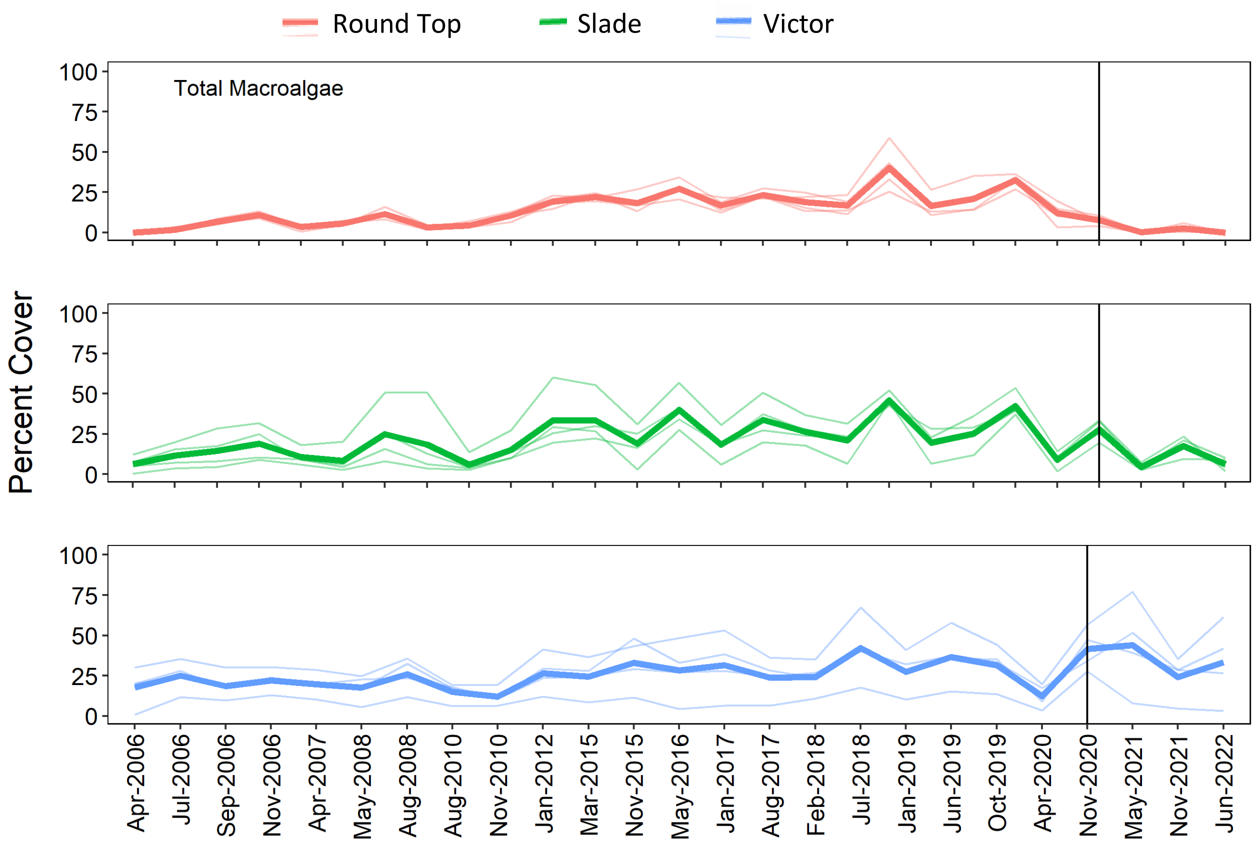

Figure A2. Changes in the cover of total hard coral by site for each location.
Graphs show grand mean percentage benthic cover from the 2021/2022 ambient surveys for each location in bold with simple lines indicating mean cover at the site level. Black line indicate the change to photoquadrat methodology in Nov 2020.